Britannia 54 (2023), 167–187
doi:10.1017/S0068113X23000375

Estimating the 'Missing' Houses of Silchester

By SCOTT ORTMAN and JOHN HANSON

ABSTRACT

Estimating the numbers of residences, and thus the residential densities and populations, of ancient settlements remains a significant problem. This is true even for 'greenfield' sites due to the differential visibility of structures made of different materials in aerial and geophysical surveys. In this paper, we take advantage of statistical relationships among elements of the built environments of Roman cities in Britannia and more broadly across the Empire, to estimate the total number of buildings, total population and population density of Silchester. The results indicate that the current site plan dramatically under-represents these values. We also consider the implications of our results for broader discussions of urbanism in Britannia.

Keywords: archaeology; population; built environment; urbanism; Silchester

INTRODUCTION

A central problem in the study of ancient societies is estimating the numbers of residences, and thus the resident populations, of settlements. This is a crucial issue, given that population and population density are key aspects of urban life and are fundamental to many other social and economic processes.[1] Estimating population is complicated because the residential densities of settlements vary with site area, across sites of similar area and over time, such that it is unrealistic simply to multiply site areas by a constant density figure. Ideally, one should estimate the residential density site by site, using evidence from across the site area dating to specific periods. Unfortunately, this is rarely possible because most ancient towns lie beneath current cities and towns – indeed, about half of the cities and towns established across the Empire during the Roman era have continued as urban centres down to the present.[2] This means that it is generally very difficult to obtain an overall plan of a settlement that allows one to count the buildings or examine their sizes, densities and orientations for any given period.

Important potential exceptions to this situation are the so-called 'greenfield' sites, of which Silchester (*Calleva Attrebatum*) in present-day Hampshire is perhaps the best-known example. This site was abandoned around the end of the Roman period and was not reoccupied. It has also been subject to extensive excavation, aerial survey and geophysical survey. Recent work

1 Wirth 1938; Angel *et al.* 2016; Duranton and Puga 2004; Lobo *et al.* 2020.
2 Hanson 2016; 2021; Scheidel 2007.

has sought to create a comprehensive catalogue of the buildings at Silchester by integrating results of antiquarian clearing with aerial photography, remote sensing and geophysical investigations.[3] As a result, we have a very clear understanding of the structures that are visible on or just below the modern ground surface today (FIG. 1). However, despite this excellent and extensive work, two aspects of the final site plan are curious. First, there is a surprisingly large amount of apparently unbuilt space within the street grid. Given that the street grid was laid out early in its history and portions were eventually left outside the city walls, this pattern suggests either that the town did not grow as much as the designers hoped or expected, or that many residences are 'missing' from the plan.[4] Second, recent excavations in Silchester and other Romano-British towns have shown that many structures were constructed of timber, even during the later Roman period, but very few of these were identified by the recent mapping project.[5] For example, excavations at the small town of Neatham, a short distance south of Silchester, encountered 24 buildings dating from the late third and fourth centuries in a 0.37 ha

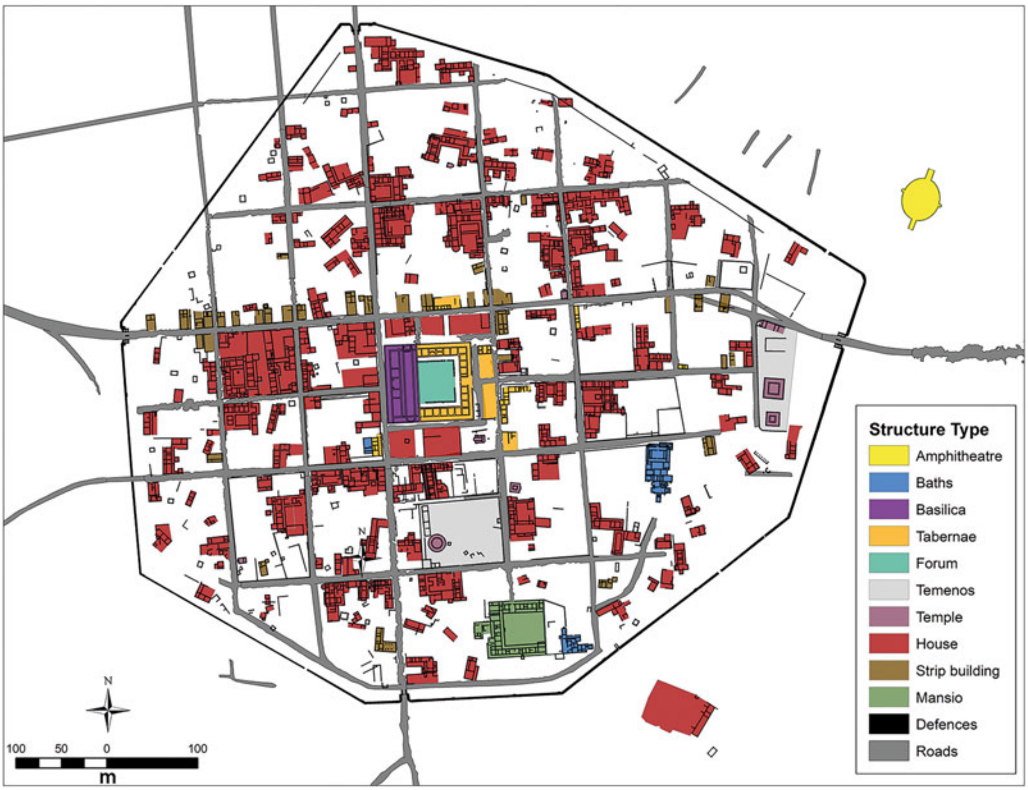

FIG. 1. Plan map of Silchester, from the Silchester Mapping Project shapefiles available from the Archaeology Data Service. Note the area within the street grid for which buildings have not been identified.

3 Creighton and Fry 2016.
4 Creighton and Fry 2016, fig. 17.2.
5 Fulford *et al.* 2006; Bowden 2018; Rippon and Holbrook 2021.

https://doi.org/10.1017/S0068113X23000375 Published online by Cambridge University Press

area, and of these only two (8.3 per cent) were built of stone.[6] These details lead one to ask whether structures are missing from the current plan of Silchester.

Resolving this question is important for overall conceptions of Roman Britain and its similarity (or otherwise) to other provinces in the Empire. Recent work has called into question the idea that Romano-British towns functioned as centres of production and exchange in the context of a wider hinterland, instead suggesting that they served as parasitic foci of elite consumption, government and administration.[7] A sparsely inhabited Silchester, dominated by elite residences and civic buildings, would fit this model quite well. On the other hand, a more densely inhabited Silchester, with a larger number of smaller residences made of more perishable materials, would seem to be more in keeping with the view that Romano-British cities functioned in similar ways to their counterparts in other provinces.

In this paper we examine the evidence from Silchester in the context of relationships among measured properties of cities and towns across Britannia and the broader Empire to estimate the number of residences that may be 'missing' from the current site plan. The relationships we examine take the form of scaling relations, which are ultimately grounded in the relationship between total settlement areas and the densities of residences within excavated areas, discussed by Hanson and Ortman, and extended to include a larger sample of Romano-British settlements here.[8] We first show that the current plan of Silchester implies a markedly low population for a Roman town of its size. Then, we employ the variety of scaling relationships noted in previous studies to derive a range of estimates for the total number of residences that would once have been present if Silchester were in fact a 'typical' Roman town of its size. These estimates are then combined to generate statistical estimates for the total number of residences that are missing from the site plan. Our analysis leads us to conclude that many relatively small residences are likely missing from the current site plan. In the process, we also find evidence that, at least with respect to aggregate properties of their built environments, Romano-British towns were similar to those found elsewhere in the Empire. This in turn suggests that their roles in Romano-British society were also similar to the roles played by cities and towns in other provinces. We begin by discussing previous attempts to estimate the population of Silchester. Then, we review the evidence for the scaling relationships mentioned above, explain our method in more detail, examine the results and consider how this approach could be extended and improved in future studies.

BACKGROUND

Silchester was a focus of antiquarian interest in the late nineteenth and early twentieth centuries (1890–1909), when an attempt was made to uncover a complete plan of the town.[9] These antiquarian excavations were extensive, but also relatively coarse and superficial, leaving plenty of scope for additional work,[10] notably the Silchester Town Life Project (1997–2014), which aimed to reveal the longer-term development of the site from its origins in the Iron Age to its abandonment in the post-Roman era.[11] In addition, the Silchester Mapping Project of 2005–10 combined extensive geophysical survey with aerial photography and earlier surveys to provide a comprehensive view of the archaeological remains at the site, with the resulting mapping layers

6 Millett and Graham 1986, 151.
7 Mattingly 2006; Perring and Pitts 2013; Pitts 2016.
8 Hanson and Ortman 2017. The data and R-code used for the analyses in this paper are published as supplementary materials.
9 Boon 1974, 27–32; Banerjea *et al.* 2015.
10 For example, of the town defences: Fulford 1984.
11 Fulford *et al.* 2006.

being made available through the Archaeology Data Service.[12] We leverage this excellent recent work in our study.

The most widely cited estimate of the resident population of Silchester at its Late Roman peak derives from the work of George Boon.[13] Boon generated estimates using a variety of methods, ranging from as few as 1,000 to as many as 7,500 people, and he suggested the most likely figure was around 4,000. This 'most likely' figure was based on a 'notional' total of about 200 houses and an average household size of about 20, which itself depends on an average family size (excluding slaves and dependents) between 8 and 12.[14] However, Boon also suggested the number of houses inhabited in the second, third and fourth centuries A.D. was not likely to have exceeded 150, and that the number of houses in the first century A.D. was lower – perhaps as little as 75, based on the numbers of unaligned buildings. This would in turn suggest a population of about 1,500 in the first century A.D. and about 3,000 in the second, third and fourth centuries A.D.[15]

There are two reasons we believe it is worthwhile to revisit these figures. The first is that Boon's estimates are based on the number of houses revealed by the antiquarian excavations and shown on the canonical site plan of 1908. These excavations involved laying out a series of parallel diagonal trenches that sought out traces of flint masonry walls, largely ignoring the more subtle traces of wooden structures. Any stone structures encountered were then isolated and cleared to floor level. As Boon noted, 'the completeness of the resultant plan is a matter with which we must deal later (p. 49): but it is at least evident that this mode of working is likely to have left much undisturbed and was not well-devised to deal with any but substantial structures and especially not with those of timber'.[16] Boon also noted the variation in the number of structures recorded from *insula* to *insula* by the early excavators as evidence that many timber structures remain undiscovered.[17] It is therefore ironic that, although a primary accomplishment of the antiquarian clearing was one of the most complete plans of any town in the Roman Empire, and certainly in Britain, information concerning an unknown number of domestic structures may be missing from this plan.[18] Although Boon was aware of these issues, he did not attempt to incorporate them into his discussion of the town population.[19]

The suggestion that substantial numbers of undocumented structures remain at Silchester has been borne out by subsequent investigations. Excavations in Insula IX, for example, have shown that the two previously identified masonry buildings within the excavated area are accompanied by at least two additional timber structures.[20] There is little chance that timber structures like these would show up consistently in crop marks, especially given the depth of the topsoil and its extensive disturbance by the antiquarians. This means that they are also likely to be under-represented in twentieth-century aerial photography and geophysical survey. As Creighton and Fry note with regard to the Silchester Mapping Project results,

> These plans will still fail to show certain types of features. FIG. 5.18 compares the number of features found in the modern excavation of Insula IX to the features found by the Antiquaries. Since the gradiometry data only added a small number of walls and buildings on the overall

12 Creighton and Fry 2016.
13 Boon 1974, 61.
14 Boon 1957; 1974.
15 Boon 1974, 61–2.
16 Boon 1974, 29–30.
17 Boon 1974, 50.
18 Boon 1974, 49.
19 Boon 1974, 61–2.
20 Fulford *et al.* 2006; Fulford and Clarke 2011; Creighton and Fry 2016, fig. 5.18.

interior plan to those noted by the Antiquaries, it is likely that the gradiometry too has missed a significant number of timber buildings.[21]

Indeed, their atlas shows traces of uncounted buildings, including patches of flooring, wells and thermal features, in several insulae, including II, III, XIII, XIV, XV, XVII and XXXV.[22]

The second reason for revisiting Boon's estimates is that he used a figure for the average size of a household that is extremely high and may reflect an effort on his part to compensate for the low numbers of houses noted above. His figure of 20 persons per household is based on the numbers of bedrooms discernible in the largest 10 per cent of houses at the site (by Boon's reckoning) and is therefore unlikely to reflect a site-wide average. Although we would expect there to be variation in the sizes of households, and there may have been some extended family residences, most recent scholars have concluded that the sizes of households in pre-modern contexts generally ranged between three and seven individuals, with an average of about five.[23] This is based on several lines of evidence, including detailed analysis of birth and death rates, life expectancy and household composition in non-modern contexts, and comparison with better-documented periods and places.[24] These figures are also supported by evidence from census returns from Egypt, which mostly date to the Hellenistic and Roman periods.[25] These censuses contain information about a total of 167 families, which had an average size of 4.3.[26] As Bagnall and Frier have also shown, the average size of households in Egypt's urban areas was about 5.3, while those in rural areas was about 4.8.[27] This difference is accounted for by the fact that the former were more likely to have owned slaves.[28] Although these average household sizes may seem small, they are perfectly in line with other societies where both birth and death rates were high.[29] These figures also make sense given what we know about the average sizes of structures and the average numbers of rooms within domestic architecture in the ancient world.[30] In addition, as Boon himself pointed out, English family sizes of more recent periods, which are based on direct documentation, tend to be much lower and generally range between about four and five. Finally, even in societies with extended family systems, at any given moment only a fraction of households are extended due to the ways the life cycle and family cycle interact, such that the average household size is only about seven.[31] There seems little doubt, then, that Boon's estimate for the population of Silchester is based on tenuous assumptions, including his figures for the numbers of houses (which are probably too low) and the average size of each household (which is too high).

It is worth noting two further aspects of Boon's account. The first is that he attempted to explain the disparity between the observed numbers of houses and the dimensions of the street network by suggesting that the urban grid was overbuilt relative to the urban development that actually occurred.[32] In other words, rather than questioning the strength of the evidence for the numbers of houses, he questioned the strength of the relationship between the observed infrastructure and the size of the community it was intended to serve. Second, Boon used the sizes of public

21 Creighton and Fry 2016, 47.
22 Creighton and Fry 2016, figs. 5.27, 5.30, 5.43, 5.46.
23 Russel 1958; Hassan 1981; Storey 1997; Hansen 2006; Wilson 2011; Hanson 2016; Hanson and Ortman 2017, 308. For discussion of potential extended family residences in rural areas, see Smith 1997.
24 Chamberlain 2006.
25 Kennedy 2006, 111.
26 Bagnall and Frier 1994; Hansen 2006, 58; 2008, 278.
27 Bagnall and Frier 1994, 67–9; Huebner 2013, 39.
28 Huebner 2013, 39.
29 Huebner 2013, 201.
30 Hanson and Ortman 2017, 307–8.
31 Wolf 1984, 283.
32 Boon 1974, 62.

buildings, especially the baths, to shed additional light on the town's population based on comparisons with other sites (a method that we essentially extend below). Based on such comparisons, he suggested the baths were large enough to serve a population of around 1,000 families. But instead of considering this as evidence of the resident population, he suggested that the original bath architects envisaged the site growing into a much larger settlement – growth that was never fulfilled. Although Boon was right to be cautious about using the sizes of the street grid, baths, and other public buildings as evidence of Silchester's population, recent work has shown that the sizes of such buildings are systematically related to the populations of their associated settlements.[33] These relationships are statistical and non-linear, but they can be leveraged in a way that extends and formalises Boon's basic intuition.

Recent studies have attempted to reconstruct the architectural designs of timber-framed buildings at Silchester.[34] But to our knowledge, the only recent alternative to Boon's estimate comes from our own work, where we extrapolated the residential density suggested by the Insula IX excavations to the entire site area.[35] The Insula IX excavations revealed four buildings dating to around the late first century A.D., including two stone buildings and two timber buildings, over an excavated area of about 0.25 ha.[36] We combined these data with a figure of five persons per household to estimate an average population density of about 80 people per hectare.[37] We then used an estimate of 45 ha for the inhabited area of Silchester, based on a combination of the walls and the urban grid, to translate this density into an implied population of about 3,600 (by sheer coincidence, this figure is close to Boon's preferred estimate).[38] Finally, we considered the overall relationship between building densities and settlement areas across the ancient world to argue that this estimate for Silchester is low, and that a more reasonable estimate is around 6,800 (i.e. towards the upper end of the range suggested by earlier scholars).[39] The shortcomings of this work are that it extrapolated a single line of evidence (the building density in cleared areas) to entire sites; and it did not provide a measure of the uncertainty surrounding the resulting estimates. In the next section, we show how this general approach can be extended in a way that addresses these shortcomings.

THE CURRENT DATA

TABLE 1 presents a tabulation of all structures identified through the Silchester Mapping Project (also see FIG. 1). Based on this tabulation, there are 186 properties (houses, strip buildings and *tabernae*) corresponding to a defended area of 43 ha. That strip buildings should be included among the individually owned residences is supported by excavations at Cirencester, Verulamium and other sites across the Roman world. As Holbrook notes, 'It is a commonplace derived from well-preserved sites such as Pompeii and Ostia that the front part of the building facing the street served as the shop area, with workshop and living accommodation to the rear

33 Lobo *et al.* 2020.

34 Banerjea *et al.* 2015 have suggested a method for reconstructing the architectural designs of timber-framed and earthen-walled structures at Silchester based on a combination of experimental archaeology and micromorphology. Unfortunately, this method can only be applied to recently excavated areas, so it cannot be used to estimate the overall numbers of timber structures at the site.

35 Hanson and Ortman 2017.

36 Fulford and Clarke 2011.

37 Hanson and Ortman 2017.

38 Wacher 1995; Hanson 2016; Hanson and Ortman 2017. The earlier inner earthwork encompassed about 32.5 ha, while the slightly later outer earthwork took in about 95 ha (Boon 1974, 44; McEvedy 2011). This was then reduced to 86 ha (Boon 1974, 46). The Silchester Mapping Project estimates a total area of 43 ha.

39 Hanson and Ortman 2017.

TABLE 1. SUMMARY OF STRUCTURES BASED ON THE INTERPRETATIONS OF THE SILCHESTER MAPPING PROJECT

Structure type	**Count**
Amphitheatre	1
Basilica	1
Baths	3
Forum	1
House	142
Mansio	1
Strip building	35
Tabernae	9
Temenos	2
Temple	9
Not further specified	55

We consider houses, strip buildings, and tabernae as 'residential buildings' or 'properties' in this paper. Most of the structures that are not further specified are small, single room outbuildings. These are shown unshaded on FIG 1.

or possibly in an upper story above the shop.'[40] We are also generous and consider blocks of shops, referred to here as *tabernae*, as including accommodation for at least a few tenants.[41] So, if one counts five persons per property, the 186 properties at Silchester imply a residential population of 930 persons, or about 22 persons per hectare. This is a very low density relative to those estimated from excavated or cleared areas in other Roman cities, in Britannia and across the broader empire, which generally range from 100 to 500 people per hectare.[42] FIG. 2 illustrates the situation using the data from Hanson and Ortman 2017, augmented by data for a sample of towns in Britannia (including the Insula IX excavations for Silchester). It is important to emphasise that for the Romano-British towns, the data derive from major excavation projects where both stone and timber buildings were identified. The data from the Silchester site plan clearly stand out as suggesting an anomalously low population density. The data used to generate this figure are presented in TABLE 2.

Another way to look at the situation is to compare the total number of residences (properties) identified at Silchester, relative to its area, in the context of estimated total residences at other sites. For other sites, total residences are estimated by multiplying the property density within excavated or cleared areas by the total site area. The result is shown in FIG. 3. Note that in this figure the estimates of site area and building count are log-transformed prior to plotting, and that when the data are looked at this way, the overall pattern in the estimates for Britannia is not distinguishable from that of other provinces. Of course, one would expect the observed structure density within relatively small excavated or cleared areas to be an imperfect means of estimating the overall average residential density of a settlement. The logic of FIG. 3 is that across many cases these errors tend to average out, and the residuals to the average relationship reflect the combination of sampling error and real differences in residential densities across sites. Even with these caveats, Silchester stands out as having far fewer residences, relative to its area, than would be expected based on the sample data from other Roman cities in Britannia and across the Empire.

40 Holbrook 1998, 209.
41 Creighton and Fry 2016, 409.
42 Hanson and Ortman 2017; Wilson 2011.

TABLE 2. SITE AREAS, INVESTIGATED (SAMPLE) AREAS, AND ENCOUNTERED STRUCTURES (# PROPERTIES) FOR A SAMPLE OF ROMAN CITIES FROM ACROSS THE EMPIRE

Key	Ancient toponym	Province	Site area (ha)	Sample area (ha)	# Properties
28	Delos	Achaea	95	1.6	50
87	Piraeus	Achaea	141	0.24	8
19	Cassope	Achaea	30	16	500
131	Hermopolis Magna	Aegyptus	155	155	7000
155	Thmuis	Aegyptus	85	85	3560
177	Gigthis	Africa Proconsularis	50	0.11	9
194	Sabratha	Africa Proconsularis	35	2.54	116
187	Meninx	Africa Proconsularis	43	0.25	6
217	Utica	Africa Proconsularis	85	0.32	6
225	Augusta Praetoria	Alpes Graiae et Poeninae	41	0.24	4
305	Pergamum	Asia	220	0.22	13
276	Ephesus	Asia	263	0.7	30
347	Italica	Baetica	49	1.85	24
404	Ratae[1]	Britannia	46	0.4475	19
399	Londinium	Britannia	160	0.04	2
408	Verulamium	Britannia	90	0.3	11
409	Viroconium[2]	Britannia	82	0.7534	29
395	Isca[3]	Britannia	37	1.147	13
386	Camulodunum[4]	Britannia	48	0.9	27
400	Luguvalium[5]	Britannia	28	0.2	16
383	Aquae Sulis[5]	Britannia	12	0.612	27
385	Calleva	Britannia	45	0.25	4
387	Corinium[6]	Britannia	93	0.5375	21
599	Alesia	Gallia Lugdunensis	97	0.14	10
620	Lugdunum	Gallia Lugdunensis	170	0.28	20
647	Glanum	Gallia Narbonensis	32	0.24	5
657	Vasio	Gallia Narbonensis	36	0.83	25
695	Celsa	Hispania Tarraconensis	18	0.3	11
700	Emporiae	Hispania Tarraconensis	21	0.4	5
776	Herculaneum	Italia (I Latium and Campania)	20	3.73	80
790	Pompeii	Italia (I Latium and Campania)	60	44.32	1151
788	Ostia	Italia (I Latium and Campania)	154	35	3153
845	Venusia	Italia (II Apulia et Calabria)	44	0.07	3
859	Metapontum	Italia (III Lucania et Brutii)	150	70	3000
861	Paestum	Italia (III Lucania et Brutii)	126	0.96	20
1037	Libarna	Italia (IX Liguria)	20	0.6	12
971	Cosa	Italia (VII Etruria)	14	10	258
984	Luna	Italia (VII Etruria)	23	0.25	4
1065	Verona	Italia (X Venetia et Histria)	52	0.59	8
1077	Augusta Emerita	Lusitania	81	1.5	36
1081	Conimbriga	Lusitania	23	1.06	14
1136	Side	Lycia et Pamphylia	38	0.1	6
1171	Cuicul	Mauretania Caesariensis	12	6.35	74
1203	Volubilis	Mauretania Tingitana	43	4.32	182
1258	Thamugadi	Numidia	50	9.96	711
1241	Bulla Regia	Numidia	31	0.94	11
1307	Himera	Silicia	82	0.24	8
1313	Morgantina	Silicia	25	0.14	8
1322	Tyndaris	Silicia	30	0.19	9
1340	Palmyra	Syria	120	0.11	2

Notes: The data are taken from Hanson and Ortman (2017), with the addition of a few additional British towns, as noted. The key is the primary key in Hanson's (2016) database. In this table, the sample area represents the area of observation of buildings through excavation, clearing or geophysical survey; and the number of properties represents the number of residences identified within that area. 1) Leicester, data from 72 Nicholas Circle, 52 Grange Lane, Republic Car Park, and Causeway Lane (Connor and Buckley 1999; Gossip 1999; Thomas 2005; Score 2006); 2) Wroxeter, data from the Baths Basilica and Macellum (Barker *et al.* 1997; Ellis 2000); 3) Exeter, data for the later civic period (Rippon and Holbrook 2021); 4) Colchester, data for the post-Boudiccan period (Gascoyne and Radford 2013); 5) Carlisle and Bath, data from the Defended Small Towns of Roman Britain dataset (M. Fulford *et al.* 2018); 6) Cirencester, data from the Beeches Road and St Michaels/Town Centre excavations, fourth century (McWhirr 1986; Holbrook 1998).

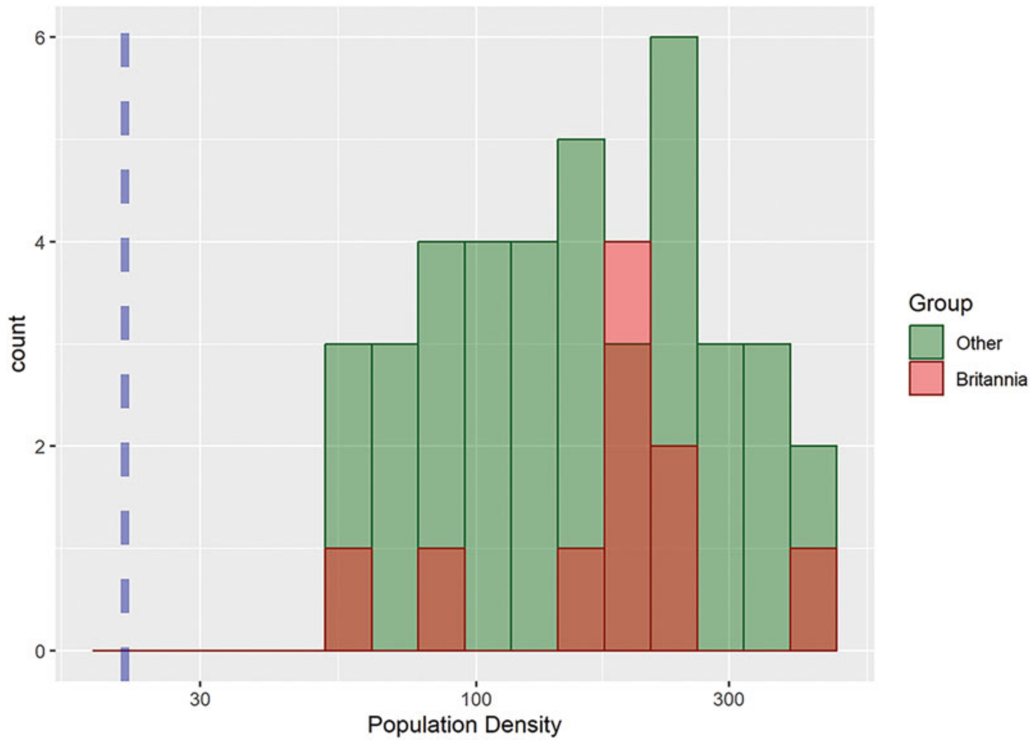

FIG. 2. The implied population density of Silchester derived from the visible structures in FIG. 1 relative to the estimated population densities of other Roman cities (based on structure counts in cleared/excavated areas). The population density scale is logarithmic (base 10), and the observed density for Silchester is shown as a dashed blue line. In the histogram, the two data series overlap. Note that the suggested population density for Silchester is substantially less than observed for all other sites in this sample, and that the distribution of density estimates for Britannia *versus* other provinces are not distinguishable.

There are three possible explanations for the anomalously low residential density suggested by the Silchester site plan. The first possibility is that the current site plan is accurate, and Silchester was a typical Romano-British town. This scenario would imply that these towns were over-built relative to the populations that actually lived there, perhaps adding weight to the idea that the Roman policy of urbanisation did not take hold in Britain as well as it did in other provinces, and that Romano-British towns functioned primarily as parasitic foci of government and administration, with limited economic impact or draw for the local population. This interpretation would require us to conclude that structure densities within excavated areas of Roman cities and towns systematically over-estimate the actual structure densities. This seems unlikely, for several reasons: 1) although one would expect some error in population estimates derived from residential densities in cleared areas, it seems unlikely that it would be systematically biased in a positive direction; 2) the overall pattern in FIG 3 includes sites like Pompeii, Herculaneum and Ostia where large fractions of the total site area have been cleared; and 3) in FIG 3, the data for other Romano-British towns are not distinguishable from those of the broader Empire.

https://doi.org/10.1017/S0068113X23000375 Published online by Cambridge University Press

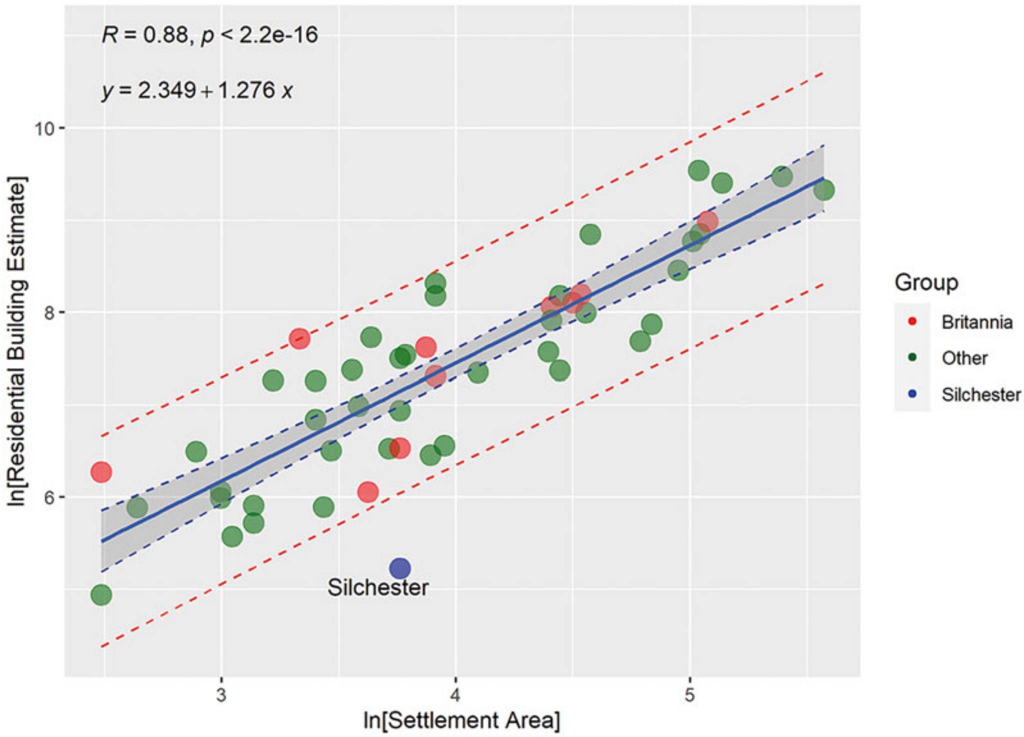

FIG. 3. Relationship between estimated population and area of a sample of ancient cities. The data have been transformed to natural logarithms prior to plotting, and Romano-British towns are distinguished. The Silchester site plan is excluded from the fit line estimation, the 95% confidence interval for the predicted mean is shown in gray, and the 95% prediction interval for a given value is indicated by the dashed red lines. Note that, based on the overall pattern, Silchester stands out as having fewer observed structures than other sites of its size. In fact, the observed structure count for Silchester lies well outside the 95% prediction interval based on the overall relationship. Note also that the prediction interval is much wider than the confidence interval. This is due in part to variation in structure density in sites of a given size, and also to imprecision in measuring structure density.

The second possibility is that the current site plan is accurate, but Silchester was not a typical Romano-British town. This would perhaps imply that the reason Silchester became a greenfield site is because it was notably unsuccessful relative to other Romano-British towns. In this scenario, the Silchester site plan would not be representative of the typical town, and one might interpret the over-built urban infrastructure, relative to the residential density, as evidence that Roman policy was unsuccessful in this specific case. It would also imply that the higher residential density suggested by the Insula IX excavations is what is anomalous, even though it just happens to be basically consistent with the overall relationship between site area and residential density across many other sites.

The third and final possibility is that the current site plan is not accurate, and Silchester was in fact closer to a typical Romano-British town. This scenario would imply that many timber structures are missing from the site plan but remain unobserved at the site, as is suggested by the Insula IX excavations and the overall pattern in FIG. 3. This seems to us to be the most likely scenario. If so, a productive approach for estimating the 'missing' structures suggested by FIG. 3 would be to move the data point for Silchester upward until it intersects the fit line representing the average relationship across all sites, and then note the structure count thus suggested. This can also be done by evaluating the fit line of the relationship between area and structure count at the value corresponding to the total area of Silchester.

This procedure might provide a better estimate of the total residences than the number of residences actually observed, but it still might not be very accurate. Fit lines like that shown in FIG. 3 represent an average relationship with variation in the independent variable, but this often provides an imperfect basis for predicting the structure count corresponding to a specific area. There are two forms of uncertainty in an analysis like this.[43] The first one, known as the *confidence interval*, represents the uncertainty in the estimate of the average structure count for sites of a given area. This is shown using gray shading and a blue dotted line in FIG. 3. The second is the *prediction interval*, which represents the uncertainty surrounding the estimate for structure count of a specific site with a given area. The 95 per cent prediction interval in this case is shown using dashed red lines.

Under normal circumstances, the proper interval to use in estimating a value from beyond the limits of a sample (the total structure count at Silchester given its area) is the prediction interval. When one does this, one finds that the actual (logged) structure count has a point estimate of about 7.1, and that about 95 per cent of the time the true value will lie somewhere between 6 and 8.2. Since these are log-transformed numbers, they translate into a point estimate of 1217 residences and a 95 per cent prediction interval of 416 to 3559 residences. This is not as helpful as one might hope.

The reason the prediction interval is typically broader than the confidence interval, as it is in FIG. 3, is that it incorporates the variance of the residuals around the fit line into the analysis. The confidence interval, on the other hand, is only the mean distance of data points from the fit line at each x, which is generally a much smaller value.

AN APPROACH TO ESTIMATING TOTAL STRUCTURES

Although the prediction interval is the correct one to use under normal circumstances, two factors lead us to suggest an alternative in this case. First, regression analysis typically assumes that the extent to which an individual data point deviates from the fit line (its residual) is due to a real fluctuation in its observed property. So, if a site has a large positive residual to the average relationship, this is because this site really was much more densely occupied than the average site of its size. However, in cases like FIG. 3, at least some of the variation in the residuals is likely due to difficulties in measuring the structure density, due to the time-averaging inherent in this sort of measurement, differences in preservation and investigation strategies, and the need to extrapolate from small, cleared areas to the entire site area. In other words, the variance in residuals around the fit line probably reflects both inaccuracy in measurement and real variation in past Roman cities.

Second, in this case, we can produce multiple estimates of the building count using additional relationships with measured properties of Roman cities. Previous work has found similar scaling relationships to FIG. 3 for a variety of additional measures, including the area of the forum, the area of streets, the capacity of the amphitheatre and the total width of gates in the city walls.[44] The total residential building estimate suggested by each relationship may not be any more precise than that suggested by the site area, but each is independent, and this allows one to combine them, and their associated uncertainties, into a refined estimate that takes multiple lines of evidence into account.

43 For background on linear regression analysis, see Kranzler 2017.
44 Hanson and Ortman 2017; Hanson *et al.* 2019; Hanson 2020; Hanson and Ortman 2020.

In ideal circumstances, one would combine these various lines of evidence using a multiple regression approach. This is not feasible for this situation because multiple regression requires a dataset with no missing values, but in this case different subsets of sites have measurements for the structure density, street area, forum area, amphitheatre seating capacity and gate widths. As a result, there are very few sites with complete data, so the dataset offers a poor basis for multiple regression.

Given this, we believe a reasonable approach to estimating the total residences that once existed at Silchester is to combine the fit line value and confidence interval (rather than the prediction interval) for several estimates, produced from different relationships, to produce a point estimate and confidence interval for the total residence count. We perform these calculations in the following section.

SCALING RELATIONSHIPS AND ESTIMATES

Our analysis proceeds in two steps. First, we multiply the estimated density of residential properties (domestic residences and *tabernae*) in specific settlements by total site areas (often the defended area) to estimate the total number of residences within these settlements. Second, we use regression to derive equations that describe the statistical relationship between other urban quantities, primarily measured from maps and plans, and the estimated residence counts. The data are transformed to logarithms for this second step because regression is most appropriate for investigating relationships between normally distributed variables, and the distributions of most socio-economic measures only become normal after log transformation.[45] These results are then used to estimate the number of residential buildings at each site based on the value of the additional urban property (as is illustrated by FIG. 3). Five relationships between residential building counts and other urban quantities are considered here: 1) the inhabited area; 2) the area of *fora* or *agorai*; 3) the area of the street network; 4) the seating capacities of amphitheatres; and 5) the total width of gates.[46] The data for these analyses derive from previously published studies, and the compiled raw data file and R-script used for these analyses are included in the Supplementary Materials. The regression results are presented in TABLE 3, with the equations being set up so that in each case they seek to predict the total residential building count based on one of the independent variables.

TABLE 3. REGRESSION EQUATIONS USED TO ESTIMATE THE TOTAL RESIDENTIAL BUILDINGS AT SILCHESTER

Independent	**N**	**Intercept (SE)**	**Slope (SE)**	**R^2**	**Significance**
Forum area	80	–.4544 (.6860)	.9502 (.0822)	.6311	F = 133.4 (df = 1,78), P < 2.2e-16
Amphitheatre seating capacity	107	–1.8434 (1.2260)	.9696 (.1275)	.355	F = 57.79 (df = 1,105), P = 1.288e-11
Street area	80	–4.6808 .9136	1.0854 (.0817)	.6936	F = 176.5 (df = 1,78), P < 2.2e-16
Site area	50	2.3494 (.4020)	1.2757 (.0997)	.7733	F = 163.7 (df = 1,48), P < 2.2e-16
Total width of gates	26	3.0132 (.9324)	1.2675 (.2695)	.4796	22.12 (df = 1,24), P = 8.834e-05

All analyses are based on log transformed values. In all cases, the dependent variable is the private property count.

Notes on the measurement of additional urban properties are as follows. The size of the *fora* or *agorai* were measured as the area that is enclosed by the colonnades and adjacent buildings, ignoring both the area that was covered by these colonnades and the surrounding non-residential structures (this is particularly important in the case of *forum-basilica* complexes

45 Aitchinson and Brown 1957; Limpert *et al.* 2001, 341–52.
46 Hanson and Ortman 2017; Hanson *et al.* 2019; Hanson 2020; Hanson and Ortman 2020.

https://doi.org/10.1017/S0068113X23000375 Published online by Cambridge University Press

like the one at Silchester). The area of the street network was derived by digitising individual blocks, digitising the outline of the settlement, and subtracting the former from the latter. The seating capacity of an amphitheatre was estimated by multiplying the seating area, which was reduced by 10 per cent to account for access and services, by an average of 0.28 m^2 per person.[47] This suggests a seating capacity of around 9,190 individuals for the amphitheatre at Silchester, based on a seating area of about 2,859 m^2.[48] Finally, the total width of gates was estimated by multiplying the number of gates by the average width of the extant gates.

Before examining the application of these relationships to Silchester, it is worth emphasising that temporal relationships between civic features and residential properties vary, both by feature and across sites. At Silchester, for example, the *forum-basilica* complex was laid out as early as the 40s A.D. while the amphitheatre was built between A.D. 55 and 77. The initial street grid dates from the Claudio-Neronian period, but it was not completed until the Flavian period, A.D. 69–96. Finally, the town walls were constructed around A.D. 200 (and strengthened around A.D. 270) and contained a total of seven gates, along with a small postern gate.[49]

It is also important to note that the residential densities of settlements varied over time, but sufficient data for assessing temporal patterns in the residential densities of Roman cities are not yet available. As a result, the regressions in TABLE 3 assess relationships between residential buildings and other urban quantities during specific periods, or as long-term averages, even though this is an obvious simplification. To give just one example, Frere's excavations within Insulae XIV, XXVII and XXVIII at Verulamium cleared approximately 0.3 ha, and within this area he identified portions of 16 early timber buildings that were destroyed during the Boudiccan rebellion, 13 timber buildings from the Flavian rebuilding that were destroyed in the Antonine fire, and 11 stone masonry buildings dating from the late third and fourth centuries.[50] In addition, the total area of the town increased from around 50 to around 90 ha over time. These data suggest that over time the population density of Verulamium decreased, even if its overall population may have grown. We used the data for the later town in this study, and for most sites our data reflect the most visible, uppermost levels. But ideally one would want to stratify the information from each settlement into chronological periods.

Finally, we cannot systematically know whether the designers of civic structures sought to serve the population that was existing at the time, or an anticipated future population. These factors mean that, even if preservation and measurement of the present-day archaeological remains were perfect, there would still be errors in relationships between civic features and building counts at each site because in most cases we are measuring the final appearance of a site rather than its appearance at any given moment, or at the time of construction of a particular feature. We seek to overcome these issues by estimating overall scaling relationships and their associated statistical uncertainties across many sites, and by averaging results from multiple analyses to estimate residential building counts. Our expectation is that this approach will average out the many different types of inaccuracy and imprecision that are embedded in the data.

With these caveats in mind, we utilise the results in TABLE 3 to make a series of estimates for the total residential building count at Silchester. The individual estimates and overall result are shown in TABLE 4. The overall result involves averaging the five individual estimates to yield a point estimate of the residential structure count; and the confidence interval is calculated by taking the square root of the sum of squared standard errors divided by the number of estimates. Under normal circumstances, the appropriate method for combining multiple estimates of the same parameter would be to weight the estimates by their variances. However, we feel the

47 Golvin 1988; Millett 1990, table 5.1; Hanson and Ortman 2017.
48 Hanson and Ortman 2020.
49 Creighton and Fry 2016, table 17.1.
50 Frere 1972.

https://doi.org/10.1017/S0068113X23000375 Published online by Cambridge University Press

simple averaging is preferred in this case because we are working with confidence intervals rather than the prediction intervals, and we wish to count each estimate equally in the overall result. FIG. 4 illustrates the results graphically and shows the relationship between each individual estimate and the overall estimate, including its confidence interval.

The overall results, on the bottom rows of TABLE 4, suggest a good estimate for the total number of residences at Silchester is 1,115, with a 95 per cent confidence interval of 899 to 1,382. Recall that the Silchester mapping project found evidence of only 186 such residences, almost all of which had flint and mortar walls. This suggests that perhaps 83 per cent of all buildings that were present at Silchester during the later Roman period were made of timber. This is slightly less than the percentage of timber buildings in the excavated sample at Neatham (92 per cent), an adjacent small town.[51] Our results also suggest the overall population of Silchester during the later Roman period was about 5,500 persons, with a 95 per cent confidence interval of between 4,500 and 6,900 persons. These estimates are within the range of figures that have been suggested by earlier scholars (between 1,000 and 7,500) and close to the most likely value suggested by Boon (4,000), despite being derived in a very different way. These results also suggest a population density point estimate of about 130 persons per hectare over the 43 ha site area, with a 95 per cent confidence interval of between about 105 and 160 persons per hectare.

TABLE 4. ESTIMATION RESULTS

Independent	**Data source**	**Silchester value**	**Estimated total residential buildings**	**Lower Boundary (95% confidence)**	**Upper Boundary (95% confidence)**	**SE**
Forum area (m^2)	(Hanson *et al.* 2019)	7.499	6.672	6.459	6.885	0.107
Amphitheatre seating capacity (persons)	(Hanson and Ortman 2020)	9.126	7.005	6.789	7.222	0.109
Street area (m^2)	(Hanson *et al.* 2019)	10.822	7.066	6.925	7.206	0.071
Site Area (ha)	This study	3.761	7.147	6.988	7.307	0.079
Total width of gates (m)	(Hanson 2020)	3.296	7.191	6.862	7.520	0.159
Overall result			7.016	6.801	7.231	0.110
Inverse Log of result			1115	899	1382	

Unless otherwise noted, all values are logarithms. Data for the Area regression are from TABLE 2. All other data are from the cited sources.

DISCUSSION

The population density of a site has important implications for many aspects of ancient life, including the spread of disease, the balance of industrial and agricultural production, the economic draw of the town relative to the hinterland and the role of the site in the economy and governance of the surrounding territory. The size of the population, meanwhile, is obviously vital for understanding of the consumption and production of resources, the size of the market for hinterland produce and the relative sizes of elite and non-elite groups. At minimum, these results show that, if the residential density suggested by the current site plan is accurate, Silchester would represent an anomalously low-density town and should not be

[51] Millett and Graham 1986,151.

https://doi.org/10.1017/S0068113X23000375 Published online by Cambridge University Press

considered as a typical or canonical example of Romano-British urbanism. While it is possible that the reason greenfield sites like Silchester are not still inhabited is that they were poorly located or otherwise not very successful, we believe the accumulated evidence most strongly supports a scenario in which Silchester was not so unusual, and the current site plan under-represents the number of buildings that were once present.

Our point estimate of 5,500 persons for the population of Silchester is somewhat larger than Boon's estimate (4,000) and slightly lower than our previous estimate (6,800). It is also about twice that of Neatham (*c.* 3,000 people), about half that of Pompeii (*c.* 10,000), one two-hundredth of the size of the Imperial capital, Rome (*c.* one million) and miniscule by comparison with modern London.[52] One interesting feature of these results is that the population suggested by the size of the *forum* is much smaller than is the case for the other four measures. This suggests the *forum* is somewhat smaller than is typical for sites of similar size across the Empire. There are several possible explanations for this discrepancy. First, it may reflect a distinct function or use of the *forum-basilica* complex, here and perhaps at other Romano-British sites, relative to the more canonical *fora* elsewhere. Second, it may indicate that, when the *forum* was laid out in the first century, the architects did not expect the population of Silchester to grow as much as it did.

Finally, a third and perhaps more exciting possibility is that the observed difference in population estimates across urban features reflect an increasing population over time. Each of the relationships in TABLE 3 represents an overall, long-term average relationship between an urban quantity and an associated residential density. This means that the estimate of the residential buildings associated with a given urban quantity most likely reflects the situation in the settlement *the time the urban feature was constructed*. Given this, it may be significant that population estimates derived from different urban features are positively correlated with their construction dates. The inner earthwork of the Late Iron Age oppidum was about 25 per cent smaller than the area enclosed by the later Roman defences.[53] In addition, the *forum* and amphitheatre, which are associated with the two smallest population estimates, were laid out shortly after the Roman conquest; the Roman street grid, associated with a somewhat larger estimate, was completed around the end of the first century; and the walled area and gates, associated with the largest estimates, were constructed around A.D. 200. This pattern is reinforced by FIG. 4, where the residential building estimates are arranged from smallest to largest. Although we do not pursue this line of inquiry further here, the prospect of tracing the demographic histories of Roman cities by incorporating construction dates of urban features into the analysis is an exciting prospect, and it would be very interesting to perform such an analysis across a broader sample of sites and assess the plausibility of the results.

Our finding that the residences displayed on the current site plan (FIG. 1) represent as few as 17 per cent of the total residences that were once present suggests that most of the 'missing' residences must be quite small, and many of them must not have had frontage along the major streets, instead having doorways along alleys or other less formal paths within the *insulae*. If our results are reasonably accurate, most of the residents of Silchester would have lived in much smaller houses than the major courtyard residences. The area taken up by all identified structures and streets in the current site plan is about 22 ha. This means the 'missing' 929 or so structures would need to fit within the remaining area of 21 ha, implying an average an area of about 225 square metres per residence.[54] By contrast, the average area of the 186 documented residential properties is 480 square metres (including interior courtyards), more than twice the suggested average of the 'missing' properties.

52 Millett and Graham 1986, 151; Hanson and Ortman 2017, 311.
53 Creighton and Fry 2016, 304.
54 This is comparable to the mean area of the strip buildings (182 m^2) shown on the current site plan.

https://doi.org/10.1017/S0068113X23000375 Published online by Cambridge University Press

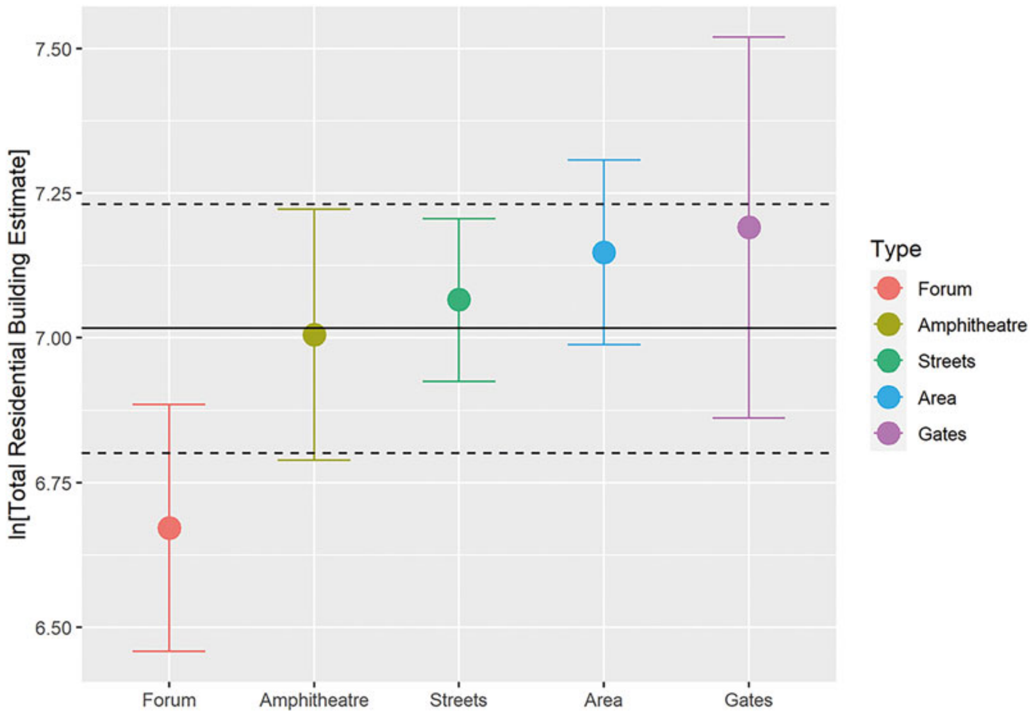

FIG. 4. Visual summary of estimates for the total structure count at Silchester. The overall point estimate is indicated by the solid black line, and the 95% confidence interval is denoted by the dashed lines. The estimates are listed in ascending order and show a rough correspondence with the construction dates of the associated features.

The implications of this scenario for patterns of inequality are interesting. Recent studies have suggested that house sizes provide a reasonable means of investigating household inequality and archaeologists have increasingly used a measure known as the Gini coefficient, which represents the deviation of a distribution from perfect equality, to compare levels of material inequality across contexts.[55] The Gini coefficient of the distribution of documented house areas at Silchester is 0.51, similar to the value calculated from measured house areas at Pompeii.[56] However, if 929 houses of 225 m^2 each are added to the list of residential properties in the calculation, the Gini coefficient drops to 0.18. This is surely an underestimate, as the areas of the 'missing' residences were not all equivalent in size, but this calculation does show that adding many small houses to the previously documented houses could reduce the Gini coefficient, thus suggesting a less unequal distribution than is suggested by the stone masonry structures on their own. On the other hand, the labour investment and value per square metre of stone masonry structures, with mosaic floors and hypocausts, must have been much higher than that of the 'missing' timber structures. So even if adding in the missing timber structures reduces the apparent level of inequality with respect to house area per person, the differences in quality and value of houses per square metre suggested by this exercise would still increase it to some extent. Nevertheless, this exercise illustrates the importance of measuring the distributions of properties across

55 Smith *et al.* 2014; Kohler *et al.* 2017; Kohler and Smith 2018.
56 Kohler *et al.* 2017; Flohr 2017. Flohr suggests a Gini coefficient of 0.62 for Pompeii.

https://doi.org/10.1017/S0068113X23000375 Published online by Cambridge University Press

representative samples of households if one wishes to study patterns of inequality in the Roman world, and this requires awareness of the biases in the available evidence.

Finally, we note that a similar approach can be applied to any site for which the relevant aggregate measures are available. A good candidate would be Wroxeter (*Viroconium*), an additional greenfield site in Shropshire. The recent Wroxeter Hinterland Project combined the same types of evidence as the Silchester Mapping Project to produce an atlas that, in the authors' words, 'offers the most complete survey of a Romano-British town currently available'.[57] The authors of this report further explain, 'One of the more important aspects of Wroxeter is the unparalleled clarity with which one can see, and interpret, the whole urban form and its topography. This is most unusual in a Romano-British town and very few can be studied in this way.'[58] Yet, when it comes to demographic reconstruction, the authors lament several of the same issues that have been discussed here with respect to Silchester:

> In considering this evidence it is worth commenting that the numbers of buildings visible in the aerial photographic and geophysical surveys are likely to be much lower than actually existed. We are seeing a palimpsest of phase and thus cannot know what buildings in any given *insulae* stood with those visible in the plot. Equally there may be many others that we simply can't see . . . Thus the total shown in Table 4.1 are just a guide, an idea of how many buildings we think we can see. Given these caveats, it would be misleading to even begin to guess population levels. For this we would point instead to Helen Goodchild's calculations presented in the first volume which give some idea of the population levels that could be supported from the produce of the hinterland.[59]

The suggestion that aerial survey and geophysical prospection identified only a small portion of the residences that were once inhabited is reinforced by the tabulation in their table 4.1, which identifies only 240 non-civic buildings within the defended area of 82 ha. This translates into a density of about 15 persons per hectare. This is comparable to the figure of 22 persons per hectare suggested by the visible structures at Silchester and is substantially lower than the point estimate of 130 persons per hectare that we estimate here. Based on these similarities, we suggest that, if comparable measurements were available, the estimated population density of Wroxeter would also be much higher, and closer to our estimate for Silchester.

CONCLUSIONS

In this paper we have reviewed previous efforts to estimate the population of Silchester and noted that the primary difficulty with such efforts has been the inability to see relatively perishable timber buildings, which can be revealed through modern excavation techniques, in aerial photography and geophysical survey. We have suggested an alternative approach that builds from the strong scaling relationships previously observed between structure densities in cleared areas and total settlement areas, street areas, *forum* areas, amphitheatre areas and city gate widths, in cities across Britannia and the larger ancient world. We evaluated each of these statistical relationships for the corresponding value at Silchester, and averaged the five results together, to produce an overall point estimate and confidence interval for the total private property count based on multiple lines of evidence. This exercise showed that the residential structures depicted on the current site map, which were identified through antiquarian

57 White *et al.* 2013, 2.
58 White *et al.* 2013, 185.
59 White *et al.* 2013, 187.

https://doi.org/10.1017/S0068113X23000375 Published online by Cambridge University Press

trenching, aerial photo interpretation and geophysical survey, likely represent only about 17 per cent of the residences that were once present at the site.

This analysis increases the estimated total residential property count from 186 to 1,115; increases the estimated population density from 22 to 130 persons per hectare; and increases the estimated total population from 930 to 5,500 persons. These results have several implications. First, they suggest that, even in greenfield sites, aerial photography and geophysical survey are inadequate for recovering a complete plan of residences. Second, they suggest that Romano-British towns were not relatively empty, low-density settlements, but were instead more typical of cities found across the Empire, at least with respect to relationships among their residential populations, densities, and other urban features. Third, they suggest that, even during the later Roman Period, most private properties in Romano-British towns were constructed of timber, earth and other perishable materials, and lacked the stone or crushed-tile floors and hypocausts that would be expected to show up in geophysical survey. Overall, they show that the picture emanating from surface studies of greenfield sites is strongly biased relative to the results of modern excavation, which are ironically more prevalent in still occupied urban centres where commercial, developer-funded archaeology is more frequent. As such, site plans of greenfield sites like Silchester, valuable as they are, should not be taken as accurate indications of what the interior of a typical Romano-British town looked like. Based on our results, it appears that their interiors were much more densely built, and contained a far larger number of small properties, than are apparent from recent surface studies.

The nonlinear scaling relationships we leveraged in this paper were initially defined to test the degree to which ancient cities express the same scaling relationships observed in contemporary urban systems.[60] Here, we utilised these empirically derived relationships to expand the interpretation of a specific site, based on the assumption that Silchester was typical in the context of other Roman towns. Our results suggest the current site plan for Silchester does not reflect the residential density of a typical Roman town of its size, and that the interior spaces on the current plan contain a large number of relatively small residences that were not identified through antiquarian trenching and are not visible in aerial photography or geophysical survey. We suggest this approach could be applied to other sites and improved as knowledge of cities across the Empire improves to provide more defensible estimates of the resident populations of urban settlements, regardless of their degree of visibility on the modern ground surface. It may also be possible to incorporate construction dates for urban features into the analysis to add a temporal dimension to such estimates. In this way, a more systematic and empirically justified picture of patterns of urbanism in Britannia and across the Roman world may begin to emerge.

ACKNOWLEDGEMENTS

Portions of this research were supported by a fellowship from the British Academy and a grant from the James S. McDonnell Foundation. We thank the investigators of the Silchester Mapping Project for making their raw data files available through the Archaeology Data Service, and we thank Rob Wiseman, Lisa Lodwick and Neil Holbrook for discussions. Finally, we thank two anonymous reviewers for their helpful comments on an earlier draft.

University of Colorado Boulder (S.G.O.)
scott.ortman@colorado.edu

60 Hanson *et al.* 2019; Lobo *et al.* 2020; Ortman *et al.* 2020.

University of Oxford (J.W.H.)
john.hanson@classics.ox.ac.uk

SUPPLEMENTARY MATERIAL

For supplementary materials for this article, please visit https://doi.org/10.1017/S0068113X23000375.

BIBLIOGRAPHY

Aitchinson, J., and Brown, J.A.C. 1957: *The Log Normal Distribution*, New York.
Angel, S., Blei, A.M., Parent, J., Lamson-Hall, P., Galarza, N., Civco, D.L., Lei, R.Q., and Thom, K. 2016: *Atlas of Urban Expansion: 2016 Edition Volume 1: Areas and Densities*, New York.
Bagnall, R.S., and Frier, B.W. 1994: *The Demography of Roman Egypt*, Cambridge.
Banerjea, R.Y., Fulford, M., Bell, M., Clarke, A., and Matthews, W. 2015: 'Using experimental archaeology and micromorphology to reconstruct timber-framed buildings from Roman Silchester: a new approach', *Antiquity* 89, 1174–88.
Barker, P., White, R., Pretty, K., Burd, H., and Corbishley, M. 1997: *The Baths Basilica Wroxeter: Excavations 1966–90*, London.
Boon, G.C. 1957: *Roman Silchester: The Archaeology of a Romano-British Town*, London.
Boon, G.C. 1974: *Silchester: The Roman Town of Calleva*, London.
Bowden, W. 2018: Urban geophysical survey and changing interpretations of Silchester, *Journal of Roman Archaeology* 31, 823–6.
Chamberlain, A. 2006: *Demography in Archaeology*, Cambridge.
Connor, A., and Buckley, R. 1999: *Roman and Medieval Occupation in Causeway Lane, Leicester*, Leicester.
Creighton, J., and Fry, R. 2016: *Silchester: Changing Visions of a Roman Town*, Britannia Monograph 28, London.
Duranton, G., and Puga, D. 2004: 'Micro-foundation of urban agglomeration economies', in J.V. Henderson and J.-F. Thisse (eds), *Handbook of Regional and Urban Economics*, Amsterdam, 2064–117.
Ellis, P. 2000: *The Roman Baths and Macellum at Wroxeter: Excavations by Graham Webster, 1955–85*, London.
Flohr, M. 2017: 'Quantifying Pompeii: population, inequality, and the urban economy', in M. Flohr and A.I. Wilson (eds), *The Economy of Pompeii*, Oxford, 56–64.
Frere, S. 1972: *Verulamium Excavations, Volume I*, London.
Fulford, M. 1984: *Silchester: Excavations on the Defences 1974–1980*, Britannia Monograph 5, London.
Fulford, M., and Clarke, A. 2011: *Silchester: City in Transition. The Mid-Roman Occupation of Insula IX c. AD 125-250/300. A Report on Excavations Undertaken since 1997*, London.
Fulford, M., Clarke, A., and Eckardt, H. 2006: *Life and Labour in Late Roman Silchester: Excavations in Insula IX since 1997*, Britannia Monograph 22, London.
Fulford, M., Lodwick, L., and Smith, A. 2018: *Defended Small Towns of Roman Britain* [*data-set*], https://doi.org/10.5284/1046751 (accessed 1 November 2021).
Gascoyne, A., and Radford, D. 2013: *Colchester, Fortress of the War God: An Archaeological Assessment*, Oxford.
Golvin, J.-C. 1988: *L'amphithéâtre romain: Essai sur la théorisation de sa forme et de ses fonctions*, Paris.
Gossip, J. 1999: *Excavations at Republic Car Park Oxford Street, Leicester*, Leicester, https://doi.org/10.5284/1023642 (accessed 1 November 2021).
Hansen, M. 2006: *The Shotgun Method: The Demography of the Ancient Greek City-state Culture*, Columbia, MO.
Hansen, M. 2008: 'An update on the shotgun method', *Greek, Roman, and Byzantine Studies* 48, 259–86.
Hanson, J.W. 2016: *An Urban Geography of the Roman World, 100 B.C. to A.D. 300*, Oxford.
Hanson, J.W. 2020: 'Using city gates as a means of estimating ancient traffic flows', *PLoS One* 15, e0229580.

Hanson, J.W. 2021: 'Cities, information, and the epigraphic habit: re-evaluating the links between the numbers of inscriptions and the sizes of sites', *Journal of Urban Archaeology* 4, 137–52.
Hanson, J.W., and Ortman, S.G. 2017: 'A systematic method for estimating the populations of Greek and Roman settlements', *Journal of Roman Archaeology* 30, 301–24.
Hanson, J.W., and Ortman, S.G. 2020: 'Reassessing the capacities of entertainment structures in the Roman Empire', *American Journal of Archaeology* 124, 417–40.
Hanson, J.W., S.G. Ortman, L.M.B. Bettencourt and L.C. Mazur 2019: 'Urban form, infrastructure and spatial organization in the Roman Empire', *Antiquity* 93, 702–18.
Hassan, F.A. 1981: *Demographic Archaeology*, New York.
Holbrook, N. 1998: *Cirencester: The Roman Town Defences, Public Buildings and Shops*, Cirencester Excavations 5, Cirencester.
Huebner, S. 2013: *The Family in Roman Egypt: A Comparative Approach to Inergenerational Solidarity and Conflict*, Cambridge.
Kennedy, D. 2006: 'Demography, the population of Syria, and the census of Q. Aemilius Secundus', *Levant* 38, 109–24.
Kohler, T.A., and Smith, M.E. (eds) 2018: *Ten Thousand Years of Inequality: The Archaeology of Wealth Differences*, Tucson.
Kohler, T.A., Smith, M.E., Bogaard, A., Feinman, G.M., Peterson, C.E., Betzenhauser, A., Pailes, M., Stone, E.C., Prentiss, A.M., Dennehy, T.J., Ellyson, L.J., Nicholas, L.M., Faulseit, R.K., Styring, A., Whitlam, J., Fochesato, M., Foor, T.A., and Bowles, S. 2017: 'Greater post-Neolithic wealth disparities in Eurasia than in North and Mesoamerica', *Nature* 551, 619–22.
Kranzler, J.H. 2017: *Statistics for the Terrified*, 6th edn, Lanham, MD.
Limpert, E., Stahel, W.A., & Abbt, M. 2001: 'Log-normal distributions across the sciences: keys and clues', *BioScience* 51.5, 341–52.
Lobo, J., Bettencourt, L.M.A., Ortman, S.G., and Smith, M.E. 2020: 'Settlement scaling theory: bridging the study of ancient and contemporary urban systems', *Urban Studies* 57, 731–47.
Mattingly, D. 2006: *An Imperial Possession: Britain in the Roman Empire*, London.
McEvedy, C. 2011: *Cities of the Classical World: An Atlas and Gazetteer of 120 Centres of Ancient Civilization*, London.
McWhirr, A. 1986: *Houses in Roman Cirencester*, Cirencester Excavations 3, Cirencester.
Millett, M. 1990: *The Romanization of Britain: An Essay in Archaeological Interpretation*, Cambridge.
Millett, M., and Graham, D. 1986: *Excavations on the Romano-British Small Town at Neatham, Hampshire, 1969–1979*, Gloucester.
Ortman, S.G., Smith, M.E., Lobo, J., and Bettencourt, L.M.A. 2020: 'Why archaeology is necessary for a theory of urbanization', *Journal of Urban Archaeology* 1, 151–67.
Perring, D., and Pitts, M. 2013: *Alien Cities: Consumption and the Origins of Urbanism in Roman Britain*, Spoilheap Monograph 7, Portslade.
Pitts, M. 2016: 'Rural transformation in the urbanized landscape', in M. Millett, L. Revell and A. Moore (eds), *The Oxford Handbook of Roman Britain*, Oxford, 720–40.
Rippon, S., and Holbrook, N. 2021: *Studies in the Roman and Medieval Archaeology of Exeter*, Exeter: A Place In Time 2, Oxford.
Russel, J.C. 1958: 'Late ancient and medieval population', *Transactions of the American Philosophical Society* 48.3, 1–152.
Scheidel, W. 2007: 'Demography', in W. Scheidel, I. Morris, and R. Saller (eds), *The Cambridge Economic History of the Greco-Roman World*, Cambridge, 38–86.
Score, V. 2006: *Archaeological Excavations at 72, St. Nicholas Circle, Leicester*, Leicester, https://doi.org/10.5284/1003984 (accessed 1 November 2021).
Smith, J.T. 1997: *Roman Villas: A Study in Social Structure*, London.
Smith, M.E., Dennehy, T., Kamp-Whittaker, A., Colon, E., and Harkness, E. 2014: 'Quantitative measures of wealth inequality in ancient Central Mexican communities', *Advances in Archaeological Practice* 2, 311–23.
Storey, G.R. 1997: 'The population of ancient Rome', *Antiquity* 71, 966–78.
Thomas, J. 2005: *An Archaeological Evaluation on land at 52, Grange Lane, Castle Ward, Leicester*, Leicester, https://doi.org/10.5284/1006525 (accessed 1 November 2021).
Wacher, J.S. 1995: *The Towns of Roman Britain*, London.

White, R.H., Gaffney, C., and Gaffney, V.L. 2013: *Wroxeter, The Cornovii and the Urban Process: Final Report on the Wroxeter Hinterland Project 1994–1997. Volume 2: Characterizing the City*, Oxford.
Wilson, A.I. 2011: 'City sizes and urbanization in the Roman Empire', in A.K. Bowman and A.I. Wilson (eds), *Settlement, Urbanization, and Population*, Oxford, 161–95.
Wirth, L. 1938: 'Urbanism as a way of life', *American Journal of Sociology* 44, 1–24.
Wolf, A.P. 1984: 'Family life and the life cycle in rural China', in R. Netting, R. Wilk, and E. Arnould (eds), *Households: Comparative and Historical Studies of the Domestic Group*, Berkeley, 279–98.