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Londinium's Landward Wall: Material Acquisition, Supply and Construction

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ABSTRACT

The construction of a free-standing stone wall was a significant occasion in Londinium's history, remarkable for the quantity of masonry used and for the continuing additions to the defences over at least three identifiable phases. Since the local geology in the London Basin does not offer suitable building stone, Londinium's walls offer an exceptional example by which to examine the logistics of construction and the transportation of materials in the context of Romano-British building projects. We examine the sources of the materials used, their transport and the scale of labour and investment involved in the construction of the Landward Wall using an energetics-based methodology. Finally, we provide new insights into Londinium's Landward Wall and the socio-economic and practical implications of its construction. Supplementary material is available online (https://doi.org/10.1017/S0068113X21000088) and comprises technical data related to the architectural energetics.

Keywords: Londinium; urban defences; energetics; labour costs; transport; building materials

INTRODUCTION

Between A.D. 190 and 225, a Landward Wall was built in stone to encircle Roman Londinium, which had reached its largest extent at that time,[1] covering an area of *c*. 1.33 km^2 (135 ha) (FIG. 1).[2] The wall measured approximately 2.7 m thick at the base

[1] Merrifield 1983, 161–3; Lyon 2007, 40–1. The assigned date is based on coin moulds (dated to *c*. A.D. 220–25) found in a rubbish deposition from a turret at Newgate. Assuming a period of around 20 years for rubbish to accumulate, a construction date for the wall of *c*. A.D. 190–220 is postulated. A section of the wall was found at Blomfield House (site code BLM87), adding to the already identified length at the adjacent All Hallows Church. A nearby drainage system fed into parallel ditches and then the large city ditch. Moulds for counterfeit coins (dated to *c*. A.D. 194–253) were found in the upper levels of the city ditch. Due to the worn condition of the moulds, Hall 2014, 167, 183 suggests a deposition date of A.D 260 or later. Recent excavations at 8–14 Cooper's Row and 1 America Square in the City of London (site code ASQ87) have provided a date range of A.D. 180–230 for the construction of two substantial stretches (*c*. 110 m in total) of the Landward Wall (site Period 2 Phase R3). The results from these more recent excavations add substantially to the dating evidence (without leading to radically different conclusions).

[2] The wall seems to not have followed the line of the earlier city boundary but was relocated further east and on a different alignment. Hunt 2010, 58 suggests that this might reflect a desire to follow an optimum line in terms of the topography and drainage or a desire to enclose a larger area to emphasise civic status.

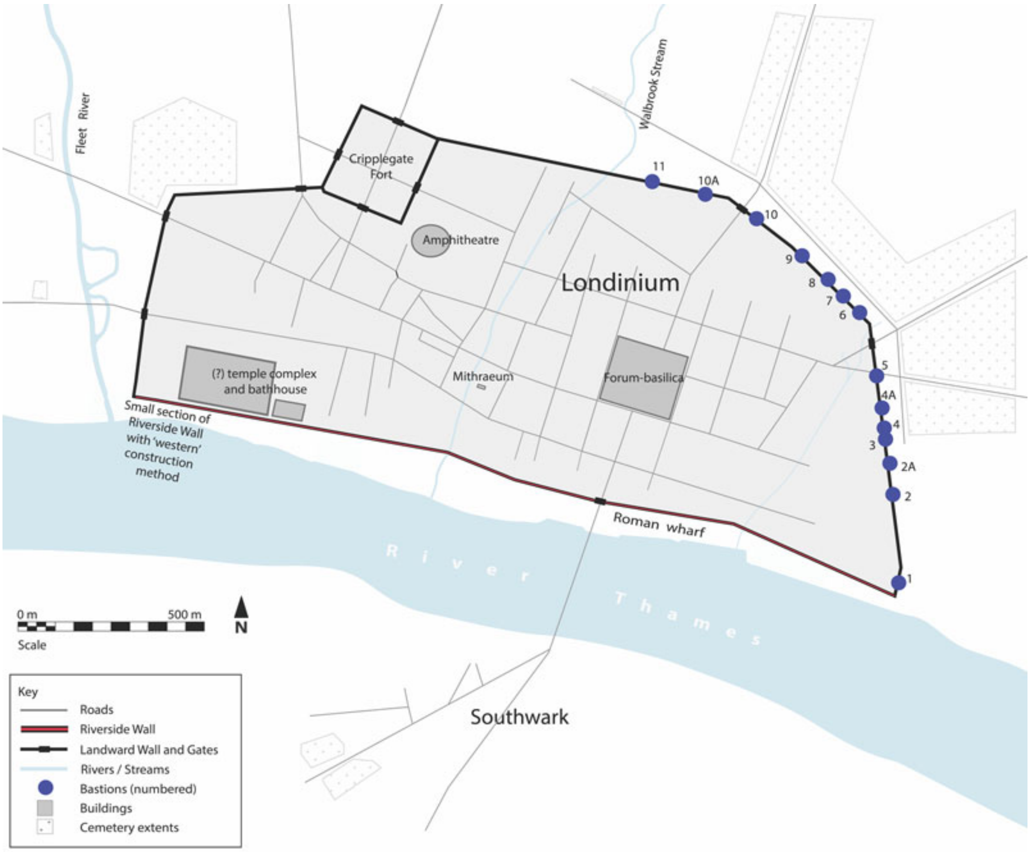

FIG. 1. Map showing approximate course of the Landward and Riverside Walls along with sites and monuments mentioned in the text (image by S. Barker and P. Coombe, based on MOLA 2011).

and stood over 6 m high, running for around 3 km in length (FIG. 2). This project represented a significant undertaking in Britannia, given the resources needed to supply and transport the building materials, particularly stone. To date, over 35 per cent of the full length of Londinium's Roman defences has been observed and recorded.[3] At some key locations, for instance in the area south of Ludgate Hill on the western side, the exact course is unknown, though it is clear that it makes use of the western and northern walls of the second-century fort at Cripplegate, perhaps for reasons of economy, practicality or security. Several sizable stretches of the Landward Wall, particularly on the eastern side, remain visible today to a considerable height, with a few later, medieval additions. Other sections can be viewed below ground level, sometimes in basements or underground car parks of modern city buildings.

The present article aims to quantify the effort required to construct Londinium's Landward Wall though an analysis of its building materials and an estimation of the labour required for its construction. The wall is ideally suited to such a task since the structure has been well documented and several sections of it are accessible for study to determine both the details and

3 Merrifield 1965, 298–325.

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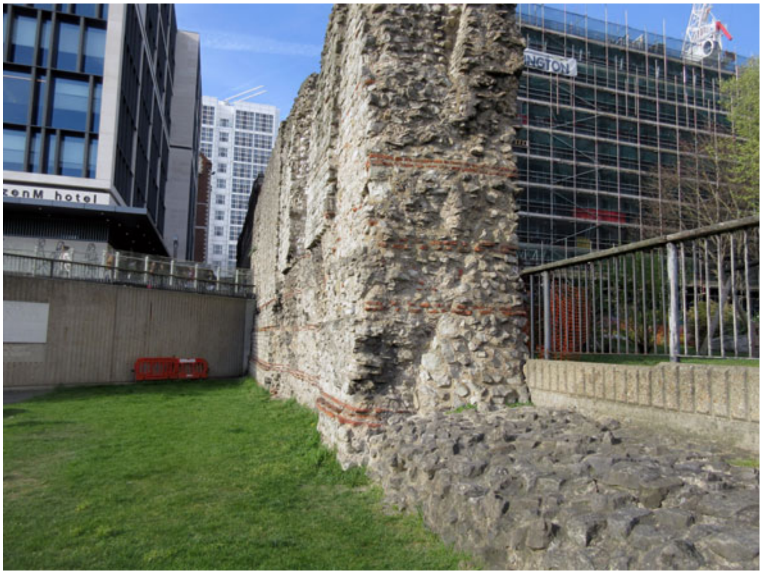

FIG. 2. Surviving section of the Landward Wall by Tower Hill showing the variety and durability of material types, particularly the bonding or lacing courses of Lydion brick and hard angular Kentish ragstone blocks. The Roman remains constitute the first *c*. 4.5 m of the height of the wall, with the rest being medieval (photo by K. Hayward).

materials of its construction.[4] While the volume of materials has already been estimated,[5] the scale and importance of the Landward Wall warrant more detailed study of the material and labour requirements for its construction to understand fully the impact of the project. By using an architectural energetics approach, our goal is to estimate the total labour 'cost' for the overall project.[6] This will form the basis for analyses of the logistics underpinning the wall's construction, the implications for the supply of labour (military or civilian contractors), the level of capital investment and the socio-economic impact of the project. A survey of the geological sources of the construction material (nearly 35,000 m^3) shows that the majority came from within 130 km of London, while other materials were sourced from over 400 km away, presenting significant logistical issues. The total labour required, estimated at just under 304,000 person-days, indicates that the construction of Londinium's stone defences represented one of the largest Roman building projects in the north-western provinces, with the exception of Hadrian's Wall.

In regard to the organisation of the article, the printed text provides a general overview of the phases and methods of construction of Londinium's Roman defences and its Romano-British and continental contexts. It also presents an overview of the geological sources for the material used, the estimated labour 'cost' for the construction and the logistical and economic implications of these figures. The online supplementary material presents technical data related to the architectural energetics, providing a summary of the assumptions underpinning the quantification, including a more detailed review of the labour figures for the production of the materials and the construction activities required for the Landward Wall.

4 Merrifield 1965, 298–325, with map showing the known remains of Londinium's defences.
5 Marsden 1980, 127.
6 Abrams and McCurdy 2019, 3.

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PHASES AND METHODS OF CONSTRUCTION OF LONDINIUM'S ROMAN DEFENCES

It is generally agreed that the Landward Wall was built from east to west, anticlockwise around the town, using a consistent style along its length.[7] We can probably assume that it was started and completed within a relatively short time frame, at around the turn of the third century. Clay and flint foundations lie beneath a bedding layer of ragstone. A rubble and mortar core is encased in the upper levels by courses of brick, added for strength, and facing stones. A v-shaped ditch in front of the wall and an earthen bank behind it provided additional security.[8]

There appears to be very little reused material in the fabric of the Landward Wall. The original construction therefore probably required a considerable volume of freshly made or quarried material and associated labour.[9] Ralph Merrifield dubbed this the greatest public work ever undertaken in Londinium and estimated that 85,000 tonnes of fresh Kentish ragstone would have been required to build it.[10] It is likely that roughly 740,000 facing stones and over 421,000 bricks for bonding courses would have been required.[11] Since the local geology in the London Basin does not offer suitable building stone, Londinium's Landward Wall represents an exceptional example of the ability of the Roman province of Britannia to handle the logistics for large-scale construction and the transportation of building materials over long distances via fluvial and maritime networks.

Following the construction of the Landward Wall, further, apparently defensive, structures were constructed in two main phases over the next couple of centuries. The Riverside Wall was built in the mid- to late third century and defensive towers, known as bastions,[12] were added in the fourth century on the eastern side of the city, possibly together with a further section of the Riverside Wall. The projecting towers that now remain on the northern and western sides of the Roman city probably date to the medieval period.

The Riverside Wall, in contrast to the Landward Wall, did include stones taken from earlier monuments and structures, including the famous blocks from a decorated arch and a screen carved with figures and busts of deities.[13] For the majority of its course, this wall was set on foundations of timber piles beneath a chalk raft. Above this and around a concrete and rubble core, it was made of ragstone facing and brick courses, and incorporated offsets. An earth bank abutting the wall on the northern side would have offered extra stability. Such solid construction of this 'eastern' portion may have been necessary due to the underlying geology of loose gravels on this part of the riverbank. At its very western end, a short portion of the wall, *c*. 75 m long, was built without timber and chalk foundations and without courses of bricks; large blocks of ragstone were simply rammed directly into the clay. A firmer underlying geology of London Clay and mudstone exists here, and so substantial foundations may have been less important.

Secure dating of the Riverside Wall has historically proved problematic. The sections of 'eastern' construction style are now considered to date to A.D. 255–75 based on comparison with timber pile samples from New Fresh Wharf and the Tower of London.[14] The western portion, by contrast, was built after A.D. 275, perhaps offering another explanation for the

7 Maloney 1983, 98. This is with the exception of minor details, which may be due to different workers.

8 The earth bank built against the inside of the wall has generally been ascribed to the original phase of the Landward Wall (Maloney 1983, 101); however, excavation at 8–14 Cooper's Row raises the possibility that it was a later addition, although precise dating evidence is lacking (Hunt 2010, 55, 58).

9 Hobley 1983, 82; Maloney 1983, 97.

10 Merrifield 1983, 154, 164.

11 Marsden 1980, 127 estimates over 1 million facing stones and *c*. 500,000 bricks; however, this calculation includes material for the incorporated Cripplegate Fort.

12 M. Wheeler in RCHM 1928; Merrifield 1965, 320–5.

13 Blagg 1980, 125–93; Barker *et al*. 2018, 332–4.

14 Sheldon and Tyers 1983, 358–60.

differences in construction method.[15] It is possible that this part of the wall dates to A.D. 350–75 and is roughly contemporary with the late fourth-century towers.[16] A final section of the wall at the very eastern end, near the Tower of London, is a late fourth-century addition (A.D. 390s), perhaps even part of a second additional wall built while the first was still standing.[17]

The bastions are clearly a later addition to the existing Landward Wall since all of them but one were built against the external face of the wall with no attempt to bond the masonry.[18] They are generally D-shaped, *c*. 5.8–7.9 m wide and project 4.4–5.6 m from the wall.[19] They were generally constructed of Kentish ragstone, pink mortar, chalk and flint, sometimes with courses of bonding or facing tiles, and were regularly spaced on the eastern side of the circuit at intervals of *c*. 60 m. Like the Riverside Wall, several of the projecting towers stand firm on rubble cores comprised of earlier tomb monuments or architectural pieces, a number of fragments of which survive and are now in the Museum of London.[20] Some of the recycled material, however, was destroyed during building clearances of the nineteenth and early twentieth centuries: bastion 11, for example, was demolished during the building of the General Post Office in 1906,[21] and the material was put through a stone-breaker on the site and used for concrete paving in the Post Office yard. The projecting towers are generally considered to date to A.D. 341–75, but, again, the chronology is not secure.[22]

A later but undated phase of the Landward Wall has been more recently identified at 8–14 Cooper's Row. The style of the masonry suggests that it was either a late Roman or early medieval addition.[23] The earlier date is suggested by the presence of a blocked doorway at the centre of the exterior elevation of this later masonry addition that may have led out into an upper level of bastion 2A. If correct, this points towards a late Roman refurbishment of the Landward Wall when the bastions were added in the fourth century.

LONDINIUM'S LANDWARD WALL IN THE CONTEXT OF OTHER TOWN WALLS AND MAJOR BUILDING PROJECTS

Londinium was not the only Roman town in Britannia to have stone defences, but no other series of stone walls in the province enclosed such a large area. Parallels for the area enclosed and the length of the circuit can be provided by a handful of towns only in Gaul and Germany.[24] Apart from the stone walls of Colchester, which were built after the Boudican revolt in the early A.D. 60s and completed by A.D. 80, it has generally been thought that, before the second century, earthworks were the main form of defence in Britain. It now appears, however, that Gloucester

15 Williams 1993, 10.
16 Perring 1991, 106, 124.
17 Marsden 1980, 178.
18 Bell *et al.* 1937, 2. The eastern bastions are widely regarded as late Roman, while the western ones are thought to be medieval (Maloney 1983, 105–10), though recent work suggests that not all the bastions fit neatly into this classification (Lyon 2007).
19 Merrifield 1965, 320–5.
20 *CSIR* GB 1.10 catalogues 23 sculpted objects from bastions 2, 4A, 8, 9 and 10 (the last of which has the largest number of carved stones – 13 – including the so-called 'Camomile Street soldier'); Barker *et al*. 2018, 335–7.
21 Bell *et al.* 1937, 107.
22 Maloney 1979, 297; Marsden 1980, 172; Maloney 1983, n. 22. This range is based on the discovery within a ditch fill contemporary with the construction of bastion 6 of a coin of Constans dated to A.D. 341–46, along with earlier pottery.
23 This second phase is represented in sections of masonry located 4.3–6 m above the plinth. The rubble core has a slightly different, orange, sandy matrix that is otherwise similar to the Roman core. Hunt 2010, 56 also notes that the facing lacks the regularity characteristic of the original Landward Wall and is also dissimilar to the later medieval additions detailed in Strickland 1999.
24 Maloney 1983, 97. For example, Trier, Autun, Nîmes, Avenches, Tongres and Vienne.

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and Lincoln too had narrow stone walls possibly as early as the end of the first century A.D.; these *coloniae* were the only towns to receive imperial permission to build defences.[25] In contrast to other areas of the north-western provinces, however, a large number of towns had earthwork defences prior to A.D. 200, sometimes including stone gates to accompany an earthen rampart or defensive towers in wood.[26]

As in other parts of the Roman Empire, the early third century saw the construction or the conversion of existing earthen defences in British towns into stone walls,[27] and, by the end of the fourth century, even the network of 'small towns' in Britain had defensive stone circuits, many including projecting towers from this period.[28] In order to set the effort for the construction of Londinium's Landward Wall in context, a summary of selected sites with significant defences in stone may be found in TABLE 1. In particular, York and Chester present interesting and important parallels with the defences of Londinium. They are potentially contemporary with the construction of the Landward Wall and, when considered as a group, perhaps lend support to the Severan/Caracallan (A.D. 193–217) dating of the Landward Wall and its association with the division of Britain into Superior and Inferior (see below).

The historical context for the construction of urban defences is frequently given as times of concern and stress during the later Empire. Many of the Gallic walls, traditionally dated to the late Roman period and frequently built with large quantities of reused material, are typically explained in this fashion, as a response to threat or crisis.[29] The lack of firm dating and the likelihood that, in fact, many stone circuits fall outside this period, however, has called this interpretation into question.[30] Britain was not without periods of instability, but these episodes appear not to have inspired construction of defences. In his review of urban defences in Roman Britain, Simon Esmonde Cleary notes that the wide date ranges assigned to the defences argue against such factors being a major reason behind their construction,[31] as they do not explain the differences in construction date or the limitation of this phenomenon to Britain with no similar instances on the continent. The walls at Colchester, for instance, could be a direct response to the Boudican revolt, but equally they would be an appropriate addition to Britannia's first capital, lending weight to the argument that walls were about prestige as well as defence. Equally, the motivation of civic status seems insufficient to explain defences built in 'small towns' throughout Britain (possibly as many as 30 by the end of the fourth century), which perhaps fulfilled 'official' or military functions.[32] It would appear that the construction of stone urban defences cannot be considered as a single experience, but instead reflects a multitude of decisions and preferences at the town level. A range of reasons, therefore, besides political and military instability, inspired construction of urban defences. The use of freshly quarried, rather than reused, material in Britain (Lincoln, Chester, the Riverside Wall and the projecting towers added to the Landward Wall are amongst notable exceptions)[33] suggests benefaction, civic pride, availability of military labour or a combination of these factors should be considered as possible alternative motivations that led to the construction of defences.[34]

25 Hobley 1983, 79; Jones 2002, 58.
26 Esmonde Cleary 2003, 79–84; 2019.
27 Pearson 2006, 31.
28 Johnson 1983a, 115–16; Esmonde Cleary 2003; 2007; 2019, 83–4.
29 Witschel 2013, 161–4, 169–74.
30 Witschel 2013, 164–5.
31 Esmonde Cleary 2019, 77–8 discusses the debate around motivations for the surge in the construction of urban defences.
32 Esmonde Cleary 2019, 77.
33 Speed 2014, 109–10, table 6; Barker *et al*. 2018, 332–42; Esmonde Cleary 2019, 86.
34 See Laurence *et al*. 2011, 141–69 for arguments about urban status. See Dey 2011, 112–21 for a discussion of the motivation for the Aurelianic Walls in Rome and the various factors involved in their construction, including defence, prestige and the undertaking of a large-scale public work to aid in the stability of Aurelian's regime in the capital.

TABLE 1. SITES IN BRITANNIA WITH CONSIDERABLE CONSTRUCTION EFFORT IN STONE DEFENCES

Site	Dimensions of town walls and volume and type of materials	Other defensive structures
Colchester: pre-Roman settlement, early Roman fort, *colonia*, provincial capital until the mid- to late 1st century	Town walls, *c*. 2.8 km long, 2.4 m thick and up to 6 m high. An estimated 45,000 m^3 of stone, brick and mortar was needed (Crummy 1997, 87–9).	Between 12 and 24 defensive towers and six town gates. Walls with gates were probably built *c*. A.D. 62–80. Internal earth bank added by A.D. 200.
Gloucester: early legionary fort and *colonia*	First city wall was probably built onto the earlier turf and timber ramparts, around 2.4 m thick, made of a core of oolite rubble faced with blocks, perhaps in *opus quadratum*. It was somewhere between 4 and 5.5 m high, surrounding an area of 43 acres (Hurst 1986, fig. 41, 104–6, 113).	Early turf and timber ramparts associated with legionary defences *c*. A.D. 65; stone facing to the rampart *c*. A.D. 87 or later (the 'first city wall'); rampart rebuilt and tower added in late 2nd century; second city wall probably dated to the late 3rd century; additions, external tower and third build of city wall, overlying remains of first wall, probably also late 3rd century.
Caerwent: pre-Roman and Roman settlement	Average wall dimensions of 5 m high and 2.5 m thick; required 40,000 tonnes of stone (Allen 2012, 5), which is *c*. 16,000 m^3.	Mid- to late 2nd-century earthwork of a single or double ditch with bank in between and masonry gates; replaced by a stone wall at end of 3rd century/early 4th century. Eleven bastions added probably *c*. A.D. 350, unevenly spaced on the N and S walls.
Lincoln: *colonia*	Wall originally 1.2 m wide and 4 m high, but thickened and raised to 6 m in the late 2nd to early 3rd century, and, again, to 7–8 m in the late 3rd or 4th century (Jones 2002, 58–9).	Early ditch, with *c*. 40 internal towers added at a later date, and four city gates. Gates were turned into monumental structures in the 3rd century. Ramparts and ditch were widened in the latest phase.
Silchester: pre-Roman and Roman settlement	Walls currently stand up to 5 m high and 3 m thick. In the order of 200,000 cartloads of material required (Allen 2013, ix). Originally enclosed an area of *c*. 100 acres (*c*. 0.4 km^2).	Gates probably date to mid-2nd century (S and SE gates probably built first). Earthen ramparts *c*. A.D. 180–200. Stone walls built *c*. A.D. 270.
Chester: Legionary base and town	Probably *c*. 3 km in length; longer if the defences also included the 'quay wall'. Base of wall around 1.5–1.7 m wide, reducing to 0.8 m in upper courses. Revetment wall rose to 4.65–4.7 m in height. Walls, gates and towers made of local Bunter Pebble Beds sandstone (LeQuesne *et al*. 1999).	Earthen rampart (*c*. A.D. 70–80) with wooden palisade and wooden towers later replaced by walls, gates and regularly spaced towers (65 m between each). Stone walls begun *c*. A.D. 100, but work was suspended and finished over a century later. Tombstones reused in repairs to the N wall of the fort in the later Roman period. Medieval walls built over or near Roman ones confuse the sequence and not all Roman remains discovered. The present course probably dates to the 12th century.

Continued

TABLE 1. CONTINUED

Site	Dimensions of town walls and volume and type of materials	Other defensive structures
Chichester: pre-Roman and Roman settlement	Walls were at least 4.1 m high and probably 2.4–3 m thick, running for a length of 2.375 km (Westman 2012, 37, 44).	Earth bank revetted on its outer face with a masonry wall, topped with a wall walk and parapet; ditches beyond; probably 4 gates, and perhaps gatehouses and towers. All added in second half of 3rd century. Eight D-shaped bastions added in 4th century.
The Saxon Shore forts: series of military forts on the southern and eastern coasts	Eleven forts, each between 6 and 10 acres in area. Volume of raw material required was in the order of 200,000 m^3. This varied considerably between forts: i.e. 14,000 m^3 at Burgh Castle and 33,710 m^3 at Pevensey (Pearson 2003, 88).	A series of forts, probably built in two phases: the earliest in classic 'playing-card' shape, without brick courses and without bastions (Brancaster, Caister and Reculver; early 3rd century). The rest, built A.D. 260– 300, have defensive towers.
York: legionary fortress, settlement and later *colonia*. Capital of Britannia Secunda from end of 3rd century	Walls are currently around 4 m high and 1.8 m wide, running for a course of around 3.4 km, but this has probably been considerably extended since the Roman period. The initial walls for the fort enclosed an area of 50 acres, had no plinth and were 1.5 m wide (Lander 1984, 32).	Early (Flavian period) defences comprised a ditch, embankment, timber fence, timber towers (spaced around 38 m apart) and gates. Later rebuilt in stone; complete by end of the 2nd century (perhaps from A.D. 107/8, if *RIB* 665 commemorates the construction of walls as well as the gate mentioned). Walls were enlarged and rebuilt over the centuries.
London: early Roman military base and town, provincial capital mid- to late 1st century, capital of Britannia Prima from end of 3rd century	**The wall was 2.7 m thick at the base and stood over 6 m high, running for around 3 km in length. Enclosed an area of *c*. 330 acres or 1.33 km^3.**	**Early 1st-century defences included an earthwork rampart and ditch; later a stone wall, *c*. A.D. 190–220. Riverside Wall was added in mid-3rd or late 4th century; bastions are late 4th century.**

Indeed, the monumentality of urban walls, which involved a significant amount of labour, material and money, meant that urban circuits 'easily match and often surpass, the urban monuments of the High Empire'.[35] The Aurelianic Walls at Rome (19 km in length, 8 m high, 3.5 m wide), for example, begun in A.D. 271, needed *c.* five to ten years to complete,[36] while David Breeze and Brian Dobson have estimated that Hadrian's Wall (117 km in length, *c.* 4.4 m high, 2.5 m wide) took three years to construct and involved perhaps 10,000 legionary soldiers.[37] In terms of the economics and costs involved in the construction of urban defences, we have few contemporary sources. An inscription from Constantinople informs us that the 6.5 km of the Land Walls of that city were constructed in nine years, with work starting in A.D. 404 or early A.D. 405 and completed by A.D. 413.[38] A restoration to the inner line of the same Land Walls was completed in two months.[39] Similarly, an inscription dated to A.D. 265 on the Porta Borsari in Verona (Italy) indicates that more than a kilometre of the walls were built in nine months.[40] Yet, such material offers little in terms of precise details about the amount and type of labour employed in these constructions. For this, we need to examine the walls themselves, to quantify the individual materials and actions that went into building urban defences and the estimated labour involved in these tasks.

Given the sheer economic investment in both human and material resources needed for the construction of urban defences (especially those constructed in stone), surprisingly few studies have sought to determine the relative costs for such structures. In fact, few studies have tackled military building projects from the point of view of quantitative analysis of the materials and labour needed.[41] For urban defences, there are of course also exceptions, including the basic labour figures for the Republican walls of Rome and the more detailed ones for Aquileia (north-eastern Italy).[42] Some labour estimates for two late Roman walls in Gaul, Bordeaux and Saint-Bertrand-de-Comminges (south-west France), have also been undertaken;[43] however, much more work needs to be done to understand fully the technological complexity as well as the organisation of the construction process of urban walls and other building projects within the provinces.

35 Esmonde Cleary 2013, 123.

36 Richmond 1930, 29–30; Dey 2011, 99.

37 Breeze and Dobson 1976, 72–4.

38 Bardill 2004, 122. The figure is from an inscription (found in front of tower 20 of the inner wall) that commemorates repairs to the wall made in A.D. 447 and explicitly states that the original construction lasted for nine years; see Lebek 1995, 138. Moreover, the decree in the *Codex Theodosianus* (15.1.51) dated 4 April 413 confirms that the walls were completed in that year.

39 *CIL* 3.734 = *ILS* 823. In his entry for the year A.D. 447, Marcellinus (*Chronicle* 447.1–2) records that the city walls suffered damage from an earthquake that brought down 57 towers and were rebuilt by the praetorian prefect Constantine in just under three months in that same year. As Jonathan Bardill (2004, 123, n. 22) notes, work took only two months, as the inscriptions records, and he suggests that the discrepancy most probably results from an error during the transmission of Marcellinus's text. He dismisses the idea of two building campaigns, one of three months, the other of two, in A.D. 447. This seems more realistic than Wolfgang Lebek's (1995, 127) suggestion that the damage to the inner wall was repaired in three months within the first half of A.D. 447 and then late in the same year the outer wall was built *de novo* in 60 days.

40 *CIL* 5.3329 = *ILS* 544.

41 For notable exceptions, see Camporeale 2011 for the military camp in Thamusida; Shirley 2000 for the legionary fortress at Inchtuthil; Breeze and Dobson 1987, Kendal 1996 and Hill 2004 for Hadrian's Wall; Pearson 2003 for the Saxon Shore forts; Bachrach 2010 for Bordeaux; Esmonde Cleary and Wood 2006 for Saint-Bertrand-de-Comminges.

42 For Rome's Republican walls, see Volpe 2014, 61–3; Bernard 2018, 75–117. For Aquileia, see Bonetto and Previato 2018. See also Bernard Bachrach's (1984) analysis of the cost of castle building at Langeais for useful comparanda from the medieval period, emphasising the person-hours of labour expended to carry out defensive building projects.

43 Bachrach 2010 for Bordeaux; Esmond Cleary and Wood 2006, 143–6, 215–16 for Saint-Bertrand-de-Comminges. Labour figures for city walls were also presented at the 19th International Congress of Classical Archaeology held at Cologne/Bonn (e.g., S. Müth and J.-C. Bessac, 'Economical challenges of building a Geländemauer in the middle 4th century BC: the city wall of Messene as an example' and S. Bernard, 'The energetics of polygonal masonry: building the colonial walls of Cosa').

THE CONSTRUCTION MATERIALS OF THE WALL: GEOLOGICAL SOURCES, SUITABILITY AND SUPPLY

Surviving parts of the Landward Wall, most notably around Tower Hill just to the north of the Tower of London (FIG. 2), are a testament to the durability of the construction materials. This section looks at these materials: what was used, from where the stone, clay and mortar were sourced and the locations of these resources in relation to the provincial capital and their supply routes. A set of tried and tested geological techniques[44] (hand specimen and thin section comparative analysis) have been applied to these materials to determine their geological character, source and suitability for intended use (e.g., ease of carving).[45]

The geological character of south-eastern Britannia around Londinium is characterised by young, soft and unconsolidated Tertiary sands, gravels and clays, many of which are completely unsuitable for use as hard building materials. The excellent riverine and maritime links afforded to Londinium by the river Thames, its tributaries and the Thames Estuary allowed better-quality stone materials to be brought in from distance in bulk.[46] By river, it was possible to access the native Middle Jurassic limestone freestone outcrops (the closest of which is at Wheatley, just east of Oxford) (FIG. 3). Seagoing vessels could be employed to make desirable coastal and continental stone types far more accessible.

For brick and mortar manufacture, however, all the necessary materials were available within easy access of the provincial capital. The locally outcropping glacial deposits provided brick-earths, gravels and clays for brick-clay production and the primary ingredients for the typical hard Roman mortar (sand, reworked flint pebble and lime). The nearby riverside Upper Chalk deposits at Woolwich would no doubt have been a key contributor to the lime.

Despite an absence of hard stone suitable for large-scale construction projects in the immediate vicinity of Londinium, the Landward Wall is built primarily in stone. It consists of a rubble core coupled with at least nine lacing courses of Lydion brick, a covering of facing blocks and a basal chamfered plinth course, and it is capped with a level of coping stones.[47] The foundation consists of a chalk and flint raft, which would have come from the aforementioned Upper Chalk deposits of Woolwich or the lower Medway.

The entire stone rubble core and the facing stones from the surviving sections of the Landward Wall consist of Kentish ragstone (FIG. 4), which in hand specimen appears as a hard dark-grey sandy, chert-rich glauconitic sandstone, with no visible fossils. FIG. 5a illustrates a sample of this rock in thin section, showing that it is made of angular quartz grains and round grains of green glauconite with an abundant matrix of high ferroan (purple) calcite and characteristic bolivinid foraminifera microfossils. Together, these properties make it one of the toughest sedimentary rocks, consistently difficult to break up with a hammer, even for rubble core, and not at all easy to shape, even for the most basic shapes of facing stone or ashlar.

Hand specimen petrological work has established the ragstone's source as the Lower Cretaceous (Hythe Formation) along the banks of the upper river Medway, Maidstone, west Kent (FIG. 6), *c.* 127 km from London via the Medway, through the Estuary and up the Thames.[48] There are five candidate Roman ragstone quarries,[49] with Teston (TQ 7045 5425) being the furthest upstream.[50] This is not surprising, as the Kentish ragstone of upper Medway

44 Hayward 2006; 2009; 2015.

45 *CSIR* GB 1.10.

46 Hayward 2015.

47 For structural details of the wall's construction, see, for example, Maloney 1983, 98–101 and Hunt 2010, 54.

48 Marsden 1994; Hayward and Roberts 2020. Simon Elliott (2018, 97–100) assumes that the Teston quarry was the starting point for the journey. All distances have been estimated from GoogleEarth.

49 Elliott 2018, 85. The five quarries are located at Allington (TQ 7446 5792), Teston (TQ 7045 5425), Quarrywood (TQ 7194 5193), Dean Street (TQ 7450 5334) and Boughton Monchelsea (TQ 7691 5180).

50 Elliott 2017, 113.

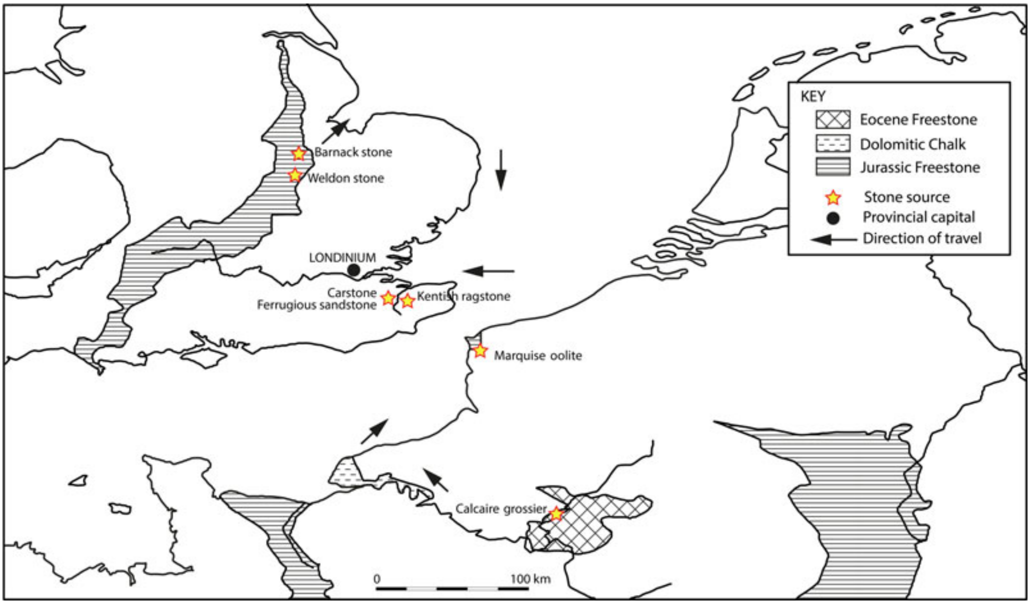

FIG. 3. Map showing geological character and source of the different freestone and ragstone materials used in the construction of Londinium's Landward Wall (illustration by K. Hayward).

was the major building material for stone structures in Londinium, including the forum-basilica complex, the governor's palace, the second phase of the amphitheatre and several bath-houses, including that at Huggin Hill.[51] We know that the stone was transported by boat or barge downstream to the Thames Estuary and upstream to the Wharf of Londinium, because a large quantity of ragstone was found in the hull of a Roman shipwreck, the Blackfriars 1-type vessel, that was discovered in 1962 in the City of London (opposite Westminster) and excavated in 1963 (see below).[52]

The bonding mortar for the Landward Wall is made of 20 mm-sized black round pebble flints bonded in a hard, chalky lime cement (FIGS 7 and 8).[53] The source of the pebbles is unclear, but the most likely candidates are the Ice Age River Terrace Gravel deposits that outcrop in the modern City of London (FIG. 6). Thus, the material could have been sourced within 1 km, from gravel terrace areas adjacent to the wall and taken directly to site by ox cart.[54] The white chalk lime would have come by boat upstream from outcrops 12 km away on the northern and southern banks of the river Thames (FIG. 6).

51 Hall and Merrifield 1986, 10; Marsden 1994, 84; Rowsome 1996, 421; Bateman 2011, 31; Elliot 2017, 112.
52 Marsden 1994, 33–95; Elliott 2016, 199.
53 Natural lime deposits can contain a proportion of clay (typically 8–12 per cent) that, when fired, provides a very strong hydraulic mortar; however, scientific analysis of a mortar is necessary to confirm if this is the case. The authors would like to thank Riley Snyder for pointing out this fact. For this natural 'pozzolanic effect' that mimics the hydraulic effect of volcanic pozzolana, a characteristic part of Roman 'concrete' construction, see Charola and Henriques 2000, 96. For this phenomenon in the mortar used for Hadrian's Wall, see Rayment and Pettifer 1987.
54 Other possible sources include Charlton on the southern bank of the Thames at a distance of 12 km or Stanmore Common, Watling Street, at a distance of 12 km.

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FIG. 4. Detail from the surviving section of the Landward Wall by Tower Hill. The view shows the brick bonding – or lacing – courses arranged at regular intervals with two or three rows of bricks and the angular Kentish ragstone blocks used for the wall's facing (photo by K. Hayward).

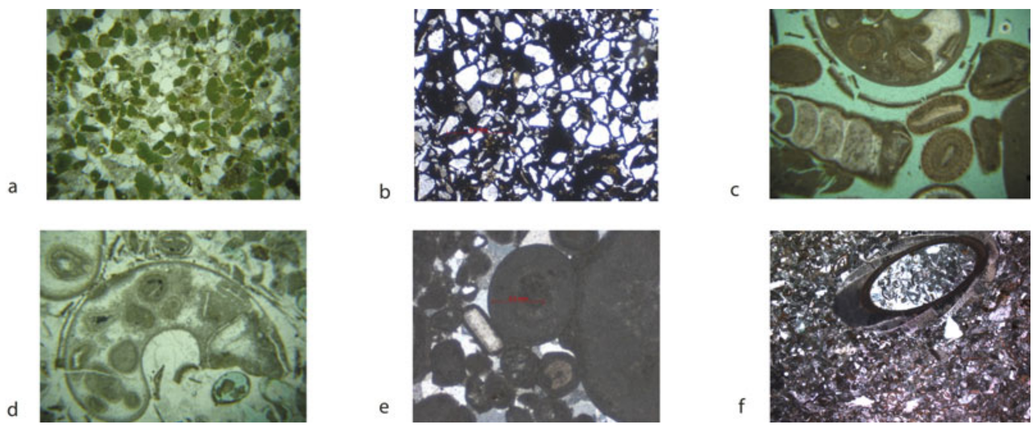

FIG. 5. Photomicrographs of the stone materials used in the primary construction of Londinium's late second- to early third-century Landward Wall: (a) Kentish ragstone – west Kent (walling rubble and facing blocks); (b) ferruginous sandstone – west Kent (basal chamfered projecting plinths); (c) Weldon stone – Northamptonshire (basal chamfered projecting plinth); (d) Barnack stone – Cambridgeshire (basal chamfered projecting plinth); (e) Marquise oolite – Boulogne – Seine Maritime (coping stone); (f) Calcaire Grossier St Maximim, Paris – Oise (coping stone). Field of view 4.8 mm plane polarised light (PPL) for (a), (c) and (d), and cross polarised light (XPL) for (b), (e) and (f) (image by K. Hayward).

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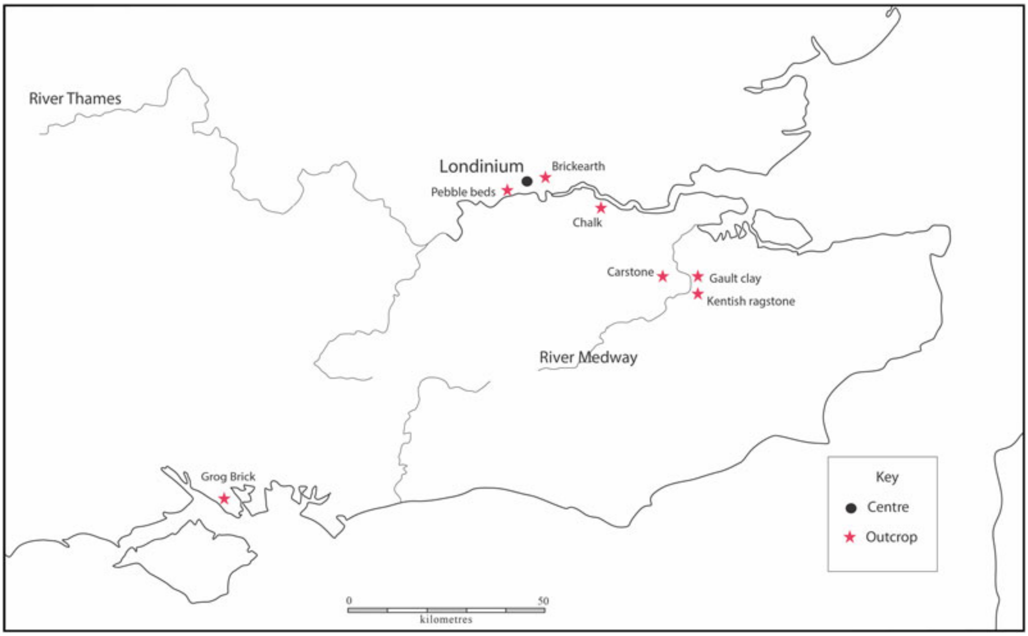

FIG. 6. Map showing the outcrop location of materials used in Londinium's Landward Wall (image by K. Hayward).

FIG. 7. Section of the Landward Wall by the Wardrobe Tower, Tower of London, showing a detailed view of the *opus caementicium* core with Kentish ragstone rubble pieces (photo by K. Hayward).

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FIG. 8. Detail of the bonding mortar (a pebbly *opus caementicium*) in a section of the Landward Wall by the Wardrobe Tower, Tower of London, made of 20-mm sized black round pebble flints bonded in a hard, chalky lime cement (image by K. Hayward).

With a ratio of 70:30, ragstone to mortar, it has been possible to estimate that 87.5 Kentish ragstone rubble pieces were used in each cubic metre section of the core (see ONLINE TABLE 1 for dimensions of individual elements of the Landward Wall). The hard, robust Kentish ragstone was also suitable as facing for the wall. The facing blocks seen in section on the wall are tightly pressed against each other, with a maximum gap of *c.* 5–10 mm for the mortar joints.

The brick bonding – or lacing – courses were arranged at regular intervals, with each course consisting of two or three rows of bricks, built with rectangular Lydion brick. The basal bonding course consists of three rows with the remaining bonding courses each consisting of two rows of bricks per course. A 4.5 m-high section of the wall, close to the Tower of London, shows up to four bonding courses of Lydion brick separated by 0.6 m of wall (*c.* five or six rows of facing blocks) (FIG. 2).

The production of tiles and bricks from local brick-earth deposits in Londinium (FIG. 6) accounts for *c.* 90 per cent of the ceramic building material used in the town during the late first and second centuries.[55] While the exact location of ceramic production centres in Londinium is difficult to determine, tile wasters and the remains of kiln structures have been identified in the western half of the city, including at Paternoster, St Paul's Cathedral and 120 Cheapside.[56] The presence of significant quantities of roof-tiles, bricks and *tegula mammata* in a kiln in Paternoster Square[57] has led Ian Betts to argue that potters and brickmakers exploited the same clay sources in these regions.[58] Moreover, a procuratorial tile kiln operated in

55 Betts 2017, 368.
56 Marsden 1969, 40–2; Betts 2017, 368–9, fig. 17.1.
57 Watson and Heard 2006, 53, 76.
58 Betts 2017, 369.

Cheapside, where waster tiles stamped with PPBRILON were discovered.[59] These tiles seem to have been used almost exclusively for Londinium's major public buildings during the late first and early second centuries, including the fort at Cripplegate.[60] This procuratorial production ceased by the time of the fire that swept through much of the town in the mid-120s. There is evidence for a small amount of private brick and tile manufacture in Londinium in the late first to mid-second century; however, the small number of civilian stamps suggests that they only formed a minor source of brick and tile for the town.[61] Alternatively, it is also possible, as Betts has argued, that only a small number (perhaps one per day) of civilian bricks were actually stamped, suggesting a larger private brick industry in Londinium than the evidence indicates.[62]

Brick production must have resumed in Londinium (if indeed it had ceased) to supply the vast amount of ceramic building material required for the Landward Wall. Due to the fact that no stamped bricks have been identified from the Landward Wall, it is not possible to identify those responsible for the brick production; however, production could have been restarted in the procuratorial kilns without stamps being employed. Indeed, such stamps would not have been needed if the bricks went straight from the production site to the site of construction. Moreover, it is worth noting that none of the new supplies of ceramic building material coming into Londinium from the mid-second century was stamped, and it would therefore appear that most producers thought it unnecessary to stamp their tiles. Obviously, where possible, bricks and tiles were also reused for the construction of the wall, but this does not seem to have been a major mechanism of supply. While, as noted above, there is not much indication of large private production of ceramic building material in Londinium, we should stress that it is of course impossible to separate unstamped private bricks from unstamped procuratorial bricks, as both used the same types of clay. Similarly, it is difficult to differentiate reused Londinium-made bricks from earlier periods and new Londinium-made bricks in the Landward Wall for the same reason. The only clear evidence for reused bricks is from a section of the wall near the Museum of London which reused Roman *tegulae* sideways to give the appearance of bricks.[63] On balance, the scenario of purpose-made kilns set up for the construction of the Landward Wall makes the most sense; indeed, it is difficult to imagine how else the large quantities of bricks needed for the wall's construction could have been supplied.[64]

In total, around 90 per cent of the bricks used in Londinium's Landward Wall were made of a red sandy fabric, sourced from the glacial brick-earth clay that underlay much of the town.[65] In addition, small quantities of 'Grog' bricks were imported from Hampshire, *c.* 337 km by sea and river from Londinium (FIG. 6).[66] The remainder consisted of fine white-yellow sandy 'Eccles' bricks (FIG. 6), sourced from the Upper Cretaceous Gault Clays of north-western Kent,

59 Betts 2015. In total, 200 procuratorial stamped tiles are known from Roman Britain, almost all from Londinium and dated to the late first to second century.

60 Betts 1995, 218; 2017, 370. Other buildings include the baths at Huggin Hill, the forum-basilica, the amphitheatre and two postulated public buildings in Southwark.

61 Betts 2017, 370.

62 Betts 2017, 370.

63 Ian Betts (pers. comm.).

64 For this point in connection to brick procurement in fifth-century Ravenna, see Snyder 2019, 87–8. He clearly shows that the process of brick supply involved a combination of newly established/re-established kilns dedicated specifically to the wall's construction and large-scale salvage and recycling operations.

65 This figure correlates with other earlier construction in Londinium, where the majority (85–95 per cent) was sourced from locally made red and orange ceramic material, with only 5–15 per cent imported (Betts 2017, 371, fig. 17.3). Betts (2017, 370) argues that, after the mid-second century, brick production moved from Londinium to regional centres nearby; however, his discussion of brick sources does not include those for Londinium's Landward Wall. It is possible that the procurator in charge of the wall restarted brick production within the town specifically for the project.

66 However, we should note that many similar silty bricks seem to have been made in northern Kent and thus are another possible source.

about 3 km downstream from the Kentish ragstone quarries at Allington (TQ 7446 5792) near Eccles Roman Villa, *c.* 114 km by river and estuary from Londinium. It seems that, in the case of Eccles bricks, the production of ceramic building materials was directly linked to the exploitation of Kentish ragstone from quarries in the Maidstone area.[67] It is likely, as Betts has argued, that these other brick sources were required due to the demand created by the construction of Londinium's Landward Wall exceeding the production capacity of local kilns.[68]

Forming the lowest course of the Landward Walls, and only visible in a section adjacent to the Wardrobe Tower of the Tower of London, are three projecting stone chamfered plinths (FIG. 9). In hand specimen, it could be seen that they are made of an entirely different material, described as a friable, dark-brown, gritty, ferruginous sandstone, also known as Carstone, which in thin section consists of numerous small, equigranular quartz grains, floating within a dark-brown ferruginous matrix (FIG. 5b). Lacking the open porosity of a good-quality freestone (see below), its homogeneous texture is nevertheless conducive to the carving of basic architectural elements. It would also have been much easier and less time consuming to work than the extremely hard ragstone used as facing stone in this section of the Landward Wall. Furthermore, its colour may have been an aesthetic choice, perhaps serving to reflect the contrast between the brown basal wall plinth and the much greyer ragstone defensive wall facing.

These plinths, which were also uncovered during archaeological excavation of other sections of the wall to the north at Dukes Place and at Aldersgate close to Cripplegate Fort,[69] are petrologically identical to medium-grained to pebbly iron-rich sandstones from the Lower Cretaceous (Folkestone Beds). These outcrop in areas of high ground between Sevenoaks and Maidstone in western Kent (FIG. 3).[70] Significantly, there are outcrops close to the river Medway near Maidstone, just 0.5 km south of the Gault clay deposits near Eccles and just to the north of the geologically older Kentish ragstone at Aylesford Sand and Gravel pit,[71] approximately 115 km by river and estuary from London.

Completing the repertoire of stone building materials for the Landward Wall is a series of better-quality limestones, used specifically in the more intricately carved and shaped mouldings and sharply dressed dimension stones, such as coping stones, ashlar and other chamfered blocks. All these materials are collectively termed freestones, which have an even-grained, soft, open porous texture that enables the rock to be worked or carved in any direction and to take inscription, yet is hard enough to withstand external weathering.[72] These better-quality materials came from much further afield. A majority can be sourced to the aforementioned Middle Jurassic limestone outcrops of central-south England as well as northern France.[73]

Three more of the chamfered blocks forming the lowest course of the wall in a section adjacent to the Wardrobe Tower of the Tower of London were made of freshly carved paler cream/white freestones of two varieties, as can be seen in FIG. 9. First, there is the open-textured, softer Weldon stone made of numerous small round carbonate grains called ooids (FIG. 5c), which is sourced to the Middle Jurassic (Bajocian) of Northamptonshire in eastern England (FIG. 3). Then there is the much harder shelly oolitic Barnack stone (FIG. 5d) from the same stratigraphic horizon but in outcrops further to the north in Cambridgeshire (FIG. 3). These would have come considerable distances by boat – *c.* 429 km and *c.* 404 km, respectively – by river over the East Anglian Fens, then around the eastern coast before travelling up the Thames. The availability of both materials as basic architectural elements in the defensive wall coincides with their much

67 Betts 2017, 371.
68 Betts 2017, 372.
69 Potter and Hayward 2006.
70 Worssam 1963; Dines *et. al.* 1969.
71 Worssam 1963.
72 Leary 1989.
73 Honeyborne 1982.

FIG. 9. Basal chamfered plinth in ferruginous sandstone (brown) and Weldon and Barnack limestone (pale-cream/white) from a section of the Landward Wall by the Wardrobe Tower, Tower of London (image by K. Hayward).

wider third-century exploitation, supply and working elsewhere in the provincial capital. A case in point is their identification in much larger sculptural blocks,[74] subsequently reused in the later fourth-century Riverside Wall.[75] These would have originally been used in the third-century monumental archway and screen of gods associated with riverside temples on the western edge of the Roman town.[76]

The largest individual elements from the defensive wall are the hemispherically shaped coping stones, which were probably used to form the top of the crenellations of the wall (FIG. 10).[77] A petrological sample taken from one of these elements found reused in bastion 9 was made of a hard, cemented pale-grey limestone,[78] characterised by millet-sized (0.2–0.5 mm) ooids and

74 Dimes 1980; Hayward 2015.

75 Blagg 1980; Barker *et al.* 2018.

76 Blagg 1980; *CSIR* GB 1.10.

77 We have chosen to include crenellations within the original design of the Landward Wall. The Roman walls at Canterbury seem to have had the classic embrasure/merlon form of crenellations (Maloney 1983, 101); however, for Londinium the evidence is less clear. Coping stones are definitely present, but how these blocks were originally arranged cannot be definitively confirmed, because the tops of the walls are absent in many places. John Maloney (1983, 110, fig. 108) reconstructed the Landward Wall with crenellations (e.g., he mentions L- and T-shaped coping stones that might have come from something more complex than simple coping-stone-topped walls). While we are slightly circumspect about reconstructing crenellations, since arguments can be made either way, for the purpose of keeping the calculations in the right order of magnitude, we have included them.

78 Maloney 1983, fig. 106.

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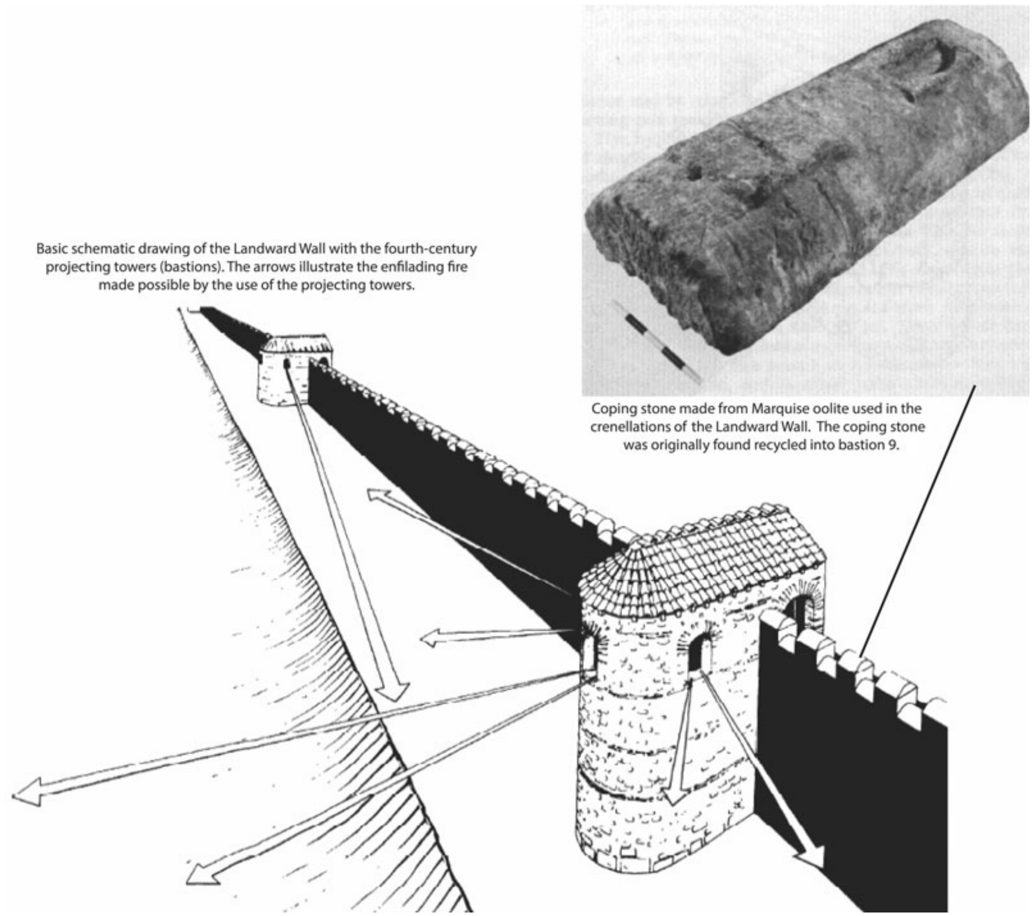

FIG. 10. Example of the coping stone made from Marquise oolite and its projected emplacement into the Landward Wall (from Maloney 1983, figs 106, 108).

pseudooids. In thin section (FIG. 5e), this limestone has an identical petrological match with samples of Marquise oolite from the Middle Jurassic (Bathonian) of Marquise, near the naval headquarters for the *Classis Britannica*, Boulogne (Gesoriacum), Département Pas-de-Calais, just 7 km from the coastline of northern France (FIG. 3).[79] The outcrop lies some *c*. 183 km by maritime and fluvial networks from Londinium. That this material has also been identified in hand specimen from the early naval bases at Richborough, Dover and Lympne suggests that the supply of at least some of the stone used in the wall was undertaken under the auspices of the *Classis Britannica*.[80]

It is possible, too, that several limestone monumental blocks reused in bastion 1 (in the present-day Wardrobe Tower of the Tower of London) (FIG. 11) relate to the upper crenellated parts of the original defensive wall illustrated in FIG. 10.[81] The Ditrupa worm holes seen in thin section (FIG. 5f) are identical to those in Calcaire Grossier, specifically Banc de St Leu,

[79] Worssam and Tatton-Brown 1990.
[80] Bushe-Fox 1926; Strong 1968; Worssam and Tatton-Brown 1990.
[81] Hayward and Roberts 2020. The examples in the Wardrobe Tower (60 cm long by 45 cm wide by 40 cm deep) are the result of reuse and breakage of these blocks.

FIG. 11. Monumental blocks of yellow Calcaire Grossier reused in bastion 1 of the Wardrobe Tower, Tower of London (photo by K. Hayward).

restricted to the Middle Eocene (Lutetian – 45 ma) of the river Oise along the Paris Basin (FIG. 3).[82] At *c*. 784 km by maritime and fluvial networks from Londinium, this material travelled a considerable distance. Not identified anywhere else in London, Calcaire Grossier is restricted in its use to large Roman construction projects at Richborough on the north-eastern Kent coast and Fishbourne Roman Palace along the West Sussex coast. The blocks in the Landward Wall are of comparable size to the monumental blocks from Richborough.[83]

The total volume of material needed for Londinium's Landward Wall is presented in ONLINE TABLE 2. To construct Londinium's Landward Wall, as well as to make the most of underlying unconsolidated sands, gravels and clays for foundation material, brick production and mortar, there existed a centralised zone of quarrying and brick production, centred on the river Medway at Maidstone some *c*. 127 km by river from Londinium, as illustrated in FIG. 6. Here, nearly all the rubble stone, facing stone and plinth stone, and some of the bricks were acquired from riverside exposures within a few kilometres of each other. This makes practical as well as economic sense, especially when considering the sheer scale of the defensive project. Supplementing these, but in a much smaller quantity, were the intricately carved elements used to define the base (chamfered plinths) and capping (coping stones) of the Landward Wall. These were made of better-quality Middle Jurassic freestones, quarried, worked and shipped in

82 Curry *et. al.* 1978; Cordiner and Brook 2017, 112–13.
83 Worssam and Tatton-Brown 1990 57; Hayward 2009.

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specifically from eastern England (Barnack stone and Weldon stone; FIG. 9) and northern France (Marquise oolite and Calcaire Grossier; FIG. 11), where they may have been quarried and supplied by the Roman navy (*Classis Britannica*). Overall, the materials used for the construction of Londinium's Landward Wall make practical sense; the majority were local and those that were not could be found on river or sea transport routes, even those from further afield in northern France.

AN ENERGETICS APPROACH TO THE LABOUR 'COSTS' OF LONDINIUM'S LANDWARD WALLS

Over the last few decades, there has been a proliferation of studies considering the production of material and the logistics of Roman construction.[84] As a result, it is now well acknowledged that a consideration of construction processes, along with the calculation of the amount and type of labour involved in the production and use of building materials, allows us to understand ancient structures in their proper social and economic contexts.[85] This energetics-based approach provides a means of quantifying various aspects of construction in terms of the labour force involved (labour 'cost'),[86] measured in person-days, along with the materials needed, in order to understand better the place of ancient structures in the ancient economy.[87]

Studies dealing with Roman Britain have considered a number of aspects of construction, especially those connected with military supplies and building projects.[88] In particular, these studies have extended our knowledge of the involvement of the military in building and supply,[89] the role of military architects,[90] Roman quarrying and stone supply,[91] and the role of stonemasons and architectural ornamentation.[92] Moreover, the source of material for these Romano-British projects has been the subject of several in-depth studies;[93] however, these studies generally have not dealt with labour estimates, with several recent exceptions. In the case of Hadrian's Wall, for example, several studies have explored the logistics, building

84 See the results published in the five proceedings of the international workshops on the archaeology of Roman construction ('Arqueología de la construcción I–V'): Camporeale *et al.* 2008; 2010; 2012; 2016; Bonetto *et al.* 2014. See also the series of international workshops on Roman brick (International Workshop 'Laterizio'): 'Il laterizio nei cantieri imperiali: Roma e il Mediterraneo' (Bricks in imperial building sites: Rome and the Mediterranean) held in November 2014 in Rome; 'Alle origini del laterizio romano: nascita e diffusione del mattone cotto nel Mediterraneo tra IV e I sec. a.C' (The origins of Roman brick: birth and diffusion of fired brick in the Mediterranean from the fourth to the first century BC) held in Padova in April 2016; 'Demolire, riciclare, reinventare: la lunga vita e l'eredità del laterizio romano nella storia dell'architettura' (Spoliation, recycling and reinventing: the long life and heritage of Roman brick in the history of architecture) held in Rome in March 2019. Currently, only the first has been published: Bukowiecki *et al.* 2015.

85 DeLaine 1997; 2001; 2017; Barker 2010; 2011; Barker and Russell 2012; Brogiolo 2017; Brogiolo *et al.* 2017. See also the recent papers published in part three of Brysbaert *et al.* 2018: 'Architectural energetics methods and applications'.

86 On architectural energetics, see Abrams 1984; 1989; Abrams and McCurdy 2019, 3.

87 For some recent examples, see Barresi 2003, 163–204; Caré 2005, 70–4; Mar and Pensabene 2010; Domingo 2012a; 2012b; 2014; Pensabene *et al*. 2012; Pensabene and Domingo 2016; 2017; Domingo and Domingo 2017; DeLaine 2018.

88 Parfitt and Philp 1981; Allen and Fulford 1999; Pearson 2003; Allen 2012; 2013.

89 Elliot 2011; 2014; 2016; 2017; 2018.

90 Evans 1994.

91 Blagg 1990a; Pearson 2006; Hayward 2009.

92 Blagg 1976; 2002.

93 For reuse of stone, see Barker *et al.* 2018; for timber, see Hanson 1978; Goodburn 1991; for iron working, see Cleere and Crossley 1995; for the production and distribution of ceramic building material, as well as the involvement of the *Classis Britannica* in these processes, see Brodribb 1969; 1970; 1980; 1987; Wright 1976; 1978; 1985; McWhirr and Viner 1978; Crowley and Betts 1992; Warry 2006; 2010; 2012; Mills 2013; Peveler 2016; for a complete overview of the production and use of ceramic building material in Londinium, see Betts 1987; 1995; 2015; 2017.

methods and person-hours required to complete the structure.[94] New work on the Antonine Wall (*c*. A.D. 140) is also investigating the labour requirements for its earth and turf construction.[95] To date, the most thorough examinations of the supply of material and the logistics and labour force required for building projects within a Romano-British context are those of the Saxon Shore forts and the legionary fortress at Inchtuthil;[96] however, Elizabeth Shirley's study of the legionary fortress at Inchtuthil (constructed A.D. 82 or 83 and carefully demolished in A.D. 85 or 86) deals almost exclusively with timber buildings. Andrew Pearson's study of the Saxon Shore forts, a series of coastal defences on the south-eastern coast of England constructed through the course of the third century, provides detailed manpower figures for production, transport and construction,[97] providing at least some comparanda for Londinium's Landward Wall. Other studies providing labour figures or material quantities for Romano-British structures are limited: those of the late third-century (*c*. A.D. 270) walls of Silchester,[98] the first-century walls at Colchester and the late third- or early fourth-century walls of Caerwent.[99] However, only the study of Silchester includes labour estimates.[100] This of course means that we have limited material with which to compare the results of the analyses presented here.

The scale of material needed for Londinium's Landward Wall is significant and makes the project, in terms of material, one of the largest projects within Roman Britain, alongside Hadrian's Wall. In the case of the Saxon Shore forts, for example, the general requirements for material were between 12,000 and 14,000 m^3 – roughly a third of what was needed for Londinium's Landward Wall. In the majority of the Romano-British cases cited above, analysis shows that most of the building material was sourced locally or involved limited use of long-distance river or coastal transport. In contrast, Londinium is without suitable local building stone, and therefore all the stone used for the construction of the wall had to be imported – via the river Thames – over considerable distances: the bulk of the stone had to be transported 127 km, though some stone was transported over 780 km. ONLINE TABLES 3 and 4 provide the overall dimensions and volumes for the wall and its constituent materials.

SUMMARY OF LABOUR REQUIREMENTS FOR PRODUCTION AND TRANSPORT

The following section assesses the total labour required for the production of the materials needed to construct the Landward Wall (the rates, assumptions and labour requirements for different

94 Bennett 1990 (estimates the person-hours involved in the building of the wall and presents figures for the volumes of the major materials used in the construction process); Kendal 1996 (provides a detailed review of the transport logistics associated with the building of the wall); Hill 2004 (provides a clear understanding of the techniques and processes of the wall's construction as well as basic manpower figures and a quantification of the materials used in its construction). More recently, O'Donnell 2020 uses energetics to look at the total person-days needed to quarry the stone for the wall.

95 For example, the Earthen Empire Project, directed by Ben Russell and Chris Beckett, and funded by the Leverhulme Trust (RPG-2018-223), seeks to highlight and elucidate the importance of earthen architecture within the Roman world. See Flügel and Obmann 2020; Snyder *et al.* forthcoming. It is worth noting, however, that the rates proposed by Hobley 1971 and used by Flügel and Obmann 2020 for cutting turf at the reconstructions of ramparts at the Lunt Roman Fort are considerably lower than the average values proposed by Snyder *et al.* forthcoming, which draw on a much wider range of sources.

96 Pearson 2003; Shirley 1996; 2000, respectively.

97 Pearson 1995; 1999; 2002; 2003. However, it is worth noting that the calculations are based on the detailed study of a single site, Pevensey Castle (Pearson 1995; 1999). The labour figure of 3.3 person-days per cubic metre of wall calculated for this fort was applied to the other forts in order to suggest the labour for each Saxon Shore fort (Pearson 2003, 97).

98 Boon 1974, 101–2; Allen 2013.

99 Crummy 1997, 87–9; Allen 2012, respectively.

100 Allen 2013, table 12.4.

elements can be found in the online supplementary material). The breakdown of the individual figures for production of bulk materials – lime, brick, stone, etc. – can be found in ONLINE TABLE 2.

The examination of the production processes for the building materials used in the Landward Wall demonstrates the high volume of labour involved in this stage of the project. In total, over 221,400 person-days were needed (TABLE 2). By far the most labour-intensive part of the production was the quarrying and working of the Kentish ragstone rubble and facing blocks, which amounted to 87 per cent of the total production labour. It is also clear that the production of stone elements required a large amount of skilled labour, unlike the production of the remaining material – pebbles, sand, quicklime, puddled clay and brick – which relied more heavily on unskilled labour.

In addition to production, the cost of transport must be addressed for material imported into Londinium, as this was an important element in construction costs. Much of the material would have been brought via river and/or sea and then transported along the river Thames to be off-loaded at the Roman Wharf (e.g. Regis House by London Bridge). For the calculations of river and sea transport, the Blackfriars 1-type vessel, noted above, has been taken as the point of reference for carrying capacity and speed (see the online supplementary material).[101] The shipwreck, dated to the late second century, contained 26 tonnes of Kentish ragstone. It is possible that the stone had been destined for the construction of the western side of the Landward Wall when the ship was wrecked near the mouth of the Fleet.[102] Gustav Milne and Simon Elliott have both argued that the Blackfriars 1-type vessel was specific to the regional fleet of the *Classis Britannica*[103] and therefore suggest the involvement of the *Classis Britannica* in the ragstone quarry industry (though it should be noted that there is little indication that the Blackfriars 1-type vessel was definitely military). Nonetheless, the Blackfriars 1-type vessel is highly suitable as the basis for our calculations. The estimates for water transport can be seen in TABLE 3. Overall, the total estimated number of boatloads needed for the material required in the construction of Londinium's Landward Wall is 1,627, and it would have taken around 8,700 boat-days to transport the materials to Londinium. If the materials were moved in one 270-day season, a fleet of 33 ships would have been required. If 20 ships operated continuously over a 270-day season, transporting the 30,000+ cubic metres of materials needed for the construction would have required 1.6 seasons of voyages, while ten ships operating continuously would have required 3.2 seasons.

In addition to sea and river transport, much of the material used in the Landward Wall was also transported over land by carts. At America Square, evidence has been found for both intramural and extramural metalled road surfaces, including wheel ruts that are likely associated with the construction of the Landward Wall.[104] Pebbles, sand and the majority of the bricks used could have been found or produced within Londinium itself (at an estimated distance of 1 km for brick and 1.5 km for sand and pebbles), and the material arriving by boat had to be unloaded at the wharf and loaded into carts for transport to the site of construction (assumed to be *c.* 1.5 km away). The total requirements for cart transport can be found in TABLE 4, which shows the

[101] See Marsden 1994, 80–9 for the Blackfriars 1-type vessel. These data were combined with constants provided for river transport by Kendal 1996; Pearson 2002; Elliot 2016; 2017.
[102] Marsden 1994, 80–9, 91–5.
[103] Milne 2000, 131; Elliott 2017, 114, appendix B.
[104] Hunt 2010, 54–5, 58. The intramural road (north–south alignment) occupied a *c.* 5 m-wide strip and consisted of a hard-rammed gravel surface up to 0.2 m thick with a camber down towards the Landward Wall. Moreover, the surface contained ragstone chippings and mortar debris, adding further evidence for the road's use and association with the construction of the wall; presumably, it remained in use until the rampart was built. A similar temporary road to the east of the Landward Wall with a north–south alignment has also been identified (presumably also associated with the wall's construction). This was established to the west of the ditch and alongside the wall.

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TABLE 2. LABOUR FOR THE PRODUCTION OF MATERIALS

Location	Labour	Pebbles pdays*	Sand pdays**	Quick lime pdays	Puddled clay pdays***	Rubble pdays	Facing pdays	Plinth pdays	Brick pdays	Coping stones pdays	Total pdays
Foundation	Unsk.	249	230	349	2,756	5,771	–	–	–	–	10,020
	Sk.	25	23	282	276	59	–	–	–	–	–
Internal bank	Unsk.	–	–	–	–	–	–	–	–	–	–
	Sk.	–	–	–	–	–	–	–	–	–	–
Wall ($\leq$ 4.4 m)	Unsk.	1,280	1,144	1,735	–	26,288	12,697	619	3,827	–	145,023
	Sk.	128	114	1,403	–	267	90,556	3,060	1,905	–	–
Crenellations	Unsk.	38	35	54	–	–	6,924	–	–	2,254	66,359
	Sk.	4	4	44	–	–	49,380	–	–	7,622	–
Total	**Unk.**	**1,567**	**1,409**	**2,138**	**2,756**	**32,059**	**19,621**	**619**	**3,827**	**2,254**	**66,250**
	Sk.	**157**	**141**	**1,729**	**276**	**326**	**139,936**	**3,060**	**1,905**	**7,622**	**155,152**
Fuel (t)		–	–	2,612	–	–	–	–	538	–	3,150

*Collecting of pebbles is estimated at 0.078 pdays/m^3 (Pearson 2003, 153, Appendix III, based on Hurst's 1865 labour rates for filling barrows with rubble stone).

**Hurst 1865, 376 provides a figure for excavating sand at 0.6 hours per cubic yard for one labourer, which is equivalent to 0.08 pdays/m^3. This is similar to the figure given in Pegoretti 1869, 1.187–8 of 1 m^3 of sand per 0.9 hours, which is equivalent to 0.09 pdays/m^3. We assume the sand was moved in baskets a distance of 25 m from the site of excavation and loaded into carts ready for transport to the construction site.

***Hurst 1865, 376 gives a rate of 1 hour per cubic yard for one labourer to dig clay and a rate of 6.5 hours per cubic yard for one labourer to puddle and spread in layers (1865, 378). This is equivalent to 0.86 pdays/m^3. We have assumed that the clay was available within 100 m of the wall. The production figure for puddled clay therefore also includes the time needed to excavate the clay, as well as time for loading and unloading. Pegoretti 1869, 1.93–4 provides a figure for extracting clay at 1.5 hours per 1 m^3, equivalent to 0.15 pdays; however, he does not provide figures for puddling clay. Pegoretti 1869, 1.193–4 and 198 give the labour requirements for laying sand and gravel at 0.15 hours and 0.25 hours, respectively. He also provides figures for tamping down 1 m^2 of soil at 0.40 hours for one skilled worker assisted by two labourers (Pegoretti 1869, 1.195).

TABLE 3. MATERIAL TRANSPORTED BY WATER: LANDWARD WALL

Material	**Distance by water to London wharf* (km)**	**Time per roundtrip including loading and unloading (days)****	**Total number of boatloads**	**Total boat days**
Kentish ragstone (rubble)	127	5.2	1,267	6,588
Kentish ragstone (facing)	127	5.8	280	1,624
Carstone	115	7.5	4	30
Weldon stone	429	11.4	1	11
Barnack stone	404	13	1	13
Marquise limestone	183	7.4	29	215
Calcaire Grossier	784	29.5	3	89
Bricks (Grog fabric)	337	10.6	4	42
Bricks (Eccles fabric)	114	6.6	4	26
Quicklime	12	2	34	68
Total	–	–	**1,627**	**8,706**

*Such as Regis House by London Bridge, for example.

**For the time for loading and unloading, see Pegoretti 1869, 1.26–7. Calculations of boatloads are based on Marsden's figures for the Blackfriar's 1-type vessel, which give an estimated carrying capacity of around 28 m^3, to a maximum weight of 50 tonnes (Marsden 1994, 89). The vessel's crew has been estimated at three men. We have calculated the density of stone at 2,640 kg/m^3. Accounting for the weight of stone (*c.* 2,700 kg/m^3), we have assumed that a maximum boatload of 19 m^3 is possible for stone transport. In the case of Kentish ragstone, it is assumed that the volume for transport increased by 50 per cent when broken into rubble (on this point, see DeLaine 1997, 110). The weight of quicklime is estimated at 1,500 kg/m^3, which would mean that the full boatload capacity of 28 m^3 could be used to transport the quicklime. Assuming the weight of each brick was 10 kg, 5,000 bricks could be transported per boatload.

TABLE 4. MATERIAL TRANSPORTED BY LAND: LANDWARD WALL

Material*	**Trips per unit (m^3 or 1,000 bricks)**	**Time per trip including loading and unloading hours****	**Maximum round trips per 12h day**	**Total cartloads**	**Total cart days**
Rubble (from wharf, 1.5km)	3.9	1.44	7	62,587	8,941
Facing blocks (from wharf)	2.6	1.2	8	13,845	1,731
Plinths (from wharf)	2.6	1.2	8	270	34
Coping stones (from wharf)	2.6	1.2	8	1,591	199
Bricks (Lydion fabric, 1 km)	10	3.44	3	37,906	12,635
Bricks (from wharf)	10	3.44	3	4,212	1,404
River pebbles (1.5 km)	1.6	1.04	9	4,338	482
Quicklime (from wharf)	1.5	1.74	6	1,425	248
Sand (from extraction site, 1.5 km)	1.6	1.7	6	7,590	1,290
Total	–	–	–	**133,764**	**26,964**

*The following weights have been estimated for the materials being transported: stones 2,700 kg/m^3; bricks 10 kg each; lime 1,500 kg/m^3; river pebbles 1,600 kg/m^3; sand 1,600 kg/m^3 (Hurst 1865, 195).

**Time for loading and unloading is estimated at 0.08 pdays per m^3 and 0.015 pdays per m^3, respectively (see Pegoretti 1869, 1.26). Calculations for the overland movement of goods are based on Kendal 1996, 144.

maximum number of round trips per day for each material. In total, 133,764 cartloads or roughly 27,000 cart-days would have been needed to transport the locally produced materials as well as those arriving via vessels landing at the wharf. The bulk of the cart transport relates to brick produced within the urban centre of Londinium (28 per cent of the total number of carts, but 47 per cent of the total cart-days) and the continued transport of rubble (47 per cent of the carts and 33 per cent of cart-days) and facing blocks (10 per cent of carts and 6 per cent of cart-days). If the work took two seasons, the demand would have been for 50 carts and drivers, plus 300/400 oxen or 400/500 mules/horses and men to manage them,[105] based on six/eight oxen per cart or eight/ten horses/mules, as estimated by Roger Kendal.[106]

SUMMARY OF LABOUR FOR CONSTRUCTION

A total of 46,725 person-days (including supervision) has been estimated for the construction of Londinium's Landward Wall (for a breakdown of the assumptions, constants and calculations, see the online supplementary material with ONLINE TABLES 5–16). The most labour-intensive section of the wall was the 4.4 m of curtain superstructure (48 per cent of the total construction time), followed by the foundations (26 per cent), the crenellations (14 per cent), the internal earthen bank (10 per cent) and the v-shaped ditch (2 per cent).

In addition to the number of person-days necessary for the overall construction and the quantity of materials required, we need to consider the workforce that would have been needed for various tasks, such as production, transport and construction. In order to accomplish this, several variables, such as the length of the construction season and the physical spacing of workers engaged in various activities, need to be addressed (see the online supplementary material). If the wall was built in 25 m-long stretches with no one working on more than one task at the same time, a workforce of 326 workers could have built the wall in 1,047 days (just under four 270-day building seasons). Alternatively, if we take a higher figure of ten lengths (250 m of wall) under construction at the same time, a total of 2,190 workers could have constructed the entire length of the wall, excluding the v-shaped ditch, in 102 days or just over one-third of a building season. If we include the labour and time requirements for the transport and construction of materials, four 270-day seasons would have required a minimum labour force of 531 workers during peak labour times, while a more conservative eight-year timescale would have required the labour of only 266 workers. Both four-year and eight-year periods are well within the dating limits of A.D. 190–220 for the construction of Londinium's Landward Wall.

COMPARISON WITH OTHER ROMANO-BRITISH AND CONTINENTAL DEFENSIVE CONSTRUCTION PROJECTS

The following section considers, as far as possible, the figures generated for the construction of Londinium's Landward Wall within the contexts of Romano-British construction projects and Roman building projects more generally. Unfortunately, as noted above, there are few monuments for which reliable labour estimates have been produced. Moreover, for those estimates that have been calculated there are issues related to how the labour figures were reached (see 'Labour constants' in the online supplementary material). Nonetheless, it is still worth setting in context the figures generated in this paper.

SCALE OF RAW MATERIALS

The principal (and main bulk of) materials used in the construction of Londinium's Landward Wall, as noted above, were Kentish ragstone (used for the facing stones and rubble for the core) and brick: calculated at *c*. 740,000 facing stones and 421,000 bricks. In comparison to other Romano-British projects, the Landward Wall represents a substantial volume of material.

[105] DeLaine 1997, 108 notes that every two to three animals needed a person to manage them. For the animal power suggested here, that would mean an extra two to three workers per ox-cart and three to four men per horse/mule-driven cart.
[106] Kendal 1996, 146.

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In total, *c.* 22,100 m^3 (*c.* 60 tonnes) of stone was needed for the facing, rubble core, chamfered plinth and coping stones, although in actuality as much as 25,000 m^3 would have been required, allowing for *c.* 15 per cent wastage during quarrying and processing. This means that once issues such as wastage and volumetric changes in producing elements such as mortar are taken into account, *c.* 50,000 m^3 of material was needed for the Landward Wall. This figure excludes the material required for the four gates at Aldgate, Bishopsgate, Newgate and Ludgate, each of which contained a double carriageway whose openings were flanked by two substantial square towers.[107] It should be noted that these gates could represent a sizeable addition to the amount of material required for Londinium's Landward Wall. At Richborough, for example, Thomas Blagg estimates that the first-century A.D. monumental arch incorporated *c.* 16,000 m^3 of material.[108] This is roughly equal to the amount of material required for the mid-third-century wall of the Romano-Celtic town of Venta Silurum (modern Caerwent, Wales).[109]

The need for a large quantity of material in Romano-British construction projects was not unique to Londinium's Landward Wall. The 11 installations of the Saxon Shore forts, for example, required approximately 200,000 m^3 of stone in total;[110] however, this was not spread equally across the fortifications: the smallest forts would each have required between 12,000 m^3 and 14,000 m^3, while those with taller and thicker walls would have required greater quantities of material. This can be seen, for example, at Pevensey, which has the longest and widest superstructure of any of the Saxon Shore forts and required 33,710 m^3 of stone,[111] making it roughly comparable to Londinium's Landward Wall. As in the case of the latter, the overwhelming majority of raw material used in the construction of the Saxon Shore forts was used to make the rubble core (*c.* 74 per cent at Pevensey).[112] By contrast, the facing stones required for these projects accounted for only *c.* 5 per cent of the total raw materials. Even the introduction of brick bonding courses at the Saxon Shore forts made little impact on the overall quantities of raw materials required for the facing. At Pevensey, only 80 m^3 of brick would have been needed (0.24 per cent of the total volume of building materials). Taken as a whole, even though in reality they were built over nearly a century, the Saxon Shore forts required roughly five times the amount of material that was needed for Londinium's Landward Wall.

While the Saxon Shore forts were a substantial undertaking, Hadrian's Wall was by far the largest defensive project in Britain, with curtain walls, milecastles and turrets that required some 1,178,000 m^3 of raw materials.[113] While Hadrian's Wall is of course on a different scale (Londinium's Landward Wall required less than one-thirtieth of the materials), it was still constructed in a relatively short amount of time and in a remote part of the Empire, suggesting that our figures for the construction of the Landward Wall are not unreasonable.

Moreover, outside of Britain, we can compare Londinium's Landward Wall with other similar projects. For example, the 885 m-long circuit of the late Roman walls at Saint-Bertrand-de-Comminges required 8,537 m^3 or 21,343 tonnes of material.[114] The late

[107] Marsden 1969, 20–3; 1970, 8–9. Dimensions from Newgate indicate that it had a double carriageway 10.5 m wide, with each gate *c.* 33 m wide by 10 m deep (Marsden 1980, 124, with plan and reconstructed elevation).

[108] Blagg 1984; 1990b.

[109] This calculation, which excludes the towers, is based on the known length of the circuit, an assumed height of *c.* 5 m and an average thickness of 2.5 m. This volume of building stone (16,000 m^3) was derived from local sources. See Allen 2012.

[110] Pearson 2002, 77–8.

[111] Pearson 2003, 149–52, tables in appendix II.

[112] Pearson 2003, 152.

[113] Bennett 1990.

[114] Esmonde Cleary and Wood 2006, 142–74, table 10. The walls are well preserved in the north-western and the south-western corners of the town, and these sections provide average measurements for the wall: a width of 1.5 m (though the wall is wider at the base, *c.* 1.7 m) and a height from the top of the foundations to the top of the wall of 5.9 m on the exterior face and 5.55 m on the interior.

third-century Roman walls of Bordeaux, which had a circuit measuring 2,350 m,[115] required over 200,000 tonnes of stone for their foundations, walls, towers and gates (for the foundations, all of recycled materials, a total of *c*. 64,800 m^3 was needed, with further stone required for the *petit appareil* used in the wall facing).[116] At Aquileia, the 3 km-long Republican walls (dated to the first half of the second century B.C.) required at least 810 m^3 of Istrian stone, 729 m^3 of sandstone and 46,786 m^3 of brick (equivalent to 3,649,526 bricks).[117] This makes the overall quantities for Aquileia's wall comparable to Londinium's, albeit with different proportions of materials and different construction techniques. The military camp at Thamusida (sidi Ali ben Ahmed, Morocco), which measured *c.* 2 ha, was surrounded by a wall that enclosed a total area of 15 ha, making it one of the largest camps in the province of Mauretania Tingitana.[118] The total height of the wall was 4.75 m, with a total volume of *c*. 4,538 m^3.[119] This represents roughly one-tenth of the material of the Landward Wall.

Londinium's Landward Wall was clearly impressive in provincial contexts, but how did it compare to the imperial capital? The much earlier Republican walls of Rome, with their roughly 11 km-long circuit, required approximately 1,023,000 blocks, or *c*. 440,000 m^3, of stone in total.[120] These figures demonstrate that, while the Landward Wall is impressive within a local Romano-British context and even within a provincial context, it is much less substantial in comparison to constructions in Rome.

SCALE OF TRANSPORT

As noted above, the transport needed for Londinium's Landward Wall was impressive, in terms of both the total number of cart- and boatloads, and in the total person-hours. Firstly, we can consider the overall distances the material needed to be transported. The majority of stone had to travel at least 100 km, with a small amount coming much further – 250 km+ and 500 km+, as seen in FIG. 12. While the sand, lime and pebbles, and the majority of the brick needed to be transported only short distances (under 12 km for lime and under 1.5 km for the remaining materials), around 10 per cent of the required bricks was sourced further afield (a distance of 113 km and 333 km). This presents a very different scale and logistical problem compared to the movement of stone and materials for the construction of the Saxon Shore forts. As can be seen from FIG. 13, the transport distances of raw materials varied depending on the location of the Saxon Shore fort.[121] At Lympne, for example, over 90 per cent of the materials used were sourced within 1 km of the fort, with the remaining material coming from no more than 10 km away. Moreover, the limestone used for rubble and facing could have been sourced as close as a few hundred metres. Reculver, on the other hand, represents the more general situation for the Saxon Shore forts, with *c*. 90 per cent of the materials sourced within a 20-km distance. Only

[115] Surviving sections of the wall at 7 de la rue Guiallume-Brochon indicate the foundations for the wall were 6 m deep and between 4 and 5 m thick. Moreover, the height of the wall is estimated at 9 m. The semicircular projecting towers were spaced every 50 m and projected 4–5 m from the walls. See Etienne and Barrère 1962, 204–6.

[116] See Bachrach 2000, 198 for the estimate of the weight. For the estimate of the volume of recycled materials used in the foundations, see Garmy and Maurin 1996, 67.

[117] Bonetto and Previato 2018, 311. The walls were 2.4 m thick in the upper levels and *c*. 3 m thick at foundation level. The original height of the wall is unknown, but it is assumed to have been *c*. 6 m tall. For the materials, see Bonetto and Previato 2018, 318–20.

[118] Camporeale 2011, 171.

[119] This included *c*. 2,848 m^3 of rubble and 1,429 m^3 of mortar (Camporeale 2011, 177, table 1).

[120] Volpe 2014, 62. This total is based on average measurements for the wall of 3.5 m wide and 9.5 m high (with foundations between 1 and 3 m), and average block measurements of 0.6 by 0.6 by 1.2 m.

[121] After Pearson 2003, 90–1, figs 49, 50.

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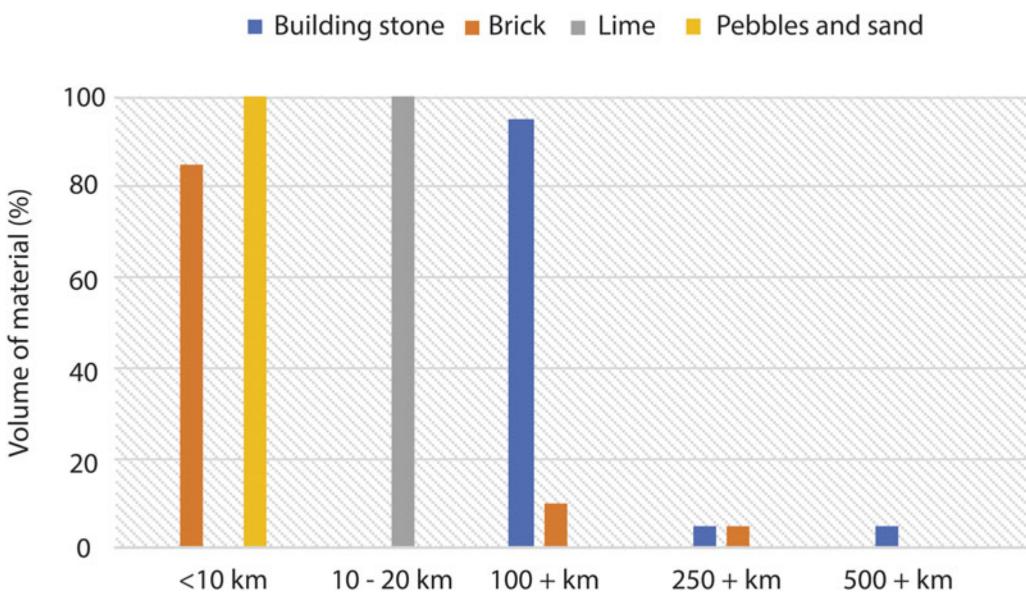

FIG. 12. Distance between extraction or production site and the Landward Wall (graph by S. Barker).

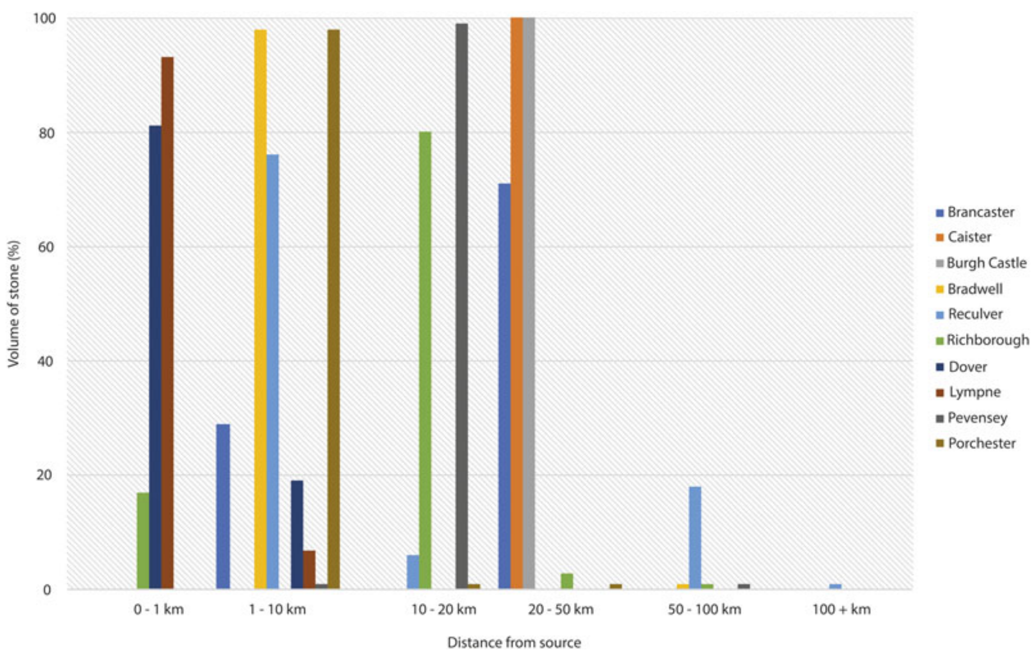

FIG. 13. Distance between quarry and selected Saxon Shore fort sites: building stone only (graph by S. Barker; after Pearson 2003, 90–1, figs 49, 50).

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the Kentish ragstone for the facing of some of the Saxon Shore forts had to be transported over a greater distance, *c*. 70 km. At Bradwell and Caister we do see material transported over longer distances (*c*. 100 km), but this was only for a very small portion of the total building material. A similar picture of locally based sourcing can be seen with regard to the walls at Silchester, where all the materials could be found within *c*. 10 km, and, in many cases, much less.[122] Londinium's Landward Wall is more in keeping with examples from other parts of the Empire. For example, the majority of stone used in the walls at Aquileia was transported 120 km by sea from quarries along the Istrian peninsula and a further 11 km up the river Natissa.[123]

In addition to considering the overall distances over which material was transported, we can also compare the total amount of labour and resources required for land transport. The near 134,000 cartloads of material needed for the construction of Londinium's Landward Wall are markedly more than Pearson's 21,980 cartloads of material required for the Saxon Shore fort at Lympne or the 26,285 cartloads needed for the walls at Silchester.[124] At Saint-Bertrand-de-Comminges, the transport requirements have been estimated at 25,109 cartloads requiring an estimated total of 6,277 cart-days to move the 21,343 tons of material.[125] However, in comparison to Hadrian's Wall, we can see that the transport requirements for Londinium's Landward Wall were on a much smaller order of magnitude: in total, over 5,000,000 cartloads of material and 932,010 cart-days would have been needed to transport the material for Hadrian's Wall.[126]

Similarly, we can compare the number of boatloads needed for Londinium's Landward Wall and the Saxon Shore forts. While the total of 6,578 boatloads needed for all the Saxon Shore forts is roughly four times the number required for the Landward Wall, the individual forts required fewer boatloads per structure. Pevensey, with its 1,580 boatloads of material, required the highest number of loads of any of the Saxon Shore forts – roughly the same amount as Londinium's Landward Wall (1,627 boatloads).[127] It is interesting to note, however, that a very different picture emerges when we compare the requisite number of boat-days for both projects. Almost all the water transport for the Saxon Shore forts was coastal seaborne transport, which meant that the vessels could travel at a much higher speed than those undertaking river transport. Therefore, many of the coastal sea journeys needed for the Saxon Shore forts could have been completed in one day. For example, Pevensey required only 1,650 boat-days for its roughly 1,600 boatloads.[128] In contrast, the majority of the water transport for Londinium's Landward Wall was undertaken by river rather than by sea. Consequently, over five times as many boat-days (8,706 boat-days) were required for the similar number of boatloads. It is therefore important to look closely at issues of transport in order to attain a more accurate

[122] Allen 2013, 106, fig. 2.29.

[123] Bonetto and Previato 2018, 318.

[124] The number of cartloads required for the walls (5,257 m in length) at Silchester is based on John Allen's figures (2013). Allen states that 100 cartloads of stone, gravel, sand and lime were required, and posits a daily rate of 10–15 cartloads of raw materials requiring a labour force of diggers, quarriers and cart drivers of *c*. 25–50 men to support each work gang at the construction site of the wall (2013, 104–6, table 12.4). At the military camp at Thamusida, we can see a higher rate of transport (*c*. 24 cartloads per day), with 3,285 person-days required to transport the 51,104 cartloads of stone and mortar needed for the fort's construction (Camporeale 2011, 183).

[125] Esmonde Cleary and Wood (2006, 143–6) use figures provided by Kendal 1996 as the basis for their calculations. Their estimates are based on a four-wheeled cart drawn by six to eight oxen with loads of 0.85 tonnes. They estimate an average speed of 3.2 km/hour and a total journey of 0.5 km to move the recycled material from the lower Roman city to the walls. They allow 1.25 hours for loading and unloading each cart in an average trip of 1.75 hours. In an average eight-hour day, one cart could complete four trips, moving 3.4 tonnes of material.

[126] Kendal 1996, 151–2, appendix.

[127] Pearson 2003, 94, table 7.

[128] Pearson 1999, 109, table 6.

picture of the logistics and costs associated with construction projects, especially, as this paper shows, in the Roman provinces.

SCALE OF CONSTRUCTION

As noted above, the overall estimate for the construction of Londinium's Landward Wall (including production and transport) is *c.* 304,000 person-days. Again, we can compare these figures to other Romano-British projects. The fort at Pevensey, for example, as the largest of the Saxon Shore forts, is perhaps the closest parallel to the Landward Wall, as it is similar in terms of perimeter and volume of material needed (*c.* 33,710 m^3). Pearson estimates that 103,400 person-days or four years for a workforce of 90 was needed for Pevensey:[129] roughly one-third of the person-days required for Londinium's Landward Wall and one-sixth of the labourers required for the same four-year construction period for the Landward Wall. If we look at the Saxon Shore forts as a whole, we see that Londinium's Landward Wall required roughly less than half the person-days that Pearson estimates for all 11 forts (665,000 person-days).[130]

The majority of this difference can be explained by the substantially different estimates proposed for the production of the building materials: 221,402 person-days for the Landward Wall compared to 30,300 person-days for Pevensey.[131] This in turn can be partly explained by Pearson's use of lower production rates, based on data from British architectural manuals, compared to the rates adopted in this study, which are based on Giovanni Pegoretti's manual (1863; 1864; 1869; and see online supplementary material). If we compare only the construction figures, excluding production and transport, Pevensey is estimated at 27,100 person-days compared to the Landward Wall's 46,725 person-days (a difference of roughly 40 per cent).[132] Since Pearson adopted several of Pegoretti's rates for various construction tasks,[133] we can suggest that here the difference in scale between the construction times is based on the scale of activity that went into the construction of Londinium's Landward Wall. The Landward Wall, for example, included additional elements, such as coping stones, which required substantial labour to be lifted and positioned. In addition, Londinium's Landward Wall required a greater volume of material for its construction (41,199 m^3) than Pevensey.

The military camp at Thamusida in North Africa demonstrates how rapidly military constructions could be undertaken. Stefano Camporeale has estimated that the camp could have been constructed in only 19,400 person-days.[134] Here we can contrast the less labour-intensive construction needed for a military installation with the higher investment required for urban walls, which often served as an important means of self-representation and civic pride. For the late third-century walls at Silchester,[135] for example, a figure of between 30,000 and 40,000 person-days has been proposed, although in reality this figure may have been as high as 90,000 person-days.[136] Moreover, if we look at the overall calculations for the whole legionary fortress at Inchtuthil, Shirley estimates that 270,000 person-days were required for its construction.[137] This figure includes all the external buildings of the fort, such as the barracks, granaries, etc.,

129 Pearson 1999, 107, tables 3, 5; 2003, 98.
130 Pearson 2003, 98.
131 Pearson 1999, 107, tables 3, 5.
132 Pearson 1999, table 5.
133 Pearson 2003, 158.
134 Camporeale 2011, 177.
135 The walls at Silchester were *c.* 3 m thick, 2 m high and *c.* 2.4 km long (Fulford and Corney 1984, 68).
136 Allen 2013, 106. This higher figure is based on the assumption of five 1.5-m lifts along the length of the circuit.
137 This figure is based on a 12-hour working day (Shirley 1996; 2000).

and it is therefore not surprising that the overall person-days needed for its construction are more on par with those for Londinium's Landward Wall.

The disparity between the scale of works is further evident when we compare the differences in the overall estimated construction (including production and transport) rates per cubic metre of walling for four different walls: 6.2 person-days per m^3 for Londinium's Landward Wall; 3.3 person-days per m^3 for Pevensey;[138] 2.75 person-days per m^3 for Saint-Bertrand-de-Comminges;[139] and 3.1 person-days per m^3 for Aquileia.[140] Clearly, the differences in construction techniques and distances that material travelled lead to these variations in overall construction rates. This is particularly evident when one considers that only 0.71 person-days per m^3 have been estimated for the Antonine Wall,[141] which was based on the less labour-intensive construction method of earth and turf, and where almost all the materials were available directly at the site of construction.[142] Similarly, at Aquileia, the provision of materials has been estimated at 149,000 person-days and the construction of the wall at 21,000 person-days, a ratio of 7:1.[143] The walls of Aquileia are primarily of brick (requiring only 1,539 m^3 of stone), which therefore allowed for a faster construction rate. Moreover, the much smaller rate needed for the defences of Saint-Bertrand-de-Comminges is mainly due to the fact that material used in their construction was recycled by systematically demolishing the buildings of the original lower Roman town. On the one hand, then, we can show the economic impact of recycling on the construction of late Roman fortifications, while, on the other, the difference between a small fifth-century circuit in southern Gaul and the walls of Londinium suggests that far greater resources were available to construct the latter than an individual town could bring to bear for the former. Indeed, the relatively slight defences of Saint-Bertrand-de-Comminges could have been constructed in as little as one to two seasons of work.[144]

If we return to the Republican walls of Rome, we can see once again that even the largest of these figures from Roman Britain does not compare with the imperial capital. Even the lowest basic estimate is a total of 2,310,000 person-days necessary to complete Rome's Republican walls – this equates to 210 person-days for each linear metre of wall.[145] If we look at this in terms of working seasons, it would have taken a workforce of 8,555 workers to construct the wall within one year, or 2,851 workers over three years.[146] This number is far greater than the estimated 531 workers over four years necessary for Londinium's Landward Wall.

For Roman Britain, wall construction on the scale of Rome's Republican walls can only be found at Hadrian's Wall, where rough estimates suggest that over 4,500,000 person-days would

[138] For Pevensey, see Pearson 2003, 97.

[139] The overall construction time needed has been estimated at 23,500 person-days, with 6,277 cart-days raising the total figure to *c.* 30,000 person-days (Esmonde Cleary and Wood 2006, 143–6, based on an average of Pearsons's figure for Pevensey and experimental labour rates: Pearson 2003: 97). Since the materials were all recycled, the figure does not include any labour for production; however, in reality the production costs would have included the labour needed for the demolition of the structures.

[140] Based on an estimated 54,540 m^3 of material for the wall.

[141] Snyder and colleagues (forthcoming) estimate that a 100-m length of the Antonine Wall (a stone base with a superstructure of turves) would have taken between 1,000 and 1,100 person-days. They further note that Hadrian's Wall, in comparison, would have likely required over three and a half times more labour than the equivalent length of the Antonine Wall. The authors would like to thank Riley Snyder for providing the cubic-metre labour figure for the Antonine Wall.

[142] For the Antonine Wall, see Breeze and Hanson 2020. For an up-to-date review of its construction, see Romankiewicz *et al.* 2020; Snyder *et al.* forthcoming.

[143] Bonetto and Previato 2018, 323–6, table 14.2. The estimates for Aquileia were calculated with labour constants drawn from Pegoretti's architectural manual (1863; 1864).

[144] Esmonde Cleary and Wood 2006, 143–6.

[145] Volpe 2014, 62. Cf. Bernard 2018, 98, table 4.3, who estimates 6,803,059 person-days for construction.

[146] Volpe 2014, 62. These figures are based on a season of *c.* 270 days per year.

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have been needed for the quarrying of material and the construction of the 117 km-long wall.[147] Rome's Republican walls, however, were only *c.* 11 km in length. In this case, the differing construction parameters of Rome's wall represent a much more labour-intensive process (roughly equal to 11.5 person-days per m^3, excluding transport).[148] Overall, we can see clearly, therefore, that the economic implications for stone walls across the Empire, like other major construction projects, depended heavily on the type and form of the materials used as well as the construction technique.

THE COST OF LONDINIUM'S LANDWARD WALL

With the basic rates of labour and transport established, we can use the Diocletianic *Price Edict* (7.1–11, 15, 30) to establish some cost estimates for Londinium's Landward Wall. The method follows that proposed by Janet DeLaine,[149] which creates a cost equivalent by adopting the following basic rates expressed in *kastrenses modii* (KM) of wheat: skilled workers at 50 denarii (or 0.5 KM, plus 0.11 KM for food = 0.61 KM) per day and unskilled workers at 25 denarii (or 0.25 KM, plus 0.11 KM for food = 0.36 KM) per day. Transport by cart is given at 0.52 KM per tonne per Roman mile (*c.* 1.478 km),[150] with sea transport at 0.012 KM per tonne per Roman mile and river transport at 0.12 KM per tonne per Roman mile upstream and 0.059 KM per tonne per Roman mile downstream.[151] The price for fuel, based on the *Edict* (14.8), is taken as 3.9 KM per tonne.[152]

We can further examine the cost differentials of different aspects of Londinium's Landward Wall by looking at the components and final figures given in TABLES 5 and 6. These manpower figures are calculated per unit volume (1 m^3 of material or, in the case of bricks, per 1,000) and give an idea of how costly different materials were to produce and transport. For example, if we look at the cost per brick for each of the three varieties used in the Landward Wall (0.02 KM for Lydion brick, 0.08 KM for Grog brick and 0.1 KM for Eccles brick), we can see that it made economic sense to use mainly Lydion bricks for the wall, supplemented with Grog and Eccles bricks, perhaps when demand outstripped the supply of the cheaper, more local bricks. Moreover, if we examine choices related to facing material, we can see that not all decisions were due to economy. A square metre of facing would have cost roughly 7.7 KM if constructed with stone and between 1.2 and 5.8 KM if constructed in brick, depending on the type of brick used.[153] Despite the extra cost, the use of stone indicates not only the (actual or perceived) military advantage of stone as a material for defence but also the prestige associated with having a free-standing stone-built wall. Alternatively, despite the potential economic advantages of brick, it is possible that the use of facing stone related to the lack of development in brick production compared to stoneworking in Roman Britain. Moreover, it seems that in an urban setting the status of stone construction and the permanence it represented added a certain prestige.

In total, the cost of the Landward Wall is estimated at *c.* 646,260 KM. It is important to stress once again that, as noted by DeLaine, this is a hypothetical cost. Nonetheless, if we assume that the

[147] This total is based on the quarry labour (O'Donnell 2020) and the construction estimate of 1,140 person-days for a 100-m stretch of the wall (Hodgson 2017, appendix II; based on Hill 2010, 121–4).
[148] The cubic-metre rate is based on the total volume of wall calculated by Seth Bernard (2018, table 4.1) and his labour estimates for quarrying/processing and construction. The figures for Hadrian's Wall are based on those quoted above in n. 94.
[149] DeLaine 1997, 209–11.
[150] Duncan-Jones 1982, 371.
[151] DeLaine 1997, 211.
[152] DeLaine 1997, 212.
[153] This is based on the assumption that an average square metre of facing contained 28 stone blocks or 58 bricks.

TABLE 5. UNIT COST OF MAIN BULK MATERIALS

Material	**Unit**	**Labour cost (KM)**	**Fuel cost (KM)**	**Transport: distances in Roman miles**				**Transport cost (KM)**	**Total cost per unit (KM)**
				Up river	***Down river***	***Sea***	***To site***		
Bricks									
Lydion fabric	1,000	6.6	9.5	–	–	–	0.68	3.5	19.6
Grog fabric	1,000	6.6	9.5	50	2	174	1	66	82
Eccles fabric	1,000	6.6	9.5	50	27	–	1	81	97
Kentish ragstone									
Facing stones	m^3	17.3	–	50	36	–	1	22	39.3
Rubble	m^3	0.7	–	50	36	–	1	22	22.7
Chamfered plinth									
Carstone	m^3	17.6	–	50	28	–	1	21	38.6
Weldon stone	m^3	17.6	–	50	38	203	1	29	46.6
Barnack stone	m^3	17.6	–	50	20	203	1	26	43.6
Coping stones									
Marquise Oolite	m^3	9	–	50	3	70	1	20	29
Calcaire Grossier	m^3	9	–	50	227	253	1	60	69
Other materials									
Quicklime	m^3	1.9	10.7	8	–	–	1	4	16.6
Puddled clay	m^3	0.7	–	–	–	–	1	0.6	1.3
Pebbles	m^3	0.2	–	–	–	–	1	0.8	1
Sand	m^3	0.13	–	–	–	–	1	0.73	0.86

TABLE 6. COST OF CONSTRUCTION (EXPRESSED IN KM)

Element	**Materials**			**Construction**	**Total cost**
	Labour	***Transport***	***Total***	***Basic labour***	
V-shaped ditch	–	–	–	287	287
Internal earthen bank	–	–	–	1,530	1,530
Foundations	5,471	66,398	71,869	4,274	76,143
Wall (≤4.4 m)	87,155	374,678	461,833	9,264	471,097
Crenellations	38,329	55,943	94,272	2,933	97,205
Total	**130,955**	**497,019**	**627,974**	**18,288**	**646,262**
% of total	20	77	97	3	100

prices listed in the *Price Edict* are at least relational, if not exact, our figure should be in the right order of magnitude.[154] Although this figure might seem high, this cost is minimal compared to the estimated cost of the Baths of Caracalla in Rome at *c*. 12 million KM.[155] If we look at how these costs are distributed, we see that labour for construction is the smallest component (3 per cent of the total) and that by far the highest costs relate to the transport of material, which forms roughly three-quarters of the total cost of the wall's construction. Another interesting aspect that comes from this analysis is the overall cost of materials. If we combine both the labour costs required to produce materials and the cost of transporting them to the build site, we find that this amounts to 97 per cent of the overall cost of the Landward Wall. This is a ratio of roughly

[154] See DeLaine 1997, 219 on this point.
[155] DeLaine 1997, 219.

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33:1 of material to construction costs, and very clearly demonstrates the impact and importance of material choices for large-scale construction projects.

Assuming a construction schedule of four years, the cost per year would be 161,566 KM. We can contextualise this figure in two ways. Firstly, we can compare it to other forms of state or imperial expenditure within the provinces.[156] In Britain, the most obvious figure is the annual cost of maintaining the army. If we use David Mattingly's assumption that the cost of the army in Britain amounted to 15 per cent of the overall annual cost of the army,[157] we can provide a rough estimate for the cost of the army in second-century Britain of *c.* 122.6 million sesterces[158] or 6.8 million KM per year.[159] This would mean that the cost of Londinium's Landward Wall was a small sum (*c.* 2.4 per cent) compared to the yearly outlay needed to maintain the army in Britain. It is also significantly lower than the *c.* 2 or 2.3 million KM needed each year for six years for the construction of the Baths of Caracalla in Rome.[160]

A second method is to compare the overall estimated KM figure with known costs for buildings in the north-western provinces. However, inscriptions recording acts of euergetism involving the construction of buildings and how much was spent are scarce in the north-western provinces, much more so than in Italy and North Africa.[161] In total, *c.* 300 such inscriptions survive from the Three Gauls and the Germanies,[162] and there are only 77 inscriptions for public building works in Britain.[163]

The most expensive structure recorded in Gaul is the stone-built aqueduct at Bordeaux, which cost 2 million sesterces[164] or 500,000 KM in the first century.[165] This is equivalent to roughly 1,110,000 KM at the time when Londinium's Landward Wall was built.[166] This shows that, while the Landward Wall was not an insignificant investment, it was by no means the most expensive form of construction in the provinces. Most provincial construction projects, however, seem to have been less costly. At the end of the first century, T. Flavius and his wife were responsible for either a construction or a restoration project at the amphitheatre at Lyon at a cost of 240,000 sesterces,[167] which is equivalent to *c.* 133,200 late second-century KM. At the same time, in Vaison-la-Romaine, 50,000 sesterces (27,750 late second-century KM) were spent on the marble ornamentation of the portico in front of the baths.[168] From Germania Superior, we have records of much smaller sums listed for construction projects: 1,500 sesterces for an unknown monument at Avenches;[169] 5,400 sesterces from a patron and their heir for the construction of an altar at Yverdon;[170] 3,200 sesterces for an unknown monument at Yverdon.[171] The largest sum noted from the region was for a bath complex at Mandeure, whose marble revetment was provided by a certain Flavius Catullus for 75,000 denarii

156 See DeLaine 1997, 220 on this approach.
157 Mattingly 2006.
158 Duncan-Jones 1994, 33–5, tables 3.1, 3.2 estimates the total annual cost of the military in *c.* A.D. 150 at 817.8 million sesterces. In all likelihood, the overall figure would have been higher, as this does not include discharge payments and donatives.
159 This assumes a figure of 18 sesterces per KM of wheat (see DeLaine 1997, 221, n. 51).
160 DeLaine 1997, 220.
161 Duncan-Jones 1982; 1985.
162 De Kisch 1979; Frézouls 1984.
163 Blagg 1990a, 13–15, table 1.
164 *CIL* 13.596–600.
165 Assuming a cost of 2 sesterces per *modius* (Duncan-Jones 1982, 146, 345–7).
166 This conversion is based on an inflation rate of 122 per cent calculated by using military pay rates from the reigns of Augustus and Septimius Severus as a basic measure (Duncan-Jones 1982, 10).
167 *CIL* 13.1723.
168 *CIL* 12.1357.
169 *CIL* 13.5073.
170 *CIL* 13.5056.
171 *CIL* 13.5061.

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(300,000 sesterces).[172] Again, these relatively modest figures suggest that the cost of Londinium's Landward Wall still represented a significant sum and must have been a substantial investment, even for a provincial capital.

Indeed, the large costs associated with Londinium's Landward Wall in relation to the private projects just noted make it highly likely that the government (perhaps on behalf of the emperor) was responsible for funding the entire project and organising the labour and transport.[173] Evidence for government-sponsored public-building programmes carried out in the Flavian period in Londinium is provided by the large-scale use of procuratorial stamped tiles.[174] While the complete lack of stamped bricks from the Landward Wall prohibits any indication of who supplied the bricks for its construction, it is highly probable that the procurator was responsible for the production and perhaps also the organisation of purpose-built kilns based in Londinium. This is especially likely given the limited evidence for private brick suppliers in the town (see above). The same is probably also true for the Kentish ragstone, which accounts for almost all the stone employed in the wall and was likely under the direct control of the procurator (see below).

Likewise, the involvement of the Roman navy (*Classis Britannica*) seems highly probable. On the basis of stamped tiles found in Londinium and Southwark (14 and 15 in total, respectively), Milne argues that the *Classis Britannica* may have supplied materials for the building of the walls of Londinium.[175] As Christoph Rummel notes, however, this must remain a hypothetical model since it lacks direct epigraphic evidence.[176] Nonetheless, Keith Parfitt's point that only the navy could have handled the logistics of transporting the scale of material needed for the project is worth considering further. He explicitly states that 'the *Classis Britannica* seems to have functioned mainly as some kind of army service corps, supporting the Government and provincial army, rather than as a Navy in the modern sense'.[177] Pearson argues along similar lines for the involvement of the *Classis Britannica* in the construction and transportation of material for the earlier Saxon Shore forts.[178] Two inscribed building stones associated with the *Classis Britannica* from Birdoswald seem to indicate the involvement of the fleet in the construction of Hadrian's Wall.[179] We have further evidence for a possible office of the *Classis Britannica* in Londinium, connected with the provincial government,[180] in the form of stamped tiles that most likely originated as ballast.[181] In terms of the fleet, again we can use the labour figures to support our hypothesis. If the construction materials were moved in one 270-day season, a fleet of 33 ships would have been required. If they were moved at this speed, it seems possible that the *Classis Britannica* was involved; however, this remains hypothetical since we do not know the number of vessels maintained by the *Classis Britannica* or its function. Equally, ten ships operating continuously would have required only 3.2 seasons, and, if the transport was spread out over the timeline of four years of building proposed above, only

172 *CIL* 13.5416; Blin 2012.
173 Esmonde Cleary 2020, 46 presents a similar situation for fourth-century Gaul north of the Loire. He suggests that there is little evidence in this region for the persistence of a wealthy aristocracy that, individually or collectively, had the resources to finance massive undertakings such as urban walls.
174 Perring 1991, 42; Betts 1995, 222.
175 Milne 2000, 129.
176 Rummel 2008, 255–6, 280.
177 Parfitt 2013, 45.
178 Pearson 2002.
179 Rummel 2008, 230 suggests that the evidence indicates a short-term detachment involved in the construction of Hadrian's Wall. The inscribed stones read: PED CLBRIT and PED CLA BRI.
180 See Milne 1995, 115 for four *Classis Britannica* stamped tiles from London.
181 Betts 2017, 379.

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eight vessels would have been needed. This is a much smaller number of vessels and arguably could have been done by private merchants.

We might imagine a combination of privately commissioned vessels used alongside state resources such as the *Classis Britannica*, which, it has been suggested, had a role in the quarrying operations of Kentish ragstone from the upper Medway valley.[182] If this is correct, the governor and procurator could have used this resource to source and transport material for the Landward Wall. Indeed, Elliott has convincingly proposed that the ragstone quarries were important aspects of the imperial economy and under state control, most likely by the procurator with the *Classis Britannica* involved as providers of transportation for the material.[183] This would be comparable with evidence for other sites outside of Britain: for example, an inscription from Bonn shows that the *Classis Germanica* was engaged in providing building materials for Colonia Ulpia Traiana.[184] Overall, the involvement of the British fleet in the construction of Londinium's Landward Wall, while probable, must remain speculative.

IMPLICATIONS FOR MILITARY LABOUR IN PROVINCIAL CONSTRUCTION PROJECTS

The likely involvement of the *Classis Britannica* in transporting stone and the use of centrally controlled funding prompt further questions about who provided the labour for Londinium's Landward Wall and how the whole project was instigated, organised and overseen. Approval by the provincial governor and the emperor would have been needed in order to commence the building of Londinium's defences.[185] There is a common assumption that large-scale projects, requiring skilled labour, were often completed by the army;[186] this is assumed for the construction of urban defence circuits in third-century Gaul,[187] and the predominance of building inscriptions recording legionaries' involvement in Romano-British projects seems to support this proposition. Indeed, if we consider urban defences as 'military' building projects, it would be quite normal for them to have been carried out by soldiers.

Although we have no direct evidence for military involvement in the Landward Wall, the use of military labour is attested in other structures in Britain.[188] Building work appears to have been a part of military daily life:[189] the Vindolanda writing-tablets preserve in some instances details of men of the 9th Cohort of Batavians, who were assigned tasks around the fort. On 25 April in a year

182 Elliot 2017, 86–7.

183 Elliott 2017, 100, 113, 119. Jones and Mattingly 1990, 217 also argue that the quarrying in the upper Medway valley was a state-run enterprise.

184 Gechter 1985, 127–8; Kaiser 1996, 70, 71, 88–9, 156; Konen 2000, 408. Stamped tiles were found built into the hypocaust and *praefurnium* of a *fabrica* in the Boeselagerhof area of Bonn. Rummel 2008, 192 argues that the tiles were part of a batch of building supplies, rather than evidence for a prolonged presence of the *Classis Germanica* at Bonn.

185 Johnson 1983b, 74; Maloney 1983, 104. The involvement of the procuratorial governor in such projects can be seen in Mauretania. At Auzia, a dedicatory inscription records that the emperor was 'attentive to the security of his provincial subjects and built new towers, etc' (*CIL* 8.20816 = *ILS* 396).

186 Blagg 1984, 249. Even when material volumes and construction processes have been carefully calculated, analysis of who completed the work is often curiously lacking; Shirley 2000, 93 and Pearson 2003, 100–5 are notable exceptions.

187 Johnson 1983a, 114.

188 One stamped tile of the *Classis Britannica* was found in the early Cripplegate Fort (Crowley and Betts 1992, 219), but, as Hingley 2018, 131 notes, this is not enough to indicate that the fleet was responsible for the construction of the fort.

189 Although from a later period, Vegetius' fourth-century *Epitoma rei militaris* discusses the skills of the military in constructing camps and fortifications: 'The legion had a train of joiners, masons, carpenters, smiths, painters, and workmen of every kind for the construction of barracks in the winter-camps … all these were under the direction of the officer called the *praefect* of the workmen' (tr. Milner 1996, 2.6).

around A.D. 97–105, of 343 men from the *c.* 1,000-strong garrison at work, 18 were employed in building work in the bath-house, with unspecified numbers more 'to the kilns, for clay … plasterers … for rubble'.[190] Building inscriptions from the milecastles, forts and centurial stones at Hadrian's Wall show that the II *Augusta* (Caerleon), XX *Valeria Victrix* (Chester) and VI *Victrix* (York) were involved in its construction.[191] Similarly, a building inscription at Birdoswald indicates that the fort was constructed by troops.[192] Pearson has proposed the Roman military as the principal source of construction labour for the Saxon Shore forts,[193] and John Allen and Michael Fulford have argued along similar lines for the late second- and third-century forts constructed on the eastern Channel and North Sea coasts.[194] Moreover, the importance of the army as a source of specialists, such as architects and surveyors, as well as labour and equipment has been highlighted by both Blagg and Kevin Hayward.[195] Michael Jones posits that graffiti at Hadrian's Wall suggests quarrying and construction may have used military knowledge either from serving soldiers or veterans, and the walls at Gloucester were built soon after the *colonia* was founded, when early settlers lived in barrack-like buildings, again with the assumption that those buildings were in some way related to the military.[196] Even in Londinium, the layout of the second forum seems to owe much of its plan to the *principia* of a legionary fortress, and the second basilica building incorporates stamped tiles of the procurator, suggesting at least some state/military involvement.[197]

Similar phenomena can be seen at sites further afield. Inscriptions from forts in Germania Inferior, such as the military installation at Nijmegen on the Hunerberg, provide direct evidence for the involvement of the military in supplying labour and building materials.[198] As Esmonde Cleary has noted for northern Gaul, the late Roman army had the necessary engineers, manpower and organisation to undertake the construction of urban defences.[199] Moreover, construction by the army seems very plausible given the ample evidence for the garrisoning of many units of the army in Gallia.[200] There is even some evidence for the involvement of the army in civilian projects and communities, albeit not from the north-western provinces. A veteran of *legio* III *Augusta* called Nonius Datus was sent to help with the reconstruction of a tunnel that was part of a plan to bring water to the town of Saldae in Mauretania Caesariensis (North Africa),[201] while another inscription from North Africa records legionaries marking out

190 *Tab. Vindol.* 2.155.

191 Crow 2006, 121. In addition, 11 of the known quarries used to provide material for the construction of Hadrian's Wall have inscriptions recording the involvement of military units (Breeze and Dobson 2000, 31).

192 *RIB* 1916: *Leg(io) VI Vic(trix) P(ia) F(idelis) f(ecit)* ('The Sixth Legion *Victrix Pia Fidelis* built this').

193 Stamped tiles identify the *cohors* I *Aquitanorum* at Brancaster and *cohors* I *Baestasiorum* at Reculver (Pearson 2003, 100).

194 Allen and Fulford 1999.

195 Blagg 2002, 182; Hayward 2009, 112; 2018. The jurist Paternus (*Digest* L.6.7) indicates that legions included building specialists, such as surveyors, glaziers, smiths, roof-tile markers, stonecutters, lime-burners and woodcutters. Evans 1994, 146 notes that there are three architects whose names are known from Britannia: *RIB* 2091 (Amandus), 2096 (Gamidiahus), 1542 (a Roman citizen named Quintus). They are recorded on inscriptions set up on the northern frontiers, suggesting that they were probably soldiers. The use of military specialists (architects, engineers, etc.) may have been more prevalent than the general use of soldiers to provide bulk labour.

196 Jones 1983, 91. Cf. Xanten, whose defences, it has been assumed, were planned by a military architect or veteran (Precht 1983, 37).

197 Marsden 1987, 76–7.

198 Inscriptions attest to the fort's construction by the *legio* II *Adivtrix*, with other legions of Germania Inferior providing building materials for the site: tiles were stamped by *legio* V, *legio* XV (both based at Xanten), *legio* VI and *legio* XVI (both based at Neuss) (Rummel 2008, 173–4).

199 Esmonde Cleary 2020, 46 notes from Ammianus Marcellinus that wall circuits were restored/reconstructed by the army in Gaul (*Res Gestae* 18.2.3, 5) and that wagons, materials and auxiliary soldiers were sent for such work by the kings of the Alamanni (*Res Gestae* 18.6).

200 Esmonde Cleary 2020, 46–7

201 *CIL* 8.2728 = *ILS* 5795.

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the boundary of a new town for veteran settlers.[202] Another similar inscription from Dacia Inferior (modern-day Romania) records that soldiers built the walls of the colony of Romula.[203]

Similarly, the military could have met the labour requirements for the construction of Londinium's Landward Wall: 531 workers for four years. While Londinium of the second and third centuries was by and large an administrative or civic and civilian centre, members of the three legions stationed in Britain are attested there.[204] Men were likely seconded from the legions to serve on the governor's staff, and this *officium* could have been around 200 strong in Londinium,[205] while the procurator likely had 20–30 staff.[206] It is possible that some of these personnel could have been housed at the Cripplegate Fort (which had capacity for 1,500 men), if it remained into the early third century,[207] perhaps alongside 1,000 or so members of the governor's guard.[208] The secondees of the *officium* most probably had assigned roles (*beneficiarii*, *speculatores*, *frumentarii* and so on), and the governor's staff would likely have been employed full-time on their assigned duties. Yet, it is possible that a small portion of these men, or other legionary vexillations (or indeed auxiliaries), could have been detached specifically for organising or completing construction work,[209] and, in general, the requirement of a few hundred men in Londinium amongst a provincial garrison of tens of thousands is not large. It seems reasonable to assume that the procurator could facilitate the use of military labour, particularly as a means for the state to make use of provincial resources.

To confirm the availability of military manpower during the late second and early third centuries in Roman Britain, we should look more closely at the historical context during the period of construction, *c*. A.D. 190–225. Construction dates at the extremes of this period seem most likely, and a date in the A.D. 190s is generally favoured.[210] As governor in the early A.D. 190s, Clodius Albinus might have initiated construction projects: Sheppard Frere and John Wacher preferred to see the construction of Londinium's Landward Walls and the apparent simultaneous provision of stone gateways at several British towns and *coloniae* in the 190s as a single programme within an Albinian defensive policy.[211] The chronology of the gateways is

202 *ILS* 9375.

203 *CIL* 3.8031 = *ILS* 510 = *IDR* 2.324, Romula. The inscription reads: 'They [the emperors Philip senior and junior] constructed from the ground with military labour a circuit of walls to ensure the safety of the citizens of the colony Romula'. See MacMullen 1963, 35–6, n. 44 for other examples of the use of soldiers in the construction of city walls.

204 For example, by their tombstones: *RIB* 11, 13, 17, 19.

205 Hassall 1973.

206 Yule 2005, 86. See also Yule and Rankov 1998 for third-century tombs.

207 If the fort went out of use at an earlier date, there may have been temporary accommodation set up to house the military workforce (Yule and Rankov 1998; Perring 2017, 55).

208 Hassall 1973. Hassall 2000, 55 suggests that some of the legions and ranks named in military inscriptions related to Londinium were under the direct command of the governor, particularly in the third century when Londinium was the capital of the southern province of Britannia Superior. See Holder 2007, 20, map 5 for the distribution of military inscriptions in Londinium.

209 A quarrying detail of a vexillation of the *Classis Germanica* seems to indicate their temporary presence providing stone for the forum of the newly established Colonia Ulpia Traiana (Pferdehirt 1995, 68; Konen 2000, 474; *CIL* 13.8036). For the role of the *Classis Germanica* in the supply of building materials, see Rummel 2008, 211–14, 217–22. Vexillations of the *legiones* IIII *Scythica*, XVI *Flavia Firma* and III *Cyrenaica* were involved in the construction of the Mithraeum and an amphitheatre at Dura-Europos during the early third century (*Dura P.R.* 7/8, 85–7, no. 847; *Dura P.R.* 6, 77–80, no. 630; Pollard 2000, 243); however, both buildings seem to have been used only by soldiers. On the use of the army in provincial construction projects, see MacMullen 1959, 214–17, where it is noted that much of the evidence relates to the second and third centuries in military structures rather than civilian projects.

210 An important *terminus ante quem* is provided by coins minted between A.D. 210 and 217, and the equipment of a forger on a floor of an internal tower of the wall. When combined with the discovery of a worn coin of Commodus from A.D. 183–84 within the deposit added to the thickening for the west wall of the Cripplegate Fort at the same time as the Landward Wall, the time frame is generated.

211 See Hobley 1983, 81.

not secure, however, and, though the timelines above suggest the wall's construction in Londinium could have been completed relatively swiftly, probably within three to five years, we lack a definitive timescale. As a consul based in Britain, with coins minted in Rome in his name, Albinus likely possessed the power to ensure swift delivery, and the time frame of his six to eight years in power would have been sufficient, if rather concentrated. Construction of the Landward Wall at this time could have been the culmination of the stabilisation of Londinium from the late second century following a period of contraction or even the stimulus for investment in the city.[212]

At the other end of the possible time frame, the re-establishment of the northern frontier and campaigns in Scotland must have been a pre-occupation of the Severan dynasty, though this coincided with the construction of the first of the Saxon Shore forts (Brancaster, Caister and Reculver) in the south of the province roughly between A.D. 207 and 235. To add to this another major construction project in Londinium, particularly one which required the capacity of the fleet to ship materials, seems to be a serious imposition. Yet, the imperial visit and the division of the province into two in A.D. 212, with Londinium forming the capital of Britannia Superior, could have offered an impetus and opportunity for embellishment. Or, seen defensively, the Landward Wall could have been a logical extension of a wider Severan building programme, and even a successful way of occupying soldiers on 'displacement activities' following a period of unrest.[213]

It is possible, however, that supply and construction processes could have been provided by civilian labourers or contractors, perhaps with the project overseen and organised by state officials. We know that military supply chains often utilised civilian providers or 'middlemen'. Evidence from the Vindolanda tablets, while focusing in large part on supplies of food and weapons rather than building materials, emphasises that private civilians could be involved in the chain of supply for the army, even for considerable quantities of provisions.[214] The need for a quantity of ships totalling more than half the Roman fleet to ship stone (if this was completed in one season) seems a particularly heavy drain on resources, especially if a Severan date is preferred for construction.[215] There is no certain indication that the Blackfriars 1-type boat was military (see above), and such barges likely plied the Medway and Thames to supply Londinium. Again, however, firm and conclusive evidence is difficult to find.

Civilian labour, both slave and free, could have been contracted from the urban population to fulfil the construction requirements. Second- and third-century Londinium contained many well-built private or civic stone structures, ranging from large houses like that near Billingsgate with its own bath-house to the London Arch and Screen of Gods. While it is not always clear who constructed these, an argument has been advanced for the latter that local Romano-British craftsmen were responsible, and no mention is made of them being from the military.[216] Though the building boom following the Hadrianic fire was succeeded by a period of contraction, and by the end of the second century the population of Londinium was declining, a workforce of up to 531 men for a period of four years must not have been difficult to secure. Unlike the Saxon Shore forts, which were located some distance from towns, Londinium was home to a large urban community (*c.* 30,000) and thus could probably have provided a pool of labourers without severe disruption to other urban activities.[217] Moreover, while we lack direct evidence for the use of non-military labour for Londinium's Landward Wall, such evidence is

212 Perring 1991, 98.
213 Pearson 2003, 108.
214 See *Tab. Vindol.* 2.180, for instance.
215 Although much later in date, the Theodosian law codes mention that shipping was a public duty not to be evaded (e.g., *Theodosian Code* 13.7, A.D. 358; *Theodosian Novels* 2.8.1, A.D. 439).
216 Blagg 1980, 180–1.
217 Swain and Williams 2008, 37.

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attested for Hadrian's Wall: five inscriptions record that builders from the *civitates* of southern Britain carried out work on Hadrian's Wall, including Civitas Catuvellaunorum, Civitas Dumnoniorum and Civitas Durotrigum Lendiniensis.[218] It seems that people from native tribes from other parts of the province were used as builders or suppliers of material in the original construction or later reconstruction work.[219] The process for employing civilians could have followed the normal mechanisms known from elsewhere in the Roman Empire, with *redemptores* (building contractors) overseeing the hiring and organisation of labourers and/or the supply of materials, and subcontracting specialists as needed.[220] Here we might even imagine building contractors being responsible for specific lengths of the wall.[221] We cannot rule out entirely that both unskilled labourers and skilled craftsmen from the civilian population could have been involved.[222]

There is minimal conclusive evidence, and no building inscriptions for Londinium's Landward Wall survive. In general, we have little direct information for the organisation of the building trade in Roman Britain,[223] but we may rely on circumstantial evidence to consider the likelihood of state, military and civilian involvement, and how the processes of quarrying, supply and construction worked together.[224] We can conclude that a mixed approach, in which the state initiated or oversaw a process that involved both civilian contractors and military officials or labourers, was possible.

CONCLUSION

The construction of Londinium's Landward Wall physically altered the topography of the town and presented significant logistical problems in terms of the supply and transport of substantial quantities of stone and other building materials (TABLE 7). The scale of sourcing materials for such a project demonstrates the significance of the Landward Wall within the urban infrastructure of Londinium. The logistics of supplying building materials and the associated transport costs were important aspects of large-scale construction projects.[225] The energetics analysis of the Landward Wall demonstrates the logistical demands it imposed on Londinium's supply networks and the capabilities of the local administrators to source and transport materials over both land and water networks. Consideration of the construction materials adds further support to the pattern of stone use in Londinium during this period. The town's urban defences are the principal example of the output of the intensive quarry industry centred on the river Medway. The estimates for the production and transportation of the materials needed for Londinium's Landward Wall, which represented a significant part of the overall 'costs', show the impressive scale of this activity, especially within the context of the north-western provinces.

218 Frere 1987, 158. *RIB* 1672, 1673 (Durotriges of Lendiniae), 1843, 1844 (Dumnonii), 1962 (Catuvellauni Tossọdio). The Durotriges were centred on Dorchester (Durnovaria) and Ilchester (probably Lindinis). The tribe of Dumnonii had their centre at Exeter (Isca Dumnoniorum), while St Albans (Verulaneum) was the tribal capital of the Catuvellauni. The inscriptions are generally ascribed to the Severan period or even later, but, as Hingley 2012, 20–1 points out, building inscriptions are rare on Hadrian's Wall after the third century.

219 Hill 2010, 114. Ling 1985, 14 also notes that the inscription might refer to architects, contractors or sponsors, who took the credit for specific lengths of walling.

220 Anderson 1997, 103–12.

221 This kind of division in public works has been suggested for a number of cases, including the Aurelianic Walls in Rome. For construction differences as a result of different workmen or *collegia*, see Richmond 1930, 66, 259.

222 Shirley 2000, 93 suggests that civilians may have been used for extracting, processing or manufacturing materials and for transport to the fort at Inchtuthil.

223 On this point, see Ling 1985, 14. Apart from the names of three architects mentioned above (n. 195), we know of a mason, Priscus, who was an immigrant from Gaul (*RIB* 149).

224 Holder 2007, 18–20 notes that very few official and military inscriptions survive from Londinium. The largest surviving class are tiles stamped with 'the Procurators of the Province of Britain at London' (see above, n. 59).

225 DeLaine 1997, 216–17 estimates that over 50 per cent of the total construction costs of the Baths of Caracalla in Rome (A.D. 212–16) were related to shipping and haulage.

TABLE 7. CONSTRUCTION FIGURES FOR THE LANDWARD WALL

Element	*V-shaped ditch (pdays)*	*Internal earthen bank (pdays)*	**Wall section** *Foundations (pdays)*	*Wall (≤ 4.4 m) (pdays)*	*Crenellations (pdays)*	**Total**
Production	–	–	10,020	145,023	66,359	221,402
Transport*						
Land	–	–	1,937	24,775	252	26,964
Water	–	–	1,196	6,630	880	8,706
Construction	877	4,676	12,144	22,601	6,427	46,725
Total	**877**	**4,676**	**25,297**	**199,029**	**73,918**	**303,797**
% of total	0.3	1.5	8.4	65.5	24.3	100
Total costs (KM)	**287**	**1,530**	**76,143**	**471,097**	**97,205**	**646,262**

*The transport figures represent only the number of boat-days or cart-days rather than person-day totals. For example, since each boat requires a crew of three, the total person-days would be three times the figure listed in table 7. Equally, each cart-day requires one driver and two or three workers to manage the animals per cart. Thus, the total person-days would be three to four times greater than the cart-day figures.

The energetics approach adopted to examine the construction of the Landward Wall also raises questions about who provided the labour and how the whole project was instigated, organised and overseen in the 'civil' south of Britain. To date, much of the work for labour figures in Romano-British contexts has related to military projects (such as Hadrian's Wall, the fortress at Inchtuthil and the Saxon Shore forts). These case studies present a more straightforward answer to questions of administration and labour. The use of the Roman army in military zones or for military projects makes sense, but for a project like the Landward Wall in Londinium, where the rationale for the wall is debated (often boiled down to whether it was primarily defensive or related to civic prestige), the situation is more complex. The common assumption that large-scale projects required skilled military manpower might be challenged by the labour figures suggested here for the Landward Wall. The total number of workers, 531 individuals if the construction was spread over four years, is arguably small enough to have enabled workers to be drawn from the urban, non-military population of Londinium. On the other hand, the construction of city walls was directly related to the needs of the military, in addition to providing protection for the civilian communities. If we combine this with the cost implications outlined above, military involvement would seem to make sense, since it would not only offset the overall costs of construction but also make use of a skilled workforce already on the payroll: the labour force would have been present and available for such duties at only a 'marginal' cost.[226] This kind of approach to large-scale public building projects may therefore have been a crucial element in the successful implementation of construction programmes in provinces like Britannia.

Finally, our energetics approach may go some way to explain, if not the impetus for the widespread construction of urban defences, at least *how* so many circuits were built across the north-western provinces.[227] For instance, if we consider the simplified schedule for the production and construction of a 25 m-long stretch of the Landward Wall (FIG. 14), we can see

[226] The economics of military labour is clear from other periods. In the nineteenth century, utilising the army was seen as a means to reduce colonial building costs. In North Africa in 1847, building works employing military personnel cost about one-quarter what they would have cost using civilian contractors (Greenhalgh 2014, 195, quoting figures from Féraud 1877, 131–2).

[227] In Gaul, for example, roughly 85 per cent of the 125 largely undefended towns were provided with walls from the third through to the early fifth century (Bachrach 2010, 38, with bibliography). In Britain, all the *coloniae* (Colchester, London, Gloucester, Lincoln and York) as well as a number of the major towns and 'small towns' had walls (Esmonde Cleary 2019).

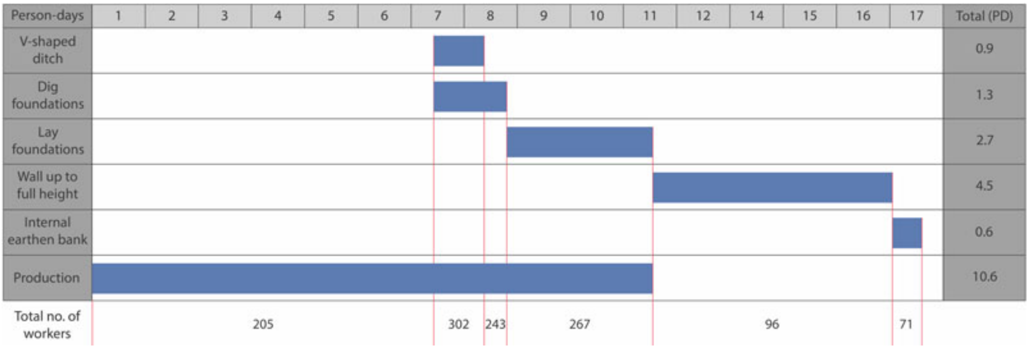

FIG. 14. Production and construction schedule for a 25-m stretch of the Landward Wall (image by S. Barker).

that the total requisite materials could be produced and the section constructed within a 16-day period, assuming a fluctuating workforce of between 71 and 302.[228] In practice, the overall schedule for each 25-m stretch would have been longer, accounting for the transport of materials (which would have impacted the overall time frame and number of workers required). Nonetheless, these labour estimates suggest that urban defences could have been constructed in relatively short periods of time with a modest workforce.[229]

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SUPPLEMENTARY MATERIAL

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[228] This assumes that certain construction tasks could be performed at the same time (i.e. the digging of the v-shaped ditch and the excavation of the foundation trench for the Landward Wall, etc.). It also excludes the time taken to transport material and additional, non-labour time needed for certain aspects of the construction or production, which of course would have impacted the overall time but not the labour input: for example, the time required for bricks to dry in forms (around 28 days) or the firing and cooling of a kiln (DeLaine 1997, 114, 118 assumes three days for firing and five days for cooling a kiln with a 65 m^3 capacity).

[229] The idea of relatively rapid construction for urban walls is also suggested by Bernard's cost analysis of Rome's Republican walls. His labour estimates suggest that construction of the wall itself could have been accomplished quite quickly, with a 36 m-long stretch of wall taking 200 men about 15 days to construct (Bernard 2018, 107).

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