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New approaches to the architectural design, amenities, and function of *macella*: typologies, scale, and the Macellum Magnum

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Abstract: In recent years, scholars have drawn particular attention to the existence in the ancient world of permanent, specialized market buildings, *macella* or *μάκελλοι*, which offered dedicated facilities for the processing and sale of luxury commodities such as fish and meat. However, important questions remain about the typologies, architecture, and "end-users" of these structures. Here, I outline a basic model for how the total and average wealth and traffic of settlements increases with estimated populations, before exploring the relationships between the total footprints and wider architectural characteristics of *macella* and estimated populations of sites. This reveals that there is a series of relationships between these measures that are not only consistent with wider theoretical and empirical expectations, but also have the potential to alter dramatically our understanding of *macella* by revealing the connections between the sizes and capacities of these structures and the wealth, connectivity, and integration of settlements.

Keywords: Markets, *macella*, urbanism, architecture, scale, Roman Empire

Introduction

In recent years, scholars have drawn our attention to the existence and apparently wide geographical and chronological spread of permanent, specialized market buildings, known as *macella* or *μάκελλοι*, in ancient cities, which offered dedicated facilities for the processing and sale of perishable, edible commodities such as fish and meat.[1] These structures should therefore be a useful proxy for the social and economic conditions of settlements, including both the average wealth and the overall levels of disposable income of their inhabitants, given that we would generally expect the most perishable commodities to be the most expensive, as well as for how well connected and integrated the settlements were, since most of these commodities were usually sourced from further afield.

There are still a number of important issues surrounding *macella* that are unresolved. First, although there has been a great deal of discussion of their architectural design and layout, there is still a significant amount of debate about the extent to which they should be regarded as conforming to a consistent typology of buildings and the degree to which any such typology varied over space and time.[2] Second, although various attempts, which now date back over several hundred years, have been made to reconstruct the Macellum Magnum in Rome on the basis of the *Forma Urbis* and coinage, this structure has never been found. This means that it is virtually impossible to gauge how reliable our current assessment of it is, despite its obvious importance for understanding the development of Nero's building program in Rome and the evolution of commercial architecture in the capital and elsewhere in the Imperial period. Third, although there has recently been

1 Richard 2014.

2 Richard 2014; Hoffelinck 2020.

more interest in how these buildings might have functioned, it has largely focused on their internal organization and accessibility within the built environment. There has been less interest in whether there is any relationship between the sizes of structures and the sizes of sites, or in how large or small a fraction of the community they were intended to serve, perhaps because of the absence of reliable estimates of the populations of ancient cities, at least until recently.

This paper therefore has four aims. The first is to test these ideas by exploring the relationship between the total footprints and the wider architectural features of *macella*, including the sizes of their courtyards and the numbers and average sizes of the units found within them, and the estimated populations of sites. These characteristics of *macella* can then be used as a proxy for the capacities of these structures, allowing us to consider how the overall level of supply and demand changed as settlements increased or decreased in size. The second aim is to use these results to reflect on the nature of the typology of *macella*, given that we would only anticipate a relationship between the sizes of sites and the sizes of structures consistent with the expectations discussed below if we are dealing with more-or-less the same type of structure. This relationship can then be used to assess how plausible the current estimates of the size of the Macellum Magnum are, since it allows us not only to make a simple prediction about how large a structure would be appropriate to a settlement of the capital's size, which can then be compared against existing reconstructions, but also to assess to what extent different propositions are outliers, potentially allowing us to identify the most likely candidate. A similar line of reasoning can be used to evaluate how anomalous other buildings are, including those in Perge and Side. Finally, this paper will explore the relationship between *macella* and various measures of connectivity and integration, using the ORBIS dataset of the sea, river, and road networks of the ancient world.

I will begin by outlining a model for how we would expect both the total and the average wealth of settlements and both the total and the average amount of traffic that flowed to and from them to increase with their estimated populations, before offering a brief review of the current understandings about *macella* in general and the Macellum Magnum in particular, since they are comparatively poorly known. I then use a combination of information from existing sources, such as Hoffelinck's catalogue of *macella*, and available maps or plans of *macella* to explore the relationships between their total footprints and the other architectural features listed above and the estimated populations of sites, before assessing the extent of the variation within the relationship and commenting on the outliers. I then use the results of previous work to explore the relationship between the sizes of these structures and their wider network potential. The results reveal that there is a relationship not only between the footprints of these structures and the estimated populations of the sites in which they were found, but also between the sizes of their courtyards and the numbers and average sizes of the shops within them, which are all entirely consistent with wider theoretical and empirical expectations.[3] The results also show that there is a series of broad relationships between the estimated populations of sites and the network values discussed above, and between the total footprints of *macella* and the same metrics for network potential. These results are then used to comment more broadly on the diets of the inhabitants of settlements, the overall standard of living and quality of

[3] Lobo et al. 2020.

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life within urban contexts, the extent of specialization, and the nature of euergetism. Finally, I explore the meaning of the deviations from the overall relationship between the footprints of *macella* and the estimated populations of sites, focusing on the Macellum Magnum and other problematic cases, such as the structures at Perge, Side, and Pompeiopolis.

Settlement scaling theory

In recent times, there has been a great deal of interest in the effects of the sizes of communities on urban life, leading to the creation of a series of general models for how the diverse attributes of settlements vary, or scale, with their populations.[4] These are based on the observation that there is a set of relationships between the infrastructure and the social and economic outputs of settlements and their populations that not only tend to have the same, or similar, slopes or exponents, but also tend not to be linear.[5] In particular, infrastructure tends to increase a little slower than population, with exponents of either about 5/6 or 2/3, depending on context, while social and economic measures tend to increase a little faster, with exponents of either about 7/6 or 4/3, again depending on context. This has been explained by the fact that settlements concentrate people in space and time, increasing their opportunities to share both resources and information.[6] This has led to the formulation of a series of formal, that is, mathematical, models that predict the values for individual cities surprisingly well. These models are based on the twin ideas that, first, settlements can be conceived of as social networks embedded within the built environment and, second, the inhabitants of cities must balance the benefits of interacting with others with the costs of moving around the built environment. An important aspect of these models, however, is that they are meant to be very general and have not been designed to be tailored to specific conditions. This means that they should be applicable to both urban and rural areas and to both ancient and modern contexts, including the Greek and Roman world.[7] As Ortman and I have shown in a number of papers, this is something that is now very well borne out by the available evidence.[8] In particular, this research has shown that there is a consistent relationship not only between the inhabited areas, densities, and populations of ancient settlements, but also between the sizes and dimensions of public spaces and the street network and the footprints and capacities of some of the most important types of monumental buildings, including basilicas, theaters, amphitheaters, and circuses, while ongoing work by the author and others is examining the remainder.[9]

Although the exact logic behind how these models are derived is too complex to review here, it is based on the idea that it is possible to come up with a series of models of the relationships between the infrastructure and social and economic outputs of settlements

4 Hanson 2023.

5 Bettencourt and West 2010; West 2017; Smith 2019; Lobo et al. 2020.

6 Bettencourt 2013; Smith 2019; Lobo et al. 2020.

7 Smith 2019.

8 Hanson and Ortman 2017; Hanson et al. 2017; Hanson et al. 2019; Hanson 2020; Hanson and Ortman 2020; Hanson 2021; Hanson 2022; Ortman and Hanson 2023.

9 Hanson and Ortman 2017; Hanson et al. 2019; Hanson 2020; Hanson and Ortman 2020; Hanson 2023.

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and their estimated populations by considering how the social networks of settlements change as they increase in size, assuming they are embedded within the built environment.[10] This leads to a relatively simple model for the relationship between the numbers of social contacts and the populations of sites, which is as follows: $K = k_0 N^{1+\delta}$, where K is the total number of social contacts, N is the population, k_0 is a constant (i.e., the baseline number of social contacts), and δ is an exponent, which is equal to about either 1/3 or 1/6. It is then possible to express this in terms of the average number of social contacts per person by dividing both sides by the population.[11] This gives: $k = k_0 N^{\delta}$, where k is the average number of social contacts per person and the other terms are as above. These models suggest that the total numbers of social interactions will increase faster than the population, while the average numbers of social interactions per person will also increase, but at a slower rate.

As Lobo et al. have noted, however, since we would also expect the total social and economic outputs of each settlement, including both the total amount of wealth that they generated and the total amount of traffic that flowed into and out of them, to be proportional to the total number of social interactions that occur within them, it is also possible to suggest a model for the social and economic outputs of each settlement by simply substituting the term for the total numbers of social contacts with one for the total social and economic output of each settlement.[12] This gives: $Y = y_0 N^{1+\delta}$, where Y is the total social and economic output of each settlement, N is the population, y_0 is a constant (i.e., the baseline social and economic output), and δ is an exponent, which is equal to about either 1/3 or 1/6. Finally, this model can then be adapted to represent the average social and economic output per person. This gives: $y = y_0 N^{\delta}$, where y is the average social and economic output per person and all the other terms are as above. This model therefore suggests that the total social and economic outputs of settlements will increase faster than their population, while average socio-economic outputs *per capita* will also increase, but at a slower rate. This, in turn, suggests that the total social and economic outputs of settlements will exhibit increasing returns to scale, since larger settlements will be more productive *per capita*. This suggests not only that we would expect the population of sites to be the most important factor behind their infrastructure and socio-economic conditions, and for the largest sites both to have had the largest disposable income and to have been the most well connected, but also that we would expect all three of these variables to be strongly related, meaning that the generation of wealth and the creation of external linkages are really two sides of the same coin (and probably mutually reinforcing). This means that we would expect both the total and average wealth associated with settlements and the total and average amount of traffic that flowed into and out of them to have increased at the same rate of approximately 4/3 and 1/3 in each case. We would expect them to be so interrelated as to be theoretically and empirically indistinguishable, so that one could even be used as a proxy for the other.

These theoretical models and empirical results therefore allow us to frame a number of specific hypotheses for how we would expect the sizes and capacities of *macella* to increase with population. In particular, although we would expect these structures to increase at the

10 Lobo et al. 2020.

11 For a full explanation of how these models are derived, see Lobo et al. 2020.

12 Lobo et al. 2020.

same rate, with an exponent of about 1, if they were simply a utility that was available to all, we would expect them to increase a little more slowly, with an exponent of about 2/3, if they were a form of infrastructure, a little more quickly, with an exponent of 4/3, if they were a reflection of the total amount of wealth or traffic associated with settlements, but very slowly, with an exponent of about 1/3, if they were a product of either the average amount of wealth of the inhabitants of settlements or the average amount of traffic flowing into and out of these sites. There is no reason to associate them with the percolation of information from an initial group of witnesses to the rest of the community, though, as has been done with theaters and amphitheaters, given that there is no evidence that they were ever designed to have a similar function to entertainment structures.[13]

Finally, this approach also gives us a powerful way of thinking about settlements, since it allows us not only to assess how the various aspects of settlements changed as they increased or decreased in size, but also to examine the extent to which individual sites deviate from the overall relationship (measures known as residuals).[14] This might then be taken as a reflection of meaningful differences between the socio-economic conditions of sites once their sizes have been taken into account (known as scale-adjusted metropolitan indicators). In other words, although we would expect the overall relationship to be driven by differences in the sizes of sites, we would also expect there to be a certain amount of variation between sites as a result of local conditions such as resource endowments, agricultural potential, and sea, river, and road connections.

It is important to point out, however, that, although we now have good evidence that the infrastructure of ancient sites generally increased at a similar rate to other ancient contexts, such that these relationships can then be used as a proxy for wider social and economic conditions, there is so far very little direct evidence for a relationship between either the network potential or the wealth of sites and their estimated populations. As I have shown elsewhere, this is best exemplified by the fact that the total areas of public spaces, such as *fora* and *agorai*, and street networks increased a little more slowly than the estimated populations of cities, at the rate of about 2/3 in both cases, while the total widths of city gates increased even more slowly than these, at the rate of about 1/3.[15] Since the latter can be used as a proxy for the average amount of traffic that was flowing in and out of cities, we would expect the total amount of traffic that passed through them to have increased a little faster than the estimated populations of cities, at a rate closer to 4/3. Despite this, however, it is not possible to find an equivalent relationship between the sizes of sites and various basic network measures, such as degree centrality, betweenness centrality, etc., derived from the ORBIS network dataset.[16] The most likely explanation is that, although the dataset is sufficiently broad to allow us to estimate the overall costs in terms of distance, time, and energy of moving between different parts of the ancient world, it is not sufficiently detailed to allow us to calculate the network values of more than a handful of the most well-known individual sites.[17] Finally, as I have also noted elsewhere, there is only a limited amount of evidence that can be used as a proxy for the wealth

13 Hanson and Ortman 2020.

14 Hanson 2023.

15 Hanson et al. 2017; Hanson 2020.

16 Hanson 2020.

17 Hanson 2020.

of settlements, at least on an imperial scale, and that can be used in a way that is comparable to other contexts, in part because of the ways that ceramic evidence has traditionally been recorded.[18]

Macella

The structures with which we are concerned here, *macella* or *μάκελλοι*, are generally regarded as providing permanent, specialized market buildings for the processing and selling of high-status commodities such as fish, meat, etc., given not only their location within the built environment, but also their architectural design and layout, accessibility, the attention that seems to have been paid to hygiene, the equipment related to commercial activities, and the evidence for the control and regulation of the prices, quality, and quantities of the commodities that were sold within them.[19] The ultimate reason for building these structures therefore seems to have been that they provided the appropriate conditions for the sale of perishable commodities and made it easier to guarantee their freshness, control their quality and quantities, and regulate their prices by bringing the foodstuffs together into a single, enclosed, space. According to Goodman, these structures should consequently be seen as a form of specialization, given that they also represent a conscious desire to devote a space to a particular kind of economic activity.[20] The development of these structures should be seen against the wider backdrop of the development of shops and workshops used for the sale or manufacture of specific commodities, such as bars and bakeries.[21] They can therefore be regarded as being closely associated with the wealth of the inhabitants of the settlements they are found within, since they seem to have been devoted to selling highly perishable and, accordingly, more expensive commodities. Although some have been hesitant about drawing any direct parallels between the sizes of these structures and the wealth of settlements, recent work suggests that there is a link between the apparent prosperity of sites, largely based on measures such as their monumentality and domestic architecture, and the incidence of *macella*.[22] As Richard has noted, for example, "*macella* were a popular amenity in many well-to-do urban centers of the Roman world."[23] It is less clear, however, whether we would expect these structures to be a reflection of the total wealth of settlements or the average wealth of their inhabitants (and thus whether they are an aggregate or *per capita* measure).

Although these structures have come to greater prominence in recent years, they are still understudied, especially compared to other types of buildings such as theaters and amphitheaters. Although the most well-known study of their numbers, locations, dates, and architectural designs and layouts is still De Ruyt's Macellum: *marché alimentaire des romains*, important work has also been done more recently by Richard and Hoffelinck.[24] The former's work has mainly concentrated on the issues related to defining and identifying the structures and their architectural forms and amenities, paying particular attention

18 Hanson 2023.

19 Nabers 1967; De Ruyt 1983; De Ruyt 2007; Holleran 2012; Richard 2014; Hoffelinck 2020.

20 Goodman 2016, 322.

21 Ellis 2018.

22 Richard 2014.

23 Richard 2014, 255.

24 De Ruyt 1983; Richard 2014; Hoffelinck 2020; Hoffelinck 2021; Hoffelinck and Vermeulen 2021.

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to the East. Meanwhile, although the latter's work has provided an updated version of De Ruyt's catalogue, which is used below, it has also mainly focused on using various methods to investigate the locations of *macella* in the built environment and, in particular, on understanding how consumers gained access to them and how commodities were transported to them. This has included looking at the relationship between *macella* and other features such as street networks, city gates, harbors, and public buildings, as well as using space syntax to investigate the links between *macella* and the streets that were most likely to have carried the greatest traffic. The reasons for the sizes and capacities of structures are therefore still poorly understood.

At the same time, there has also been significant debate about the extent to which *macella* can be regarded as being part of a consistent typology of buildings, while some scholars have raised doubts about whether the category even exists.[25] As Richard has noted, there are generally two different approaches to this issue, which relate to the two main categories of evidence available.[26] The first comprises a small group of structures that are explicitly referred to as a *macellum* or *μάκελλον* in inscriptions, such as the Macellum Magnum and the structure at Perge, while the second is a much larger group of structures that have the same architectural characteristics and amenities as others that have conventionally been regarded as *macella*, meaning that they can be identified as *macella* on purely architectural grounds.[27] A certain amount of caution is required here, though, because the ancient references to *macella* may refer to the kinds of activities that took place within these structures, rather than the structures themselves, undermining their value for creating architectural typologies. The most useful approach has therefore been to focus on the architectural design and amenities of structures in the attempt to identify a common type of building, perhaps based on Roman and Italian prototypes, which had the same features and thus probably the same function, although it is obviously important to be aware of the scale of the regional and chronological differences between structures, especially between East and West (Fig. 1).[28] The most characteristic features are usually regarded as being a central courtyard surrounded by ranges of smaller rooms, accompanied by a central columnar monument, or *tholos*.[29] A fuller and more detailed list might include an enclosed, self-contained layout, a central courtyard, suites of equally or nearly equally sized, closable, and either inwards- or outwards-facing rooms, and a *tholos* that was generally proportional to the overall size of the structure, along with paved surfaces and colonnades, thresholds that restricted access to pedestrians, facilities for the processing of fish and meat, and a method of providing water, creating a relatively specialized, restricted, and hygienic environment.[30]

These structures are natural candidates for the scaling analysis advocated in this article and provide an excellent opportunity to test theoretical models against empirical data and explore their potential for understanding structures. As we will see below, although it is necessary to expend some effort on collecting evidence for the dimensions of *macella*

25 Nabers 1973; Richard 2014.

26 Richard 2014.

27 Richard 2014.

28 Richard 2014.

29 De Ruyt 1983; Richard 2014.

30 Richard 2014.

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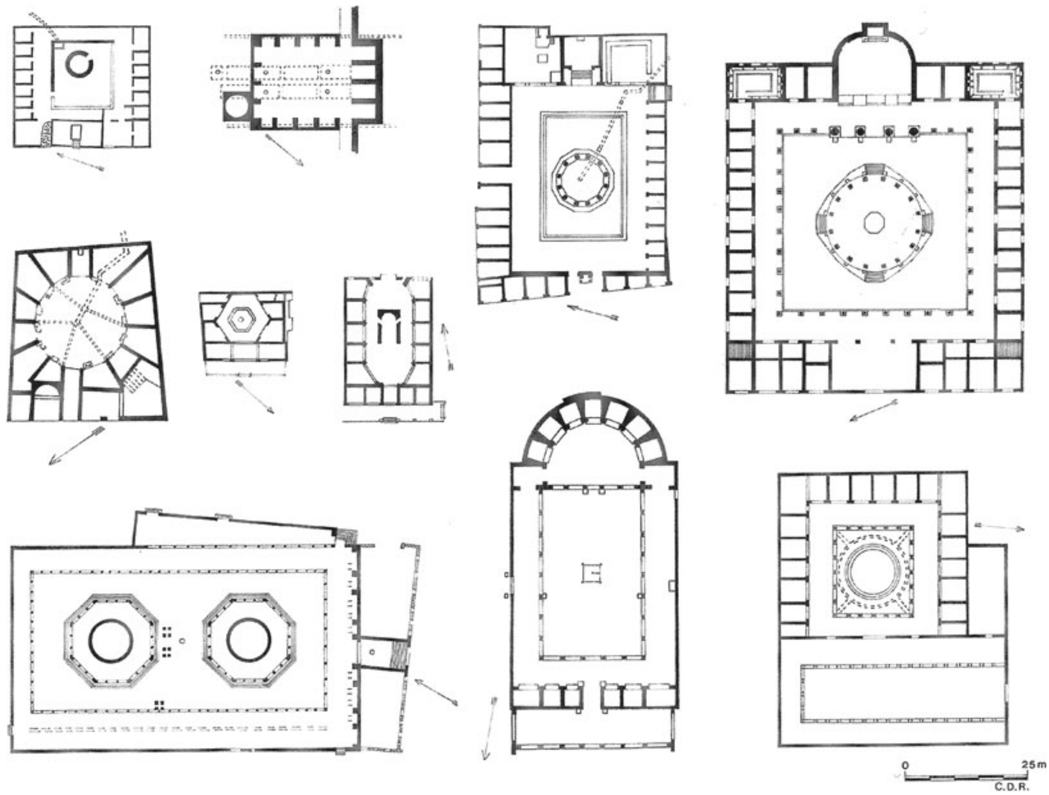

Fig. 1. *Examples of* macella *(after Richard 2014, fig. 1 [based on De Ruyt 1983: Plates. III and IV]). Left to right, top to bottom: Morgantina, Alba Fucens, Pompeii, Pozzuoli, Herdonia, Saepinum, Baelo Claudia, Lepcis Magna, Thamugadi, Hippo Regius. The structures are drawn to approximately the same scale.*

and measuring their other architectural characteristics from maps and plans, there is usually only one *macellum* per settlement. This matters for this study, as it means that we generally do not have to confront the same kinds of sampling issues as we do with other kinds of structures, such as temples, of which the numbers of extant and measurable examples vary, leading to concerns about the representativeness of the samples used. At the same time, these models should allow us to shed new light on *macella*, since they enable us not only to explore the relationships between the sizes of the structures themselves and the estimated populations and network potential of sites, but also to distinguish between the sites that simply have larger *macella* because of their greater size and the sites that have larger *macella* than we would expect based on their size as a result of more favorable local conditions or external linkages. Finally, this approach might also enable us to test how usual or unusual a given structure is (and thus whether it has been correctly identified and interpreted) by assessing the extent to which it conforms to the overall relationship. Consequently, this approach can be used to identify whether structures conformed to a single type in the first place, given that we would not expect a random selection of heterogenous structures to vary, or "scale," with population, and to identify any anomalous structures that should not be included in this group. The next section will therefore focus on the evidence for the Macellum Magnum and four other important, but potentially problematic, cases.

There are two qualifications that need to be made before proceeding. First, these structures were not the only places where high-end commodities could be sold: others include

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the *forum* or *agora* and perhaps the *tabernae*. Having said this, we would expect a good proportion, if not all, of the high-end commodities that were available in each settlement to have been sold in *macella*, given the facilities they offered for controlling and regulating prices and quality, and the logic behind grouping specialist activities into one location. Second, we must also be careful not to remove these structures from their wider social, cultural, political, and economic contexts, or to regard them as an exclusively commercial phenomenon. As some scholars have argued, they might also have had a religious function, given their regular proximity to temples and possible role in the distribution of meat from sacrifices, at least in Italy and the West (this is based on the idea that the parts of the carcasses that were not offered to the gods were prepared for consumption and displayed on selling tables).[31] This should not make that much difference to the results below, however, given that such distributions can also be seen as a form of conspicuous consumption and therefore as a reflection of the overall amount of disposable income that was available in each settlement.

The Macellum Magnum

Although it is possible that earlier cases existed in Rome, the first evidence we have for a structure resembling the kind of market building with which we are concerned here comes from the statement in ancient sources that two markets for fish and meat in Rome were grouped into a single complex, which was referred to as a *macellum*.[32] This complex seems to have been located near the Forum Romanum and to have been built sometime during the 3rd c. BCE.[33] Although there is some uncertainty about what exactly happened to this structure and why it was replaced, reflecting some confusion in ancient sources, the modern consensus is that it was superseded by two structures.[34] The first, the Macellum Liviae, seems to have been built by Augustus and located on the Esquiline, while the second, the Macellum Magnum, which is our focus here, seems to have been built by Nero, dedicated around 59 CE, and located on the Caelian.[35] This structure then seems to have been restored after the fire of 64 CE and continued to operate for at least a hundred, if not several hundred, years.[36]

Although there has been much speculation about the exact location and the architectural design of the Macellum Magnum, there are no extant remains of the structure, meaning that our only significant evidence comes from a combination of near-contemporary and later references in textual sources, the representation of the façade of the building on contemporary coinage, its inclusion on the later marble plan of the capital, some epigraphic

31 Van Andringa 2007; Richard 2014, 266.

32 De Ruyt 1983; Richard 2014, 256.

33 Holleran 2012, 165; Richard 2014, 256.

34 Holleran 2012, 165; Richard 2014, 256 n.11.

35 Holleran 2012, 165; Richard 2014, 256 n.11; Hoffelinck 2020, 244. Compared to the Macellum Magnum, much less is known about the Macellum Liviae. Although some archaeological remains have been found on the Esquiline, which effectively consist of an elongated building, it is only possible to come up with a tentative reconstruction of this structure, while its identity is extremely debatable (Bertrand and Chillet 2016). I have therefore not included the structure in what follows, although future work could experiment with including or excluding different reconstructions.

36 Holleran 2012, 165.

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evidence, and comparison with other structures. The textual material comprises an apparent reference to the building by Dio, who describes the construction of a "provision market called the Macellum" in Rome around 59 CE, and a direct reference to the building in the 4th-c. CE Regionary Catalogues the *Curiosum* and the *Notitia*, which locate it in Regio II, the Caelimontium, and list it between the Temple of the Deified Claudius (Claudium) and the neighboring brothels (*lupanarios*).[37] The structure is also shown on various contemporary or near-contemporary *dupondii*, most of which bear the inscription MAC. AUG. S. C. (*mac(ellum) Aug(usti)*) and show a simplified view of the building, and it appears on three fragments (157a,b,c) of the marble plan of Rome installed in the Temple of Peace under the Severans, the *Forma Urbis Romae*, which show it in plan (Figs. 2 and 3).[38] These fragments also clearly include the word "MACELLUM" and, although this label could, in principle, refer to another structure on the missing parts of the slab, its placement is most likely consistent with that of other labels on the *Forma Urbis Romae*, which are generally below the structure to which they pertain.[39] This structure is therefore normally interpreted as being the Macellum Magnum.[40] Finally, it is also worth mentioning the funerary stele of one L. Calpurnius Daphnus, given that it explicitly refers to him as an *argentarius* working in the Macellum Magnum and depicts him alongside two freedmen carrying baskets of fish.[41]

There have been several attempts to locate the structure.[42] Although earlier scholars assumed that it was situated under the church of San Stefano Rotondo, largely on the basis of the round plan of the basilica, this idea was dispelled by the discovery of the remains of the Castra Peregrina on the same site.[43] Meanwhile, although both Rainbird et al. and De Ruyt have suggested new locations, in the grounds of the Villa Fonseca (for complicated reasons that involve reinterpreting earlier descriptions and linking them to known remains) and to the northeast of the Temple of the Deified Claudius (on the basis of the relative locations of the known fragments of the *Forma Urbis Romae*) respectively, both possibilities have been ruled out by more recent excavations, largely on the grounds of the absence of sufficient space for such a large structure.[44] The exact location of the structure therefore remains unknown. Having said this, given the likelihood that the structure was at least partially designed to accommodate the sale of fish and related products, and the importance of supplying fresh water for filling and cleaning fish tanks, it might be productive to focus on the available free space along the line of contemporary aqueducts. This proposition also raises the intriguing possibility that at least part of the reason for Nero's construction of the new branch of the earlier aqueduct, the Celimontano Aqueduct, at some point between 54 CE and his death in 68 CE might

37 Cassius Dio, *Roman History* 62.18.3; *Descriptio XIV Regionem Urbis Romae, Curiosum - Notitia*; Holleran 2012, 166–67; Hoffelinck 2020, 244.

38 Wulzinger 1933; Carettoni 1960; Rodriguez Almeida 1981; Bocciarelli and Bizet 2016; Campana 2016; Holleran 2012, 165; Hoffelinck 2020, 39.

39 Rodriguez Almeida 1981.

40 Holleran 2012.

41 *CIL* VI 1648; Holleran 2012, 176; Hoffelinck 2020, 237.

42 Holleran 2012, 166–67.

43 Holleran 2012, 166–67.

44 Rainbird et al. 1971; De Ruyt 1983; Holleran 2012, 166–67.

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Fig. 2. *One of the* dupondii *of Nero showing the Macellum Magnum (now in the British Museum; asset no. 637159001). © The Trustees of the British Museum. Used under a Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International (CC BY-NC-SA 4.0) license. No changes were made to the image.*

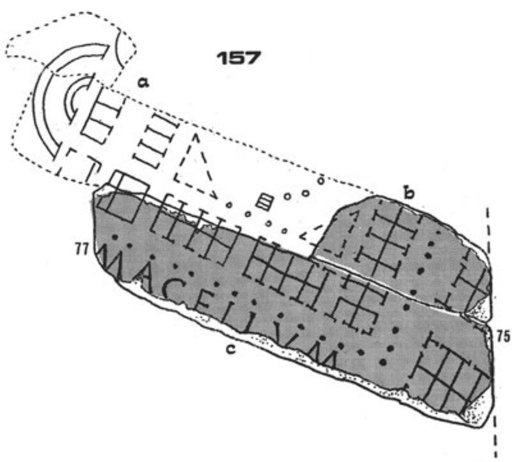

Fig. 3. *Drawing of the fragments of the* Forma Urbis Romae *showing the Macellum Magnum; the inset number refers to the slab, while the letters refer to fragments (after Rodriguez Almeida 1981, pl. 40). The original figure has been cropped.*

have been to feed the Macellum Magnum rather than just the Domus Aurea, as has traditionally been suggested.

Although there are small variations between the coins, they are consistent in showing a two-storied building with a central *tholos* that rests on a high podium, has a short flight of steps, is surmounted by a domed roof, and is surrounded by porticoes on both sides.[45] The *tholos* also contains a life-size statue of a deity, probably Neptune, while garlands are strung between the columns of the *tholos* and porticoes.[46] Meanwhile, the relevant fragments of the *Forma Urbis Romae* show an L-shaped building that seems to consist of an entrance, a central courtyard containing a circular colonnade on a podium reached by steps, a rectangular portico, several ranges of small rooms that run along at least three

45 Holleran 2012, 166; Hoffelinck 2020, 230.

46 Holleran 2012, 165; Hoffelinck 2020, 255 n. 194.

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sides of the courtyard and face both inwards and outwards, and at least one *exedra*.[47] It is important to bear in mind, however, that the *Forma Urbis Romae* reflects slightly later conditions and, therefore, might also include some evidence for later rebuilding in either the 1st or the 2nd c. CE.

This evidence has been used to suggest various reconstructions of the building that are based on the assumptions that the imagery shown on the coins is relatively reliable but simplified and that the building shown on the marble plan was more or less symmetrical.[48] Although there are some differences between these reconstructions, they largely agree that the building took the form of a square structure with three or four entrances that led onto a central courtyard with a *tholos*, on a podium, that could be accessed by one of four staircases, was comprised of 16 columns, and probably contained an over-life-size statue. This courtyard was surrounded by at least four ranges of shops, while the exterior of the building was also articulated by a portico, with additional shops that opened onto the street. These were accompanied by at least one and probably two *exedrae*, which have been interpreted variously as fountains or niches for statuary by other scholars but as latrines by Carandini and Carafa, and up to four triangular fish tanks.[49] The main differences between the rival reconstructions have therefore revolved around the exact number and function of the *exedrae*, although Carandini and Carafa have also raised the interesting possibility of a bridge connecting the *tholos* with the second floor of the portico.[50] Meanwhile, although earlier reconstructions, such as Tameanko's, have now largely been dismissed by scholars, they are still valuable in reminding us of the potential existence of other features, such as shrines.[51]

I have followed Carandini and Carafa's reconstruction, using it to estimate the total footprint and explore the other architectural features of the structure referred to above, because it is the most up-to-date and the most in keeping with what we know of the wider architecture of Rome under Nero (Fig. 4).[52] This suggests that the building was just under 95 m long by just under 80 m wide, covering a total footprint of about 7,600 m^2 (the exact figure is 7,573 m^2), and included four blocks of eight rooms (four facing outwards and four inwards), two ranges of 12 (seven outwards and five inwards), four further blocks of three rooms, and four more miscellaneous rooms, coming to a final total of 72. It is worth pointing out, however, that we would expect any slight variations in the reconstruction to have only a minor effect on the results, especially when examined using logarithmic scales.

Other problematic cases

Aside from the Macellum Magnum, there is a small number of other problematic cases. It is important also to discuss these briefly, since there has been some uncertainty as to whether they should be classified as smaller public spaces or large commercial markets (i.e., *macella*).

As Richard has noted, although there has been significant debate about it, recent work on the "Lukasgrab" at Ephesus has shown that it should probably also be regarded as a

47 Holleran 2012, 166.

48 Tameanko 1999; García Morcillo 2000; Carandini and Carafa 2017; Bocciarelli and Bizet 2018.

49 Carandini and Carafa 2017.

50 Carandini and Carafa 2017.

51 Tameanko 1999.

52 Carandini and Carafa 2017.

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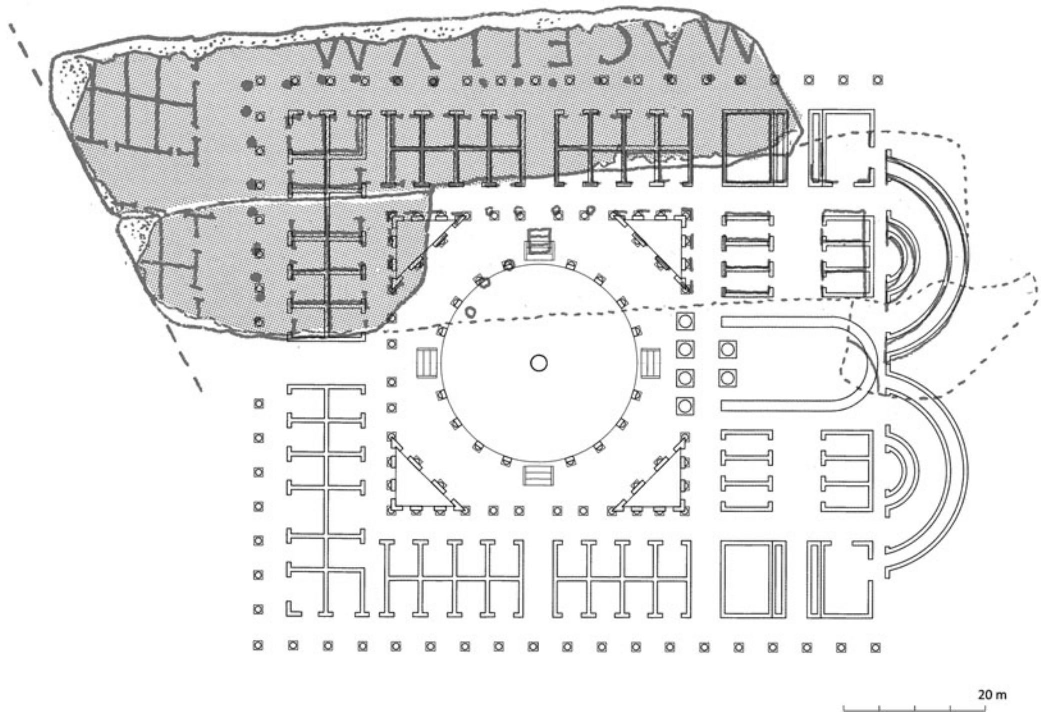

Fig. 4. *A comparison of the known fragments of the* Forma Urbis Romae *showing the Macellum Magnum and Carandini and Carafa's reconstruction of the same structure (based on Rodriguez Almeida 1981, pl. 40, and Carandini and Carafa 2017, pl. 138). The scales and orientations are approximate.*

macellum, on the basis of the circular structure that was found in its middle; therefore, it has been included in the set of data used below.[53] As Hoffelinck has shown, this *tholos* was probably added later, perhaps dating to some point in the third quarter of the 2nd c. CE, while the portico itself is a little earlier, probably dating to the first half of the 1st c. CE.[54] As we will see below, this structure is also the fourth largest in the catalogue, measuring about 63 by about 81 m, on the basis of recent geophysical survey and excavation, giving a total footprint of about 5,103 m^2 and placing it on a par with other public, rather than commercial, spaces. This means that it is interesting to assess how well this structure compares with the other structures discussed below.

Two other important cases are the structures at Perge and Side, given that these have also been described by scholars both as commercial *agorai* and as *macella* (despite the fact that the former is explicitly referred to as a *μάκελλον* in inscriptions).[55] These structures both comprised a large square containing a central circular columnar structure (i.e., *tholos*), lined on all sides with porticoes and with either inwards- or outwards-facing shops (35 at Perge and two sets of 30 and 13 at Side), accompanied by latrines (at least at Side) (Fig. 5).[56] These structures are unusual given not only their relatively large sizes, about 5,776 m^2 (76

[53] Richard 2014, 263.

[54] Hoffelinck 2020, appendix 1.

[55] Richard 2014, 261, 265.

[56] Richard 2014, 261–63.

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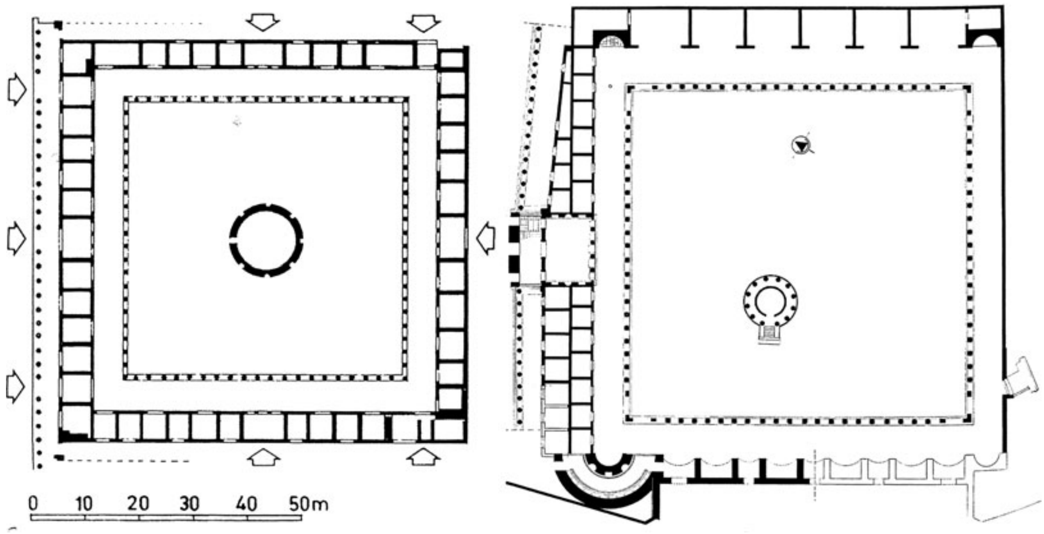

Fig. 5. *The* macella *at Perge (left) and Side (right) (after Richard 2014, figs. 3 and 4). The original figures have been combined.*

by 76 m) and 8,554 m^2 (91 by 94 m) respectively, but also the fact that the central structures within them are less in proportion to the overall footprint than elsewhere, and the one at Side is notably off-center.[57] As Richard has noted, "in the case of the gigantic complexes at Perge and Side … we could instead be dealing with agorai which happened to include a *tholos*-like (cult?) building."[58] It is for this reason that I have assumed that they were public spaces in earlier work.[59] Finally, as we will see below, there seem to be similar issues with the structure at Pompeiopolis, largely known through geophysical prospection, again because of its enormous size: it covered roughly 65 by 120 m, giving a total footprint of 7,800 m^2.[60] These structures have therefore been set aside for the moment, although the extent to which they conform to the wider relationship, and to the wider typology, is also explored below.

Data and methods

Given the uncertainties about both the definition and the identification of *macella*, and the issues with the quality and quantity of the data, I have begun by deriving a basic list of structures from Hoffelinck's work, which largely supersedes earlier work such as Cristilli's, since it includes nearly double the number of structures.[61] This not only provides us with a list of known or suspected *macella* throughout the Roman world in the Imperial period, but also includes details about their exact locations and their dates of construction, along with some figures for their lengths and widths (although there is no attempt to estimate their

57 Richard 2014, 261–63; Hoffelinck 2020, appendix 1.

58 Richard 2014, 270.

59 Hanson et al. 2019.

60 Bielfeldt 2011; Linck et al. 2013; Hoffelinck 2020, 137.

61 Cristilli 2015; Hoffelinck 2020.

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total footprints or to explore how the sizes and proportions of structures varied between sites).[62]

As Hoffelinck has shown, these structures are much more abundant in Italy, parts of North Africa, and (to a slightly lesser extent) the East than in the northwest and the Balkans, although this might be more a result of the relative density of cities, which is also highest in these regions, than anything else.[63] Meanwhile, although the evidence for the construction of these structures peaks twice, during the Julio-Claudian dynasty and the Nervan/Antonine dynasty, they are relatively common throughout the Imperial period as a whole.[64] This generally matches what is known of construction rates throughout the empire. It is important to remember that large numbers of these structures are of unknown date, but there is no reason to suspect that being able to specify these would dramatically affect the overall picture. This means that these structures are a relatively discrete phenomenon.

As noted above, architecturally, *macella* are usually enclosed, self-contained entities and are normally made up of a central courtyard, surrounded by ranges of smaller rooms, with a circular structure known as a *tholos* in the middle.[65] They are either square or rectangular, with entrances on all four sides, although they can have a slightly irregular shape. They occasionally have upper stories, but not always. The rooms are usually of a uniform size, with wide, closable thresholds, so that they are normally interpreted as shops, while the *tholos* generally consists of a few steps, a ring of columns, and a domed roof. Although we do not know the exact function of the *tholos*, the most likely options are that it was where fish was sold, where weights and measures (and other equipment) were held, where small rituals were performed, or where auctions took place. *Tholoi* are therefore often described as multi-functional kiosks, which could be used to accommodate a number of different things, from basins or fountains to statues or shrines devoted to the gods associated with commercial activities. Finally, as Hoffelinck has shown, *macella* are also usually located in or near accessible locations, such as in the heart of the urban center, near the *forum* or *agora*, on main streets, by the gates, or on the outskirts of a settlement near harbors, rivers, or roads (although they are usually found within settlements, they are also occasionally found immediately outside them), given the obvious need for access by both producers and consumers.[66]

I have used Hoffelinck's figures for the lengths and widths of structures to estimate their rough area: given that the majority of these structures are either square or rectangular, this should be a close approximation of their total footprints.[67] However, I have not included any of the structures where either the length or width is unknown, where there is some uncertainty about one of these measurements, or where we only know a limited amount about aspects of them, such as the radii or diameters of their *tholoi*.

In total, this provides us with useable figures for 49 structures, which are associated with about the same number of sites and which represent about a third of the 145

62 Hoffelinck 2020.

63 Hoffelinck 2020, fig. 195; Hanson 2016.

64 Hoffelinck 2020, fig. 196; Hanson 2016.

65 Richard 2014; Hoffelinck 2020.

66 Hoffelinck 2020.

67 Hoffelinck 2020.

structures (and 135 sites, because some sites have more than one structure) recorded in Hoffelinck's catalogue, illustrating the relatively limited amount of information that we have about this type of structure (these data are detailed in the Supplementary Materials). The catalogue includes a series of new figures for the sizes of the structures, of which the most notable for the purposes of this article are the "Lukasgrab" at Ephesus and the *macellum* at Pompeiopolis, where the measurements are based on recent geophysical surveys and/or new excavations. The Macellum Magnum itself, however, was never included in Hoffelinck's catalogue, and has therefore been added, bringing the grand total to 50 structures and about the same number of sites.

It is important to make three observations about these data. In the first place, as Richard has noted, one of the challenges of looking at these structures is that, although a large number of them have been documented, only a few have been comprehensively excavated, recorded, and published.[68] This means that we generally have better evidence for the West than the East (in fact, we only have evidence for a handful of structures in Asia Minor and the Levant), the exception to this being Greece. Therefore, our evidence is a little biased. Second, as noted above, although there is usually only evidence for one *macellum* per settlement, there are a limited number of examples with evidence for more than one. In those cases, I have simply taken the largest structure. The most important example of this is at Thamugadi (Timgad), where I have taken the value for the early 1st-c. CE Market of Sertius, rather than for both that and the late 2nd- or early 3rd-c. CE Central Market.[69] The differences in scale between them are slight, however (38 by 26 m, as opposed to 29 by 22 m), and including both makes hardly any difference to the results. Finally, it is also worth noting that the measurements do not include upper floors, given the uncertainties about how much of the footprint these occupied and what the space was used for (in particular, whether it was given over to more shops or used for other things, such as storage). Since this condition has been applied to all the sites dealt with here, it should not make that much difference to the results given below.

Next, I have also taken the opportunity to use a combination of ArcGIS and existing maps and plans to measure the sizes of the structures' courtyards, using the same approach as in earlier work, but only focusing on the structures with the clearest, most detailed, and most complete maps and plans, meaning that the size of this sample is a little smaller.[70] This makes it possible to either measure or estimate the total area that was given over to shops within most of these structures, to count the total number of units within these areas, and then to divide the former by the latter to calculate the average sizes of the shops within each structure.

I have then used the same evidence for the estimated inhabited areas, densities, and populations of sites as I did elsewhere (originally published in this journal).[71] This is based on a calibration dataset of all the sites where it is possible to measure both the

68 Richard 2014.

69 Hoffelinck 2020, appendix I.

70 Ward-Perkins 1981; De Ruyt 1983; Gros 1996; Uscatescu and Martín-Bueno 1997; Láng 2003; Palmieri 2010; Poupaki 2011; Marc 2012; Evangelidis 2019; Hanson and Ortman 2017; Hanson et al. 2019; Hanson 2020.

71 Wilson 2011; Hanson 2016; Hanson and Ortman 2017; Hanson et al. 2017; Hanson et al. 2019; Hanson 2020; Hanson and Ortman 2020.

inhabited area of the site and the number of residential units in a specific zone within it, meaning that it is then possible to estimate the population densities of each site, assuming an average of five people per household. This approach can be used to explore the overall relationship between estimated inhabited areas, densities, and populations, and to provide a method for estimating any site's population based on its inhabited area. The figures have been rounded to the nearest thousand in the results and discussion below to reflect their likely reliability, but not in the underlying analysis, where it is best to use the original estimates to assess the statistical significance of the relationship, examine the amount of variation between sites, and assess the residuals of the relationship with a view to understanding sources of error and accounting for other, secondary effects. As in earlier work, I have assumed that most of these structures coincide with the maximum expansion of each settlement or are at least close enough to it to have no marked effect on the results.[72]

I have then assessed the relationship between the footprints and other architectural features of these structures and the estimated populations of the sites using a common form of regression known as ordinary least squares regression (Table 1). As has been noted elsewhere, this is feasible because $y = bx^m$ and $\log y = m \log x + \log b$ are equivalent expressions.[73] Therefore, we can estimate the exponent and pre-factor of the power function by estimating the y-intercept and slope of the best fit linear function, so long as it is based on log-transformed values, as well as measuring the extent to which each side deviates from it.

Next, I investigated whether the best-connected and best-integrated sites had the largest *macella* by exploring the relationship between the sizes of these structures and their network potential. To do this, I used ORBIS: The Stanford Geospatial Network Model of the Roman World (henceforth ORBIS), which offers a simplified dataset of cities and sea, river, and road networks in the Greek and Roman world, roughly reflecting conditions around 200 CE (Fig. 6).[74] Although this dataset only includes a limited selection of settlements, 678 in total, it does allow us to calculate the distance, time duration, and financial expense associated with different types of travel between different locations for most of the sites that we are interested in here. I therefore began by cross-referencing these data with the catalogue of cities referred to above. I then used standard techniques to identify the most significant nodes in the network. The measures we are concerned with are degree centrality (the number of edges to a node), betweenness centrality (the number of times a node acts as a bridge along the shortest path between two other nodes), and Eigenvector centrality (the likelihood of a node being connected to other well-connected nodes in the network).[75] The last of these assigns a score to each node that is based on the idea that a node will be more important if it is linked to other important nodes in the network. The network was then analyzed in Gephi, assuming that all the edges are undirected, but using the cost of moving along these edges in terms of distance (in km), time (in days), and expense (in *sestertii*) as their weights (I have disregarded the season, though, since this is not relevant at this scale). In total, it is possible to estimate the network

72 Hanson et al. 2017; Hanson et al. 2019; Hanson 2020; Hanson and Ortman 2020.

73 Bettencourt 2013; Ortman et al. 2014; Hanson and Ortman 2017; Hanson et al. 2019; Hanson and Ortman 2020.

74 http://orbis.stanford.edu (accessed January 18, 2019).

75 De Nooy et al. 2005.

Table 1.
The results of regressing the total footprints, courtyard areas (both in m^2), number of shops, and average sizes of shops (again in m^2) of *macella* against the estimated populations of sites. All regressions are done using ordinary least squares regression on log-transformed values.

Dependent variable	*Number of observations*	*Exponent (95% CI)*	*Pre-factor (95% CI)*	R^2	*Significance (p-value)*
Total footprint (m^2) (including the Macellum Magnum)	50	0.41 (0.27–0.55)	22.13 (6.51–75.19)	0.42	<0.00001
Total footprint (m^2) (excluding the Macellum Magnum)	49	0.40 (0.24–0.56)	24.83 (5.99–102.90)	0.33	0.00001
Length (m)	49	0.22 (0.13–0.31)	4.53 (2.06–9.98)	0.32	0.00002
Width (m)	49	0.18 (0.09–0.27)	5.43 (2.44–12.08)	0.25	0.00028
Courtyard area (m^2)	22	0.46 (0.29–0.63)	3.71 (0.72–19.07)	0.57	0.00005
Number of shops	20	0.26 (0.12–0.39)	1.46 (0.42–5.08)	0.43	0.00161
Average shop area (m^2)	20	0.19 (0.10–0.28)	3.23 (1.36–7.58)	0.48	0.00075

values of 341 sites from throughout the Roman world in the Imperial period (this number is simply a product of the number of sites that are included in the ORBIS model).

Finally, I have examined the relationship between the extent to which each site deviates either positively or negatively from the overall relationship discussed below (a value that is known as a residual) and measures of the numbers of calories that could be derived from agriculture (this is known as a total calorific suitability index), the distances between sites and the nearest harbors, and the same network measures discussed above, using the same data as in previous work.[76] This can be used to assess whether any of the extra capacity that is contained within some structures can be explained by the presence of either slightly more or slightly less favorable agricultural and commercial circumstances.

Results and discussion

In total, it is possible to estimate the footprints of 50 structures (including the Macellum Magnum), which are associated with the same number of sites. They vary widely in size, ranging from as little as 196 m^2 (Genava) to as much as 7,573 m^2 (Rome), but with an average of about 1,265 m^2. This is interesting in its own right, as it suggests that most structures were substantial buildings, with an average size about five times larger than the average domestic unit in Pompeii and Herculaneum.[77]

The results of regressing these data reveal that there is a strong relationship between the footprints of these structures and the estimated populations of sites (Table 1 and Fig. 7). At the most basic level, this confirms that it is legitimate to regard these structures as

76 Hanson and Ortman 2020; Hanson 2021.

77 Wallace-Hadrill 1994.

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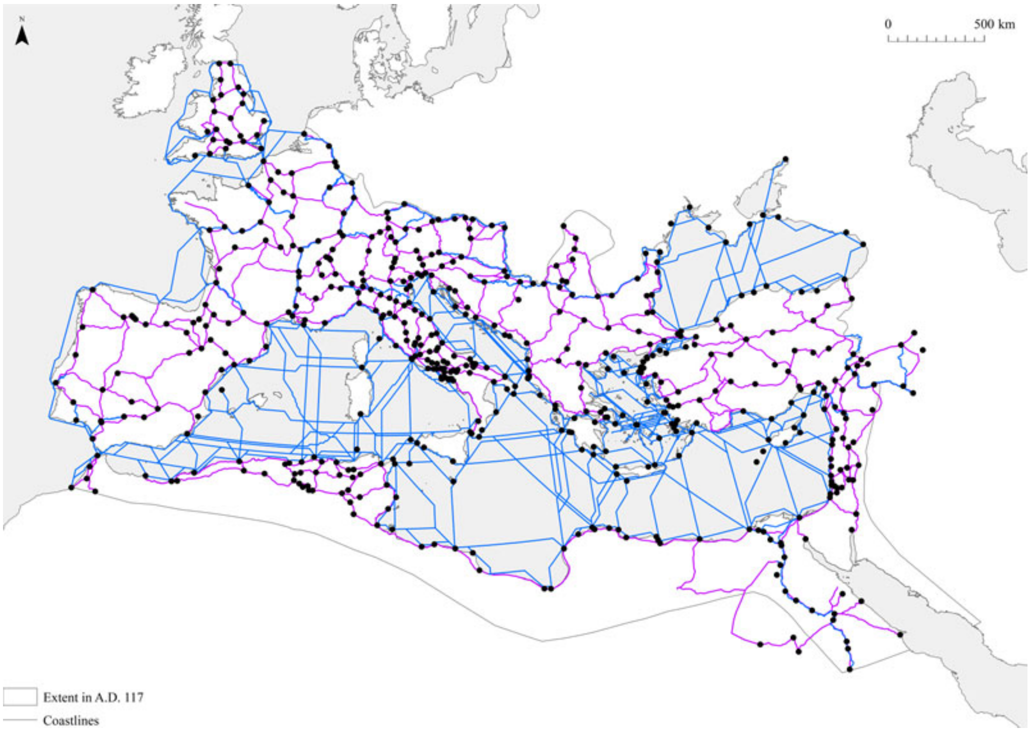

Fig. 6. *The ORBIS model, which offers a simplified dataset of cities and sea, river, and road networks in the Greek and Roman world, roughly reflecting conditions around 200 CE (after Hanson 2020, fig. 3). The black circles represent cities, the blue lines represent the sea and river network, and the purple lines represent the road network. The data are derived from https://purl.stanford.edu/mn425tz9757 (accessed January 18, 2019). No changes have been made to the underlying data.*

belonging to the same basic type of building, although, as we will see below, this does not necessarily mean that all of the structures that have been dealt with should be included within this category. Another feature of these results is that the exponent of the relationship is very close to, if not exactly the same as, the expected value of 1/3, while the confidence intervals include this figure comfortably, meaning that it is consistent with the theoretical and empirical work discussed above. The overall relationship is also statistically significant at the 0.00001 level (the *p*-value is <0.00001). This is remarkable, given that the datasets used are completely independent (i.e., they are derived from separate published sources). Although the R^2 of the relationship is relatively low overall, reflecting a reasonably large amount of unexplained variation in the relationship, it is nonetheless relatively high for historical and archaeological data and is more or less comparable with both earlier and ongoing work on other types of structures (for example, the R^2 for *macella* is 0.42, while for basilicas and theaters and amphitheaters it is 0.39, 0.38, and 0.35 respectively).[78] The reasons for this variation will be returned to below. It is also worth noting that including or excluding the Macellum Magnum makes little difference to the results, simply decreasing the exponent of the relationship from about 0.41 to 0.40 and increasing the pre-factor from about 22 m^2 to about 25 m^2 (marginal differences). Although it also has the effect of reducing the R^2, this is probably to be expected, given that removing this structure also has

[78] Hanson and Ortman 2020.

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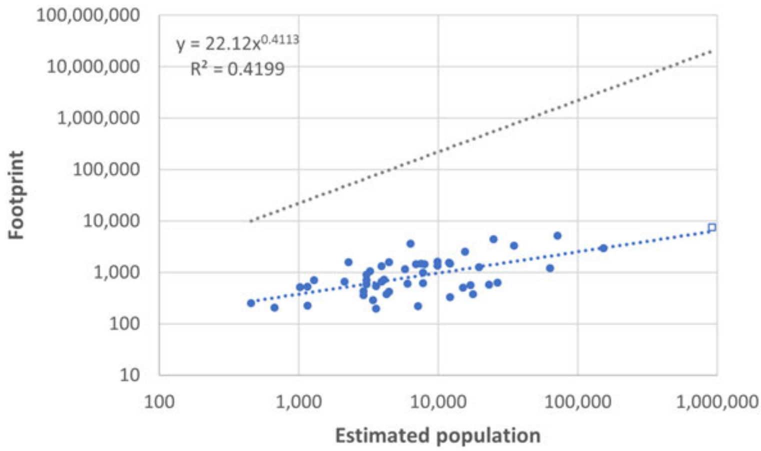

Fig. 7. *The relationship between the total footprints of* macella *(in m^2) and the estimated populations of sites (in persons). Both scales are logarithmic. The lighter grey line indicates a linear relationship, which is provided for reference. The Macellum Magnum, which is included in the dataset here, is marked with an open square. For the effects of including or excluding it, see Table 1.*

the effect of lowering the numbers of orders of magnitude being dealt with in each case. The Macellum Magnum has therefore been retained within the data below. The relationship is also extremely sublinear, meaning that, although the largest communities do tend to have the largest *macella*, the sizes of these structures tend to increase much more slowly than the estimated populations of sites (or, in other words, doubling the size of a settlement does not lead to a *macellum* that is twice as large). This means that these structures increase at a rate that is broadly comparable to that of theaters, amphitheaters, and city gates, but markedly different from *fora/agorai* and street networks.[79] This has interesting implications for our understanding of *macella*, as it suggests that there is an increasingly small ratio between the size of the population and the size of *macella*, meaning that there is a decreasing amount of space per person as cities increase in size (i.e., there is a decreasing amount of space *per capita*).

One of the most striking aspects of this relationship for the purposes of this article, however, is that the slope, or exponent, of the relationship is closest to the value of 1/3, rather than 2/3, 1, or 4/3, as we might have expected. At first glance, this is surprising, given that we might have expected a relationship similar to that associated with buildings that function like a form of infrastructure; this usually scales in a sublinear fashion, but with a slope, or exponent, of 2/3. Alternatively, we might have expected the relationship to be similar to the social and economic outputs of settlements, which generally scales in a superlinear manner, with a value of 4/3. These results, however, suggest that the sizes of *macella* should be interpreted as a reflection of both an increasing average amount of wealth and a greater amount of traffic per person, in both cases as the sizes of settlements increase.[80] The reason for this is that, as noted above, although we would expect the total amount of wealth and traffic generated by a settlement to have increased at a rate of 4/3, we would only expect the average amount of both of these measures *per capita* to have increased at the rate of 1/3.

79 Hanson et al. 2019; Hanson and Ortman 2020.

80 Lobo et al. 2020.

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Finally, it is also interesting to consider the pre-factor, or y-intercept, of these relationships, since this can be used as an index of the baseline size of structures.[81] This is about 22 m^2, indicating that these structures were relatively modest in comparison with other kinds of buildings (such as theaters and amphitheaters, which have a pre-factor for their seating capacities of 292 and 630 persons respectively, equating to very roughly 82 m^2 and 176 m^2 each).[82]

Next, it is interesting to note that the lengths and widths of these structures increase with estimated population at almost identical rates, in keeping with the assumption that they were mostly square structures. Meanwhile, although the number of observations is a little lower, given the smaller amount of available information, it is also striking that there is a series of relationships between the estimated populations of sites and the architectural features of the structures found within them (Table 1). These results suggest that the sizes of the courtyards within *macella* generally increase much more slowly than the estimated populations of sites. Although the exponent of the relationship does not match any of the theoretical expectations discussed above, the confidence intervals do include the value of 1/3 (the relationship also has a relatively high R^2 and is significant at the <0.00001 level), suggesting that it might be profitable to measure the total amount of space available for moving and interacting with others within a larger range of types of structures in the future. Perhaps more importantly, these results also suggest that both the numbers and the average sizes of the shops that are found within these structures also increase much more slowly than population and at broadly similar rates, especially if one considers the full range of values included within the confidence intervals (both of these relationships also have a relatively high R^2 and both are significant at the <0.005 level, although the p-value for the former is a little lower than for the latter). This suggests that roughly half of the gains of increasing the sizes of cities were put into building larger shops and roughly half into building more of them (allowing for a little margin for error in both relationships). This echoes recent work on the widths of gates, which has also suggested that about half the gains that were made by larger settlements went into building more gates and about half into making wider ones.[83]

Although we obviously have to be cautious about assigning any specific functions to these rooms without more detailed excavation (and most importantly without more detailed ethnobotanical and archaeozoological studies), these results nonetheless strongly suggest that the larger *macella* that were associated with larger sites could have provided both a greater volume and a greater range of commodities, assuming the number of rooms is an index of diversity and their sizes are an index of capacity. These results might have wider implications for our understanding of food supply, since they suggest that the inhabitants of larger cities might have had access to not only more foodstuffs, but also a greater range of them, meaning that they might have had a more varied diet (and a greater amount of choice), with obvious implications for our understanding of supply and demand. These results also reveal, for the first time, that it is possible to extend the basic approach behind settlement scaling theory to the numbers of rooms within structures, moving far beyond earlier work, which has simply focused on the total footprints

81 Hanson 2023.

82 Hanson and Ortman 2020.

83 Hanson 2020.

or overall dimensions of structures. This is a result that could have significant implications for future research.

Given everything that has been noted above about the interrelated nature of wealth and traffic, it is also not surprising that there is a series of broad relationships both between the populations of the sample of sites used here and the network measures discussed above (and *vice versa*), and between the footprints of *macella* and the same network measures (and *vice versa*) (Table 2).[84] This effectively means that the largest structures are found not only in the sites with the largest numbers of immediate neighbors (degree centrality), but also in those with the greatest likelihood of being passed by traffic moving along the network (betweenness centrality) and the greatest overall influence over the rest of the network (Eigenvector centrality), supporting the suggestion that was made above that we would expect the largest *macella* to be found within the most well-connected and integrated sites. None of these relationships, however, match the expectations discussed above very closely, perhaps because none of them is a direct equivalent for the volume of traffic itself. Finally, although we need to be careful about overinterpreting these values, it is notable that the figures for the R^2 of the first and last sets of relationships are the largest. This is important, as it suggests that the numbers of immediate neighbors and the overall influence over the rest of the network are the most important of the three factors discussed here. These results therefore have significant implications for our understanding of the ancient world, since they suggest not only that the sizes and capacities of market buildings, the estimated populations of cities, and their overall levels of connectivity and integration are all related, but also that increasing population is associated with both increasing urban demand and increasing ability to supply that demand through external linkages.

More generally, these results have important consequences for our understanding of the different kinds of food that were supplied to cities and the facilities that were built to support this. In turn, there are implications for our understanding not only of the nature of wider retail, but also of the diets of the inhabitants of settlements and the overall standard of living and quality of life within urban contexts. In the first place, these results demonstrate the importance of large, specialized market buildings for the supply of food to cities, as well as raising the possibility that the residents of larger cities might have had access to a more plentiful and wider diet than their counterparts in smaller cities. This echoes recent ethnobotanical and archaeozoological work in other contexts, such as Rome, Pompeii and Herculaneum, and Silchester, that has been used to suggest that there was a significant widening of tastes throughout the Roman world in the Imperial period.[85] Secondly, these results suggest that these structures can be seen as a reflection not only of a significant amount of economic development, but also of the development of middle-income groups with a certain amount of disposable income. Thirdly, these results are in line with the increasingly widely held view that ancient cities were extremely highly integrated and connected with the rest of the Roman world, and the related suggestion that they induced a significant amount of professional specialization, including in relation to food.

84 These results are also exciting because they demonstrate that it is possible to detect a relationship between the sizes of sites and the network measures used here, providing an important update to the more negative result provided by earlier work (Hanson 2020). The reason for this is the smaller but much more well-documented sample that is derived by only focusing on sites with *macella*, rather than all known sites.

85 Killgrove and Tykot 2013; Lodwick 2014; Rowan 2016; Rowan 2017.

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Table 2.
The results of regressing the total footprints of *macella* and the network potential and estimated populations of sites. All regressions are done using ordinary least squares regression on log-transformed values. The number of observations is 29 in all cases.

Dependent and independent variables	*Exponent*	*Pre-factor*	R^2
Degree centrality versus estimated population	0.27	0.28	0.46
Betweenness centrality versus estimated population	0.71	1.62	0.36
Eigenvector centrality versus estimated population	0.47	<0.00	0.45
Total footprint (m^2) versus degree centrality	0.89	360.12	0.27
Total footprint (m^2) versus betweenness centrality	0.25	181.54	0.19
Total footprint (m^2) versus Eigenvector centrality	0.62	6854.40	0.40

As shown elsewhere, although we do not have much information about the numbers of occupations in ancient cities, we do have evidence for the numbers of professional associations, such as *collegia*. These can be used as a proxy for the range of activities that occurred in settlements, suggesting an expansion of both specialization and diversification with city size.[86] In addition, as Kaše et al. have shown, drawing on epigraphic material, there is evidence for a much larger number of occupational categories in general and a much larger number of occupational categories related specifically to food production in large cities compared to both medium-sized and small ones.[87] Meanwhile, although there is evidence for at least 200 different crafts or trades in the capital, of which about 35 are related to the importation, preparation, or sale of food, there is very little or no comparable evidence for most other sites.[88] In the capital, at least, there were also a number of structures that seem to have been named after specific commodities (or the traders of them), implying that they also specialized in certain kinds of merchandise.[89] Finally, these results also have implications for our understanding of urban munificence, given that most market buildings seem to have been funded by local citizens, acting either as private benefactors or within the framework of political offices or religious appointments, according to the associated inscriptions mentioning individuals.[90] It could therefore be instructive to extend the approach here to other structures associated with commerce, including *tabernae*.[91]

At the same time, although there is much less variation in the extent to which each site deviates from the relationship than for other structures discussed elsewhere, there is still a certain amount of variance that needs to be explained.[92] As noted above, although we would expect these deviations, which are known as residuals, to be the result of errors both in how the sizes and densities (and therefore populations) of sites have been estimated and in how the footprints of these structures have been measured (especially given that the latter have been calculated by multiplying their lengths and widths, rather than measuring them from maps and plans), not to mention mismatches in date, they can also be taken as a reflection of meaningful differences between sites, including differences in their social and

86 Hanson et al. 2017.

87 Kaše et al. 2022.

88 Joshel 1992.

89 Goodman 2016.

90 Richard 2014, 259.

91 Ellis 2018.

92 Hanson and Ortman 2020.

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economic conditions.[93] The residuals of the relationship between the total footprints of these structures and the estimated populations of sites are shown in Figure 8.

This reveals a somewhat mixed picture, since, although there is a small number of sites that have larger *macella* than we would expect, based purely on their size, and are clearly associated with major ports, such as at Ephesus, Ostia, and Puteoli (which have the large, positive residuals of 0.37, 0.30, and 0.48 respectively), there is very little overall relationship between the sizes of these residuals and the distances between each site and the nearest useable harbor. This is particularly apparent in Figure 8, where the sites that are less than 1 km away from a useable harbor are marked in orange. In addition, many of the sites with the largest positive residuals are relatively far from the coast, as illustrated by Aquincum (with a residual of 0.30). Somewhat disappointingly, there is also very little evidence for any relationship between the sizes of these residuals and the total calorific suitability indices and the network measures discussed above, although it is worth noting that the sites with the largest positive residuals do tend to have the largest Eigenvector centrality. This result echoes recent work, on subjects such as the relationship between the seating capacities of theaters and amphitheaters and the sizes of sites, that also shows that there is very little or no relationship between the residuals of these relationships and the network measures derived from the ORBIS model.[94] These results therefore suggest that it is not possible to explain the additional capacity of specific structures with reference to these conditions, at least based on current evidence.

Next, our results illustrate the potential of using settlement scaling theory to address some of the uncertainties about the structures within particular sites by assessing how well they conform to our expectations. In the first place, as noted above, this relationship can be used to assess how plausible the current estimates for the size of the Macellum Magnum are, given that it allows us to make a simple prediction about how large a structure would be appropriate to a settlement of the capital's size that can then be compared against existing reconstructions. Although we would expect the capital to have had a *macellum* with a footprint of about 5,842 m^2, based on an estimated population of just under one million for the site and the overall relationship discussed above, Carandini and Carafa's reconstruction, which is the most widely accepted, indicates that it would have covered about 7,600 m^2.[95] This suggests that, although the figures that have been given for the dimensions of the Macellum Magnum provide us with an estimate for the size of this structure that is about 30% larger than we might have expected, this is not unreasonable and is well within the range of variation that is incorporated into the rest of the relationship. This means that it is almost certainly legitimate to regard the estimate as being relatively reliable, despite the notes of caution that were raised above about the reconstructions of the structure. It also perhaps allows us to be slightly more optimistic about the utility of the *Forma Urbis Romae* and coinage as evidence for missing structures than we have generally been. It is also worth noting that the Macellum Magnum is only a modest positive outlier if it is included within the relationship, with a residual of just 0.08, placing it in the middle of the pack (23rd out of 50). This also supports previous work, which suggested that, although Rome often has by far the largest example of any particular type of building,

93 Bettencourt et al. 2010; Hanson and Ortman 2020; Hanson 2023.

94 Hanson and Ortman 2020.

95 Hanson and Ortman 2017.

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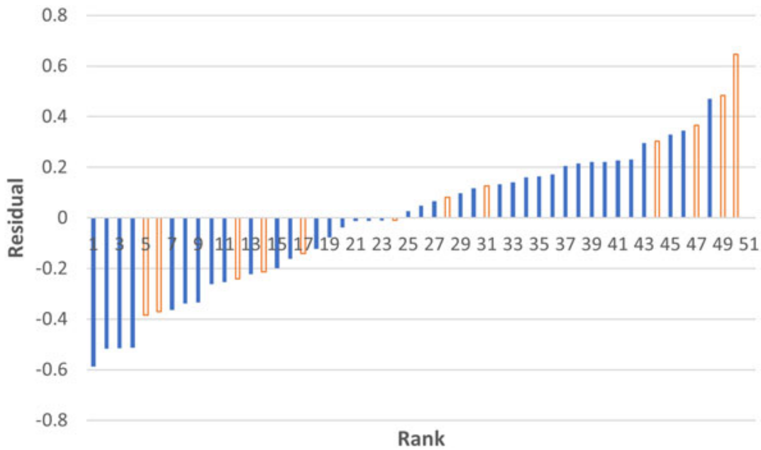

Fig. 8. *The residuals of the relationship between the total footprints of* macella *(in* m^2*) and the estimated populations of sites (in persons). Note that the values are logarithmic. The sites that are less than one 1 km away from a useable harbor are marked in orange.*

these structures are also often almost exactly the size or capacity that one would expect once we have taken account of the city's (comparatively) enormous size.[96] This, in turn, suggests that the capital was much more normal that we might have expected. These results are akin to the modern situation in the USA, where New York City is ranked only 88th out of the 363 Metropolitan Statistical Areas (MSAs) studied for their total income, which makes it seem more normal than abnormal, again once its size has been taken into account.[97]

Second, these results support the idea that the "Lukasgrab" at Ephesus should be regarded as a *macellum*, given that, although it is the fourth largest structure in the catalogue, with a total footprint of 5,103 m^2, this is not particularly large once the size of the site has been taken into account, and it falls well within the expected range for the size of the structure associated with it, again based on the overall relationship between the footprints of *macella* and the estimated populations of sites discussed above.

In contrast, both Perge and Side would be major outliers from the overall relationship if included, given that the former is nearly six times larger than we would expect, based on the size of the population of the site, while the latter is over 11 times larger. This is because, as noted above, although the *macella* at Perge and Side have total footprints of about 5,776 and 8,554 m^2 respectively, we would only expect them to have total footprints of about 1,001 and 758 m^2 apiece based on the overall relationship described above and the estimated populations suggested previously.[98] These results therefore surely support the idea that these structures had a different function from the other sites discussed above and that would be better interpreted as commercial *agorai* than as *macella*. Interestingly, these results reveal that Pompeiopolis is also an extreme outlier from the overall relationship, for similar reasons, with a structure that is again over 10 times larger than we would expect, at least on the basis of the current estimates for its

96 Hanson 2023.

97 Hanson 2021; Hanson 2023.

98 Hanson 2016; Hanson and Ortman 2017.

population and the size of its *macellum* (in this case, while the *macellum* has a total footprint of 7,800 m^2, the line of best fit predicts a structure of only 750 m^2). This suggests that it was also correct to exclude it. There are several possible explanations. The first, of course, is that the current estimates for the population of the site, which are based on its wall circuit, are too low, while the second is that the current estimates for the size of the *macellum* itself are much too high. This is perfectly plausible, given that the latter are mainly based on GPR and magnetometer survey, combined with limited excavations, while it is also striking that the current estimate is the second largest in Hoffelinck's entire dataset, after Side. It is also intriguing, however, that this structure is very similar in both length and width (and therefore in overall size) to the Macellum Magnum, as well as sharing many of the same architectural features. This raises the possibility that the structure was inspired by, or intended to be in direct competition with, the one at the capital. Given that all three sites, Side, Perge, and Pompeiopolis, are located in modern Türkiye and date to either the 2nd or 3rd c. CE (and specifically to the 2nd c. CE, middle or second half of the 2nd c. CE, and 2nd or 3rd c. CE respectively), this raises the question of whether these structures should be regarded as being part of a unique regional and chronological phenomenon, possibly led by direct competition between them.[99]

Finally, although it is not possible to comment on all the sites that are included in the dataset at any length here, it is worth noting that both Lepcis Magna and Thamugadi lie almost exactly on the best fit line, with residuals of effectively 0 and 0.05 respectively, while Pompeii, Gerasa, and Aquincum lie somewhat above it (0.22, 0.32, and 0.30) and Corinth lies somewhat below it (-0.24), reflecting earlier results for other kinds of structures, such as theaters and amphitheaters, to different extents. An obvious avenue for future research will therefore be not only to discuss these specific deviations in more detail, but also to compare and contrast the values for different kinds of structures across different sites, allowing us to come up with a much more nuanced understanding of fluctuations within and between sites.

Conclusions

In this article, I have shown that there are relationships not only between the footprints of *macella* and the estimated populations of the sites in which they were found, but also between the numbers and average sizes of the shops within *macella* and those estimated populations that are all consistent with wider theoretical and empirical expectations.[100] One of the most surprising aspects of these results, however, is that the exponent of the first of these relationships increases at the rate of about 1/3, not 4/3 as we might have initially expected, meaning that the footprints of the structures should be interpreted as a reflection of the average, rather than total, amount of wealth and traffic that was generated *per capita*, while the other two relationships suggest that about half of the gains associated with increasing city size were put into the building of larger shops and about half into simply building more of them. This is important, given that it not only demonstrates the significance of large, specialized market buildings for the supply of food to cities, but also raises the possibility that the residents of larger cities might have had access to a

99 Hoffelinck 2020, table 9.

100 Lobo et al. 2020.

greater volume of commodities, as well as a greater range of them, with obvious implications for their diets. If this is correct, it suggests that these structures can be seen as a reflection of a significant amount of economic development, and of the development of middle-income groups with a certain amount of disposable income, with significant implications for our understanding of the connectivity and integration of the ancient world, the extent of the division of labor, and the role of euergetism within this. Perhaps unsurprisingly, this work also reveals that there is a series of broad relationships between the estimated populations of sites and the network values discussed above, and between the total footprints of *macella* and these metrics for network potential, suggesting that population, average traffic, and average wealth are all connected. There is no relationship, however, between the residuals of these relationships, which can be taken as a measure of the unique social and economic circumstances of each site after taking their sizes into account, and these basic network values. Finally, the results demonstrate the potential of this method to assess whether the evidence for a given site seems plausible or not, based on how much (or how little) it deviates from the overall relationship. Here, this suggests that, although the figures that have been given for the dimensions of the Macellum Magnum provide us with an estimate for the size of this structure that is a little large, it is well within the range of variation that one might expect, meaning it can probably be treated as reliable. In contrast to this, the results also seem to confirm that both Perge and Side would be major outliers if included in these relationships, supporting the suggestion that they should be treated as a separate type of structure, along with Pompeiopolis. This highlights the importance of continuing to probe both how and why individual sites deviate either positively or negatively from the underlying relationships described here and elsewhere.

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Supplementary Materials: The Supplementary Materials contain information about the lengths, widths, and footprints of *macella*, the dimensions of the central courtyards and the numbers and average sizes of the units around them, and estimates of the network potential and CSI of sites. To view the Supplementary Materials for this article, please visit https://doi.org/10.1017/S104775942400031X.

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