Check for updates

RESEARCH ARTICLE

REVISED The Ditch and the House. Construction Energetics in Early 7th-century BC Megara Hyblaia: A Preliminary Study.

[version 2; peer review: 2 approved, 2 approved with reservations]

Frédéric Mège, Eleonora Delpozzo

Department of Humanities, Ca' Foscari University of Venice, Venice, Veneto, Italy

v2 **First published:** 14 Jul 2025, **5**:184
https://doi.org/10.12688/openreseurope.20518.1
Latest published: 03 Dec 2025, **5**:184
https://doi.org/10.12688/openreseurope.20518.2

Abstract

Background: Megara Hyblaia, a Greek colony founded in the third quarter of the 8th century BC on Sicily's eastern coast, exemplifies early Western Greek urbanism. By the early 7th century BC, Megara had likely reached its maximum intramural size of approximately 60 hectares. This study focuses on that formative phase to evaluate whether the community possessed the resources to undertake two key construction projects: the first city fortification and residential expansion. **Methods:** Archaeological evidence shows that residential structures spread across the Southern Plateau and toward the Archaic West Gate by the early 7th century BC. This urban spread correlates with the construction of the city's earliest defensive structure, an "agger-wall". The article investigates the feasibility of these projects using two case studies: the agger-wall and the house on plot 113W4. Using data from stratigraphic excavation, 3D modelling, Building Information Modelling (BIM), and architectural energetics, the study estimates construction time and labour requirements. **Results** The aforementioned methods allowed us to estimate the construction of the agger-wall defence line at 11478 p-d (person-day) and the building of the house on plot 113W4 at 187–196 p-d. These figures then need to be put into perspective with an estimated population of 404–538 individuals in the first quarter of the 7th century BC, of whom roughly half are considered fit for construction work and available for it for five to six months per year. **Conclusions:** In evaluating the feasibility of early construction projects at Megara Hyblaia, findings suggest that the second-generation population could have built both the fortifications and sufficient housing within a year, without disrupting agriculture or essential tasks. Thus, 7th-century BC inhabitants likely had sufficient workforce for fortifications and housing. This study also highlights the promise and limitations of BIM tools in reconstructing

Open Peer Review

Approval Status ? ✓ ? ✓

	1	2	3	4
version 2 (revision) 03 Dec 2025			? view	✓ view
version 1 14 Jul 2025	? view	✓ view		

1. **Felat DURSUN**, Izmir Institute of Technology, Urla,, Turkey
2. **Vasiliki Palieraki**, National Technical University of Athens Ship Design Lab, Zografou, Greece
3. **Ifechukwu Gil-Ozoudeh**, Enugu State University of Science and Technology, Enugu, Nigeria
4. **İrfan Kocaman**, Erzurum Technical University, Erzurum, Turkey

Any reports and responses or comments on the article can be found at the end of the article.

ancient architecture and informing future digital heritage research.

Keywords
Megara Hyblaia; Archaic Sicily; Ancient Construction; Architectural Energetics; 3D Modelling; BIM.



This article is included in the Marie-Sklodowska-Curie Actions (MSCA) gateway.



This article is included in the Horizon 2020 gateway.

Corresponding author: Frédéric Mège (frederic.mege@unive.it)

Author roles: Mège F: Conceptualization, Data Curation, Funding Acquisition, Investigation, Methodology, Project Administration, Supervision, Validation, Visualization, Writing – Original Draft Preparation, Writing – Review & Editing; **Delpozzo E**: Formal Analysis, Investigation, Methodology, Resources, Software, Visualization, Writing – Original Draft Preparation, Writing – Review & Editing

Competing interests: No competing interests were disclosed.

Grant information: This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie Grant Agreement No 945361.
The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Copyright: © 2025 Mège F and Delpozzo E. This is an open access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

How to cite this article: Mège F and Delpozzo E. **The Ditch and the House. Construction Energetics in Early 7th-century BC Megara Hyblaia: A Preliminary Study. [version 2; peer review: 2 approved, 2 approved with reservations]** Open Research Europe 2025, **5**:184 https://doi.org/10.12688/openreseurope.20518.2

First published: 14 Jul 2025, **5**:184 https://doi.org/10.12688/openreseurope.20518.1

REVISED **Amendments from Version 1**

The title has been modified to better reflect the scope of the study and its preliminary nature. In the abstract, the Results section now focuses exclusively on describing the main outputs of the research. Three figures have been added to provide a clearer view of the site (Figure 1) and of the two case studies (Figure 2: the agger-wall; Figure 3: the house on plot 113W4). Additional details have been incorporated into the text and new footnotes regarding the construction techniques of both the fortification and the house, particularly in the sections "3D Modelling Workflow" and "The Ditch and the House". Consequently, Table 1 (Architectural Energetics Calculations For the 7th-century BC Agger-Wall in Megara Hyblaia) has been supplemented with new references and data. Furthermore, the hypothesis concerning the use of local stone and the nature of the bedrock has been clarified. The study's outcomes are now also contextualised through comparison with other relevant research on architectural energetics. Finally, the demographic estimates—especially the choice of the annual growth rate—are now supported by additional explanations.

Any further responses from the reviewers can be found at the end of the article

Introduction

Megara Hyblaia was part of the first wave of Greek expansion to the West, known as the Greek colonization. Founded in the third quarter of the 8th century BC on the eastern coast of Sicily[1], approximately 20 km north of Syracuse, the city flourished until 483 BC, when Gelo of Syracuse emptied the settlement and deported its inhabitants (Herod.7, 156). Before this upheaval, Megara Hyblaia had expanded to around 60 hectares, a spatial definition that may have been established as early as the first decades of the 7th century BC (see Figure 1).

This era is the one around which this paper revolves, namely: Megara Hyblaia, two generations after the time of its foundation. The earliest known houses date to the late 8th century BC and have been identified only around the Agora. Before this point, it remains undetermined how the first inhabitants sheltered, whether in perennial structures or in tents/huts[2]. Be that as it may, by the mid-7th century BC, residential structures had spread throughout the city, from the agora district to the Southern Plateau and even to its westernmost areas, near the West Archaic Gate. As a matter of fact, houses from the first half of the 7th century are known around the Agora district, where they multiplied compared to the first phase of the late 8th century (estimates in De Angelis, 2003, p.40–45), but also on the Southern Plateau where they seem to appear right in the early 7th century (Gras *et al.*, 2004, p.151–155). On the western end of the urban space, houses from the same era have been uncovered in the vicinity of the Archaic West Gate[3]. This demonstrates that, at this period, housing had stretched to the furthest limits of the intramural space, and this could well be related to the construction of the first defensive line of Megara (see Figure 2).

These structures were first identified on the western limit of the city, before being investigated in its southern part, and then again on the western side[4]. They belong to the "agger-wall" type, which includes, in the latter case, from the outside toward the inside: a ditch, a wall, and a bank. The bank is generally made of the material extracted when digging the ditch, while the wall serves the double purpose of a retaining wall and a fortification wall. The exact chronology for Megara's agger-wall construction remains imprecise, but there is some body of evidence that allows us to realistically place it in the first half of the 7th century, most certainly around the beginning of the century[5]. In ancient cities, the creation of a city wall not only had a defensive purpose but also served to materialise the limits of the urban space (the intramural space, or *asty*).

Two generations or so after the foundation, we therefore witness the temporal and functional conjunction of a fortification that defined and protected the urban space, and of housing that projected itself away from the initial core and up to the furthest limits. The goal of the present article is to estimate whether the Megarian community at that time had the necessary resources to bear the costs of these construction projects—in other words, whether it had the required workforce and time[6]. To that end, we will consider two case studies: the first fortification (the agger-wall, see Figure 3) and the house on plot 113W4 (see Figure 4). The latter is the first to have been extensively excavated and recorded according to the strict requirements of stratigraphic archaeology: we therefore possess first-hand and accurate data on the construction technique and the chronology of the house[7]. Located close to the Northwest sanctuary,

[1] The foundation dates of Megara Hyblaia and of Selinous can be deduced from different traditions. The "Thucydidian chronology" (Thuc. 6, 3–4) implies that Megara was founded in 728 BC. On the other hand, a Diodorus Siculus' account (Diod. 13, 59, 4) precisely states that Selinous was sacked by Carthage 242 years after its foundation, hence in 651/0 BC. Now, Selinous was the colony of Megara and is said by Thucydides to have been founded 100 years after the metropolis: consequently, Megara's foundation date would be 751/0 BC. Be that as it may, the archaeological documentation is more in line with Thucydides' foundation dates.

[2] On the so-called "encampment phase" see Gras *et al.*, 2004, p.523–524. It would mean anyways that the first Megarians waited almost one generation to build long-lasting houses, which seems quite unlikely.

[3] Unpublished excavations. A summary of the main results is in Tréziny, 2008.

[4] The agger-wall fortification was most certainly built only on the west and south side of the city, while the north side was somehow already protected by the declivity toward the Cantera river. No defensive structures have ever been reported on this side before the 6th century BC heavy masonry fortification.

[5] It is not known however whether the wall was built before, allowing houses to be built in security, or after, to protect the houses constructed there. See Gras *et al.*, 2004, p.230–231; Tréziny, 2008.

[6] This study is part of the BICAS project (PI: Frédéric Mège). See grant information.

[7] Unpublished investigations part of the project MEGA 2017–2021 (https://mh2021.hypotheses.org/le-projet-2017-2021). Excavation reports for the years 2017, 2018, 2019 are available online in the *Chronique des activités archéologiques de l'École française de Rome* (https://journals.openedition.org/cefr/213); for the year 2021, online in the *Bulletin archéologique des Écoles françaises à l'étranger* (https://journals.openedition.org/baefe/).



Figure 1. **Megara Hyblaia; in red, Archaic urban space boundaries as defined by 6th century BC walls (background map: open-source data from SITR, https://map.sitr.regione.sicilia.it/gis/rest/services/ortofoto/ortofoto_2019_20cm_sicilia/ImageServer).**

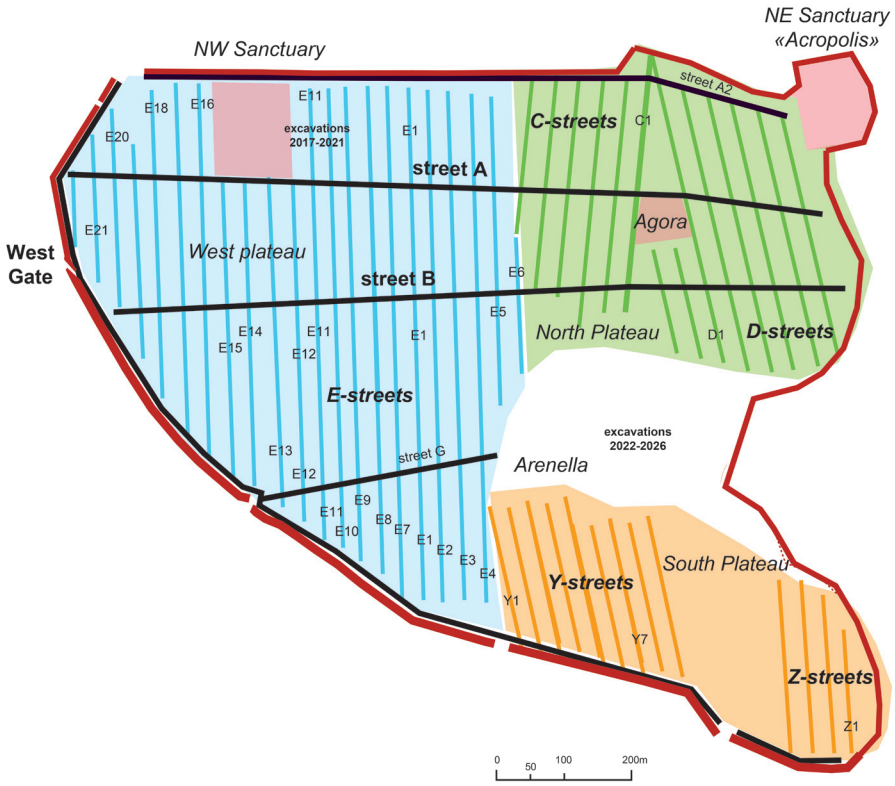


Figure 2. **Megara Hyblaia; diagrammatical plan of the Archaic city.**



a: wall of the agger-wall, west facing



b: embankment (agger) of the agger-wall seen from north



c: embankment seen from south

Figure 3. **Megara Hyblaia; west part of the agger-wall, after 2006 excavations.**



Figure 4. **Megara Hyblaia; the house on plot 113W4 (both phases), after 2018–2019 excavations.**

the first phase can be dated to the first quarter of the 7th century, and thus belonged to the housing expansion to the western area. The ground plan was of the *pastas*-type—a design that tended to become canonical in the cities of Greek Sicily from this time onward (Fusaro, 1982). The agger-wall was also well investigated and its structure accurately characterised, even if the precise dimensions of the ditch still remain somewhat conjectural, not having been fully excavated. To quantify these costs and their implications for the Megarian community, we will appeal to specific methods of investigation: a dedicated digital environment, 3D modelling and Building Information Modelling, and the field of architectural energetics.

3D modelling and BIM for archaeological reconstructions

In recent years, archaeology has become increasingly oriented toward a three-dimensional approach, as 3D technologies are now widely employed to record and analyse archaeological sites and monuments. The availability of this digital documentation enables the development of virtual reconstructions with a high degree of accuracy and scientific rigor, grounded in interpretation and comparative analysis. While these reconstructions are often disseminated primarily for communication and visualization purposes, they also hold significant potential for advancing archaeological research. Moreover, as these reconstructions are based on data obtained through precise digital survey methods, they can also be applied to fields such as architectural energetics, particularly for quantifying the volumetric distribution of construction materials in a given structure (Lancaster, 2021).

The increasing use of 3D reconstructions has prompted the experimental application of Building Information Modelling (BIM)[8] within archaeology—not merely as a modelling tool, but as a potential methodological framework for data management, interpretation, and long-term conservation. Various efforts have been made to apply BIM to archaeological sites; however, preliminary results reveal a wide range of approaches to the subject[9]. To date, only a limited number of projects have utilised BIM to create virtual reconstructions of lost buildings, based on historical and archaeological data, while the majority focus on modelling archaeological remains still *in situ* (Garagnani *et al.*, 2016; Guerrero Vega & Pizzo, 2021). In this context, Megara Hyblaia represented a significant case study through which to explore the potential of BIM as a methodological framework and to experiment with its integration into architectural energetics research. The house on plot 113W4 was modelled using a BIM approach, whereas a more conventional 3D reconstruction was employed to visualize part of the fortifications and their building technique.

Software framework

The field of 3D modelling encompasses a wide array of software solutions, each with distinct strengths and areas of application. Among these, Blender is widely recognised as one of the most versatile and commonly used open-source platforms for 3D modelling[10]. In this regard, an open-source approach to BIM offers several key advantages: it enables the creation of native OpenBIM environments, supports vendor-neutral development, and promotes digital sustainability. Furthermore, it allows for the construction of workflows based on open standards such as IFC (Industry Foundation Classes)[11], which enhance interoperability and data longevity. For this project, Blender was employed alongside *Bonsai*[12], an open-source add-on for BIM modelling currently under development by the Open-Source Architecture community. *Bonsai* is designed to be a comprehensive and native IFC authoring platform, integrating BIM functionalities within Blender (see Figure 5).

3D modelling workflow

Each case study was modelled separately within Blender given the unique methodological approach required for each. In both cases, the virtual reconstruction was informed by excavation data, which provided the precise measurements and details necessary to the modelling process.

The agger-wall system was modelled using traditional manual techniques, as applying BIM to non-building structures remains challenging. The semantic structure of BIM, in fact, is not inherently flexible and is typically not designed to accommodate features beyond architectural buildings. The model represents the first phase of the fortification, dated to the early 7th century BC, in which the embankment was stabilised by a stone retaining wall on the outer side, facing the ditch[13]. This reconstruction was intended to clearly illustrate the construction technique, and thus only a small segment of the landscape was rendered in three dimensions. All available measurements were derived from excavation plans and sections, while some aspects—such as the

[8] Originally developed for architectural design and construction planning, BIM is now widely employed across the Architecture, Engineering, and Construction (AEC) industry. The acronym refers to a process for generating and managing digital representations of the physical and functional characteristics of a facility. As a methodology, BIM enables the creation of semantically enriched 3D models, facilitating the structured management of information throughout the entire life cycle of a building. Given its potential for both visualization and data storage, this methodology has been successfully adapted for built heritage (HBIM) and is increasingly becoming the standard in historic building preservation (see Arayici *et al.*, 2017).

[9] Recent bibliography and overview of the issue in Delpozzo & Balletti, 2023.

[10] The adoption of open-source software plays a crucial role in academic research, as it fosters accessibility, transparency, and long-term reproducibility—values that are particularly significant in the context of virtual archaeology. By contrast, BIM models are predominantly produced using proprietary software, while Free and Open-Source Software (FOSS) solutions remain relatively underdeveloped in this domain.

[11] https://www.buildingsmart.org/standards/bsi-standards/industry-foundation-classes/

[12] https://bonsaibim.org/

[13] For the west part of the agger-wall, the data on construction come from an unpublished excavation report (for a short account, see Tréziny, 2008); from a section drawn in the report, we deduced the alleged width (0,6 m) and height (2 m), although the latter could have been somewhat higher. The masonry technique is described according to the poorly preserved remains found in the south and west part of the agger-wall (see footnote 20).

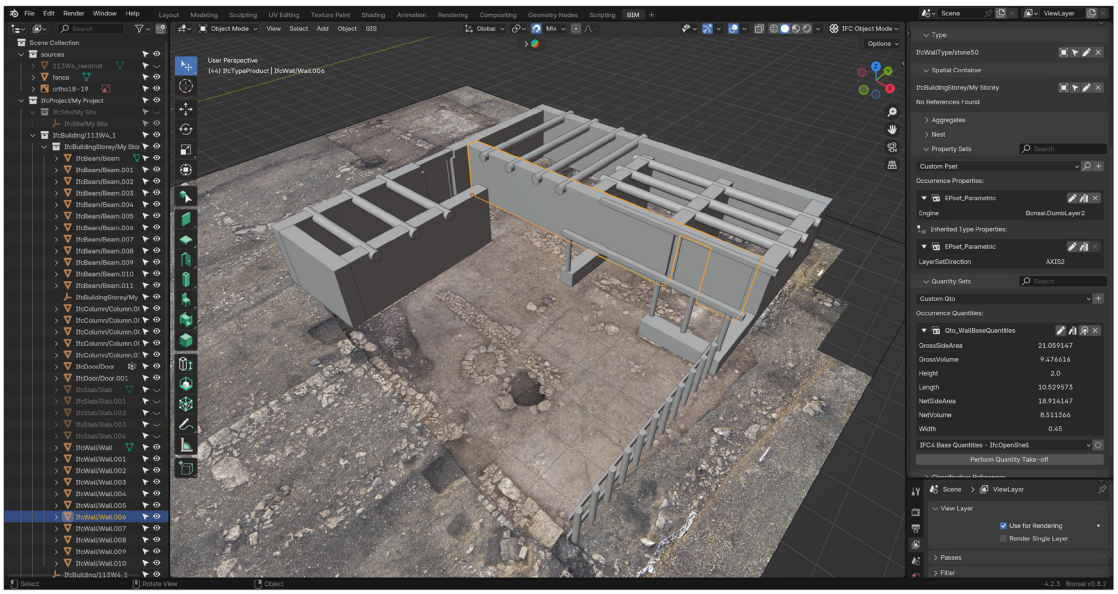


Figure 5. Screenshot of the software interface, showing Bonsai operating within Blender.

total height of the wall—are based on plausible hypotheses (see Figure 6).

For the second case study—the house on plot 113W4—the modelling process began with the import of relevant excavation data into Blender, specifically an orthophoto of the final excavation phase, which was scaled to match the software's unit system. Using Bonsai, a new IFC project was created, and a spatial instance of the building was defined. Within the semantic structure of BIM, this instance functions as a "spatial container" that houses all associated construction elements. These components were defined using standard IFC classes[14], and their geometry was modelled based on both estimated measurements and established knowledge of construction techniques prevalent in the 7th century BC[15]. One of the primary challenges during the modelling process was the accurate reconstruction of the beam layout used to support the roof. In this context, the virtual reconstruction proved essential for testing and verifying the feasibility of multiple structural hypotheses. Information regarding the materials used in construction was also integrated into the model. The building materials correspond to those locally available in the area during the period, including stone, wood, and perishable organic components[16]. Upon completion, the BIM model of house 113W4 was used to estimate the volume of materials required for its construction—data that can serve as a basis for more precise architectural energetics calculations (see Figure 7).

Architectural energetics calculations

The ditch and the house

Various methods exist for estimating the costs of ancient construction projects. Greek and Latin epigraphic sources provide detailed building accounts, listing expenses in local currencies, but these records pertain exclusively to monumental and public structures, particularly temples. For domestic architecture, we must turn to architectural energetics—a methodology developed primarily in Mesoamerican archaeology but later applied to Mediterranean contexts, where epigraphic building accounts serve as useful comparative data[17]. The principle of architectural energetics involves breaking down a building project into separate but interconnected tasks, each requiring a measurable labour investment, expressed in person-days (p-d). In ancient construction, the key tasks included raw material procurement, transportation, and assembly. By quantifying these steps, we can estimate the total labour required to construct a house from scratch, providing valuable insight into the broader effort needed to build sufficient housing for an ancient community.

In the following charts, we present architectural energetics calculations for construction of the agger-wall and of the house on plot 113W4. This analysis is based on a substantial body of

[14] Namely IfcBeam, IfcColumn, IfcDoor, IfcWall, IfcSlab.

[15] Construction techniques in Archaic Megara Hyblaia have been presented by Vallet, Villard, and Auberson, 1976 (p.255–257), summarised in Gras, Tréziny, and Broise, 2004 (p.459–460), and further discussed by Fitzjohn, 2013 (p.633–636). These hypotheses are based on archaeological evidence, visual observations, and reasonable assumptions, given the conservative building methods employed throughout Antiquity (as noted by Pakkanen, 2013, p.55, for the ancient Greek world). Lancaster, 2019 (p.99–100) presents similar domestic architecture in nearby Syracuse. See also Lancaster, 2021 (p.56–58) for further discussion on the flat-roof techniques adopted in the present study.

[16] Lancaster, 2021, p.58.

[17] Non-exhaustive list of publications on the topic in Mediterranean contexts: Brysbaert, 2023; DeLaine, 1997; Devolder, 2013; Fitzjohn, 2015; Lancaster, 2019; Lancaster, 2021; Pakkanen, 2013; Pakkanen, 2021. For a reassessment on architectural energetics in Mesoamerica: Abrams & Bolland, 1999. For a comparison between archaeological records and building accounts, see Pakkanen, 2023.

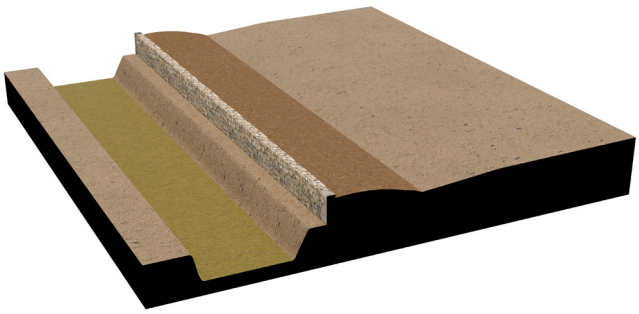


Figure 6. Megara Hyblaia; 3D model of the agger wall construction technique.

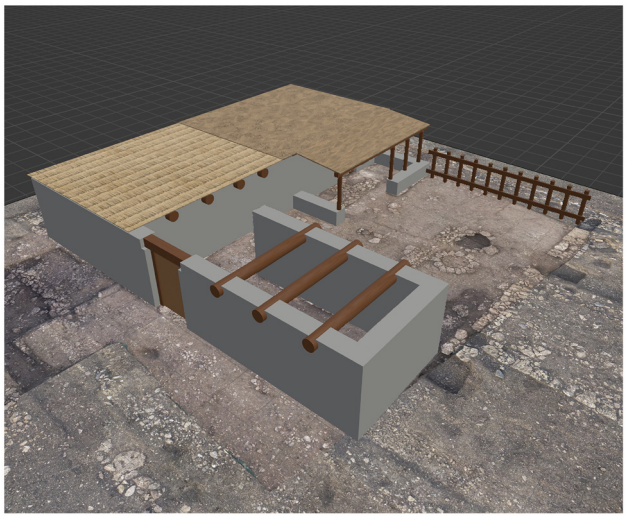


Figure 7. Megara Hyblaia; BIM model of house 113W4, with different roof layers: wooden beams, reed matting, raw earth.

scholarship from the 1990's, in which the methodology was applied across various architectural contexts and building programs (see footnote 17). However, adapting these results to the present study required careful selection and adjustment of figures[18]. One key modification concerns the definition of a working day. Like most scholars, we assume a fixed daily labour duration, accounting also for seasonal variations—shorter daylight hours in winter and extreme heat in summer, which limited effective working time. However, given that these were predominantly agrarian societies, labourers engaged in construction would still have had other essential duties, particularly in food production. We take these duties and we therefore define an effective working day as eight hours—a practical year-round average for outdoor labour[19]. Beyond labour time, several site-specific factors influence construction costs. Access to raw materials varies depending on the local environment, significantly affecting transportation costs. Additionally, workforce availability differed between cities and must be adjusted accordingly—this aspect will be addressed further in the paper.

The architectural energetics calculations for the agger-wall are described and presented in the following chart. The rather simple architecture of this fortification requires only few additional explanations. When digging the ditch, top soil and loose rubble from the bedrock were used to build the embankment (the agger). The bedrock layer could then provide adequate rubble stones[20] to construct the retaining wall (see Table 1; also Figure 3 and Figure 6).

The house on plot 113W4, however, needs some contextualisation. All excavated archaic houses in Megara feature full-stone walls. Like other scholars, we consider that these walls were built using rubble sourced from the local bedrock, whether extracted or simply collected[21]. This was the case for the vast majority of Archaic houses, as implied by Vallet, Villard, and Auberson, 1976 (p.250–252) and Gras, Tréziny, and Broise, 2004 (p.460–465). Recent research on construction stone in Megara (Mège *et al.*, 2020) has confirmed the existence of three main lithotypes used throughout the Archaic period and into the Roman period[22], and has suggested three potential extraction sites[23]. Nevertheless, it has been clearly demonstrated that the walls of Archaic houses were composed of small blocks—either rubble or, at times, ashlars with one worked face[24]. Hence, two scenarios for the procurement of stone are proposed below. Scenario 1: the stone was extracted or collected *ad hoc*. Scenario 2: the construction stone (rubble blocks)

[18] The figures presented here are selected and adapted from some of the above cited works. However, calculations will not be fully detailed: only rates and data source will be indicated. A complete account will nevertheless be published in 2026, after the conclusion of BICAS project.

[19] Same pace used in Brysbaert, 2020, p.62.

[20] For the south part of the agger-wall, Gras, Tréziny, and Broise, 2004 (p.166) describe a type 2a masonry (dry rubble masonry, according to the typology by Vallet, Villard, Auberson, 1976, table 2) very similar to 7th-century houses' walls, though with somewhat larger rough ashlars. The (unpublished) excavations on the west part of the wall reports rubble stones assembled in a similar technique, although smaller, and with their external facing roughly dressed. These rubble stones could be easily extracted from the bedrock layers (see below footnote 34).

[21] See in particular Vallet, Villard, Auberson, 1976, p.247–251, p.258 and Gras, Tréziny, Broise, 2004, p.460–465, followed by Fitzjohn, 2013, p.633, and anew by Fitzjohn, 2015, p.136–137.

[22] The first one is the "Yellowish Calcarenite", a lower Pleistocene packstone with grain-supported texture. The second is the "Panchina", aka "Giuggiulena", a grainstone with grain-supported texture of the middle Pleistocene. The third one, aka "Melilli Stone", comes from the Climiti Mountains Formation (Melilli Member), and is an Oligocene-Miocene wackestone with mud-supported texture. These stone types were first highlighted by Vallet, Villard, Auberson, 1976 (p.248–249).

[23] Respectively, the latter lithotypes correspond to "Cave dell'Intagliata," the Thapsos peninsula, and the "Pirrera di Mellili," all located within a 5 km radius. The first two quarries supplied the most prized stones used in Megarian construction. These were extracted as rough, unworked blocks to be dressed and were intended for monumental structures from the third quarter of the 7th century BC onwards — including temples, civic buildings, fortifications of the late 7th and 6th centuries BC, and sarcophagi. See Mège *et al.*, 2020 and Gras, Tréziny, Broise, 2004, p.460–465.

[24] Rubble masonries: type 1, type 2; ashlars masonries: type 3, type 6, type 7 (Vallet, Villard, Auberson, 1976, table 2). See footnote 15 for further references.

Table 1. Architectural energetics calculations for the 7th century BC agger-wall in Megara Hyblaia.

The agger-wall	Person-days (p-d)	Comments[25]
Ditch Digging		Width = 7 m; Depth = 2 m; Length = 1500 m Total volume = 21000 m^3
soft levels[26]	436,8	Depth = 0,4 m; Volume = 4200 m^3
mixed levels[27]	514,5	Depth = 0,2 m; Volume = 2100 m^3
bedrock[28]	5108,25	Depth = 1,4 m; Volume = 14700 m^3
Removal		
loose rubble[29]	567	Volume = 6300 m^3
rubble stones[30]	661,5	Volume = 1800 m^3
Fortification Construction		Length = 1500 m
embankment[31]	1039,5	Width = 3,6 m; Height = 2 m; Volume = 10800 m^3
wall[32]	2250	Width = 0,6 m; Height = 2 m; Volume = 1800 m^3
finishing[33]	900	External wall facing = 3000 m^2
TOTAL	**11477,55**	

was obtained from the material excavated during the digging of the ditch[34]. Both scenarios are discussed hereafter (see Table 2; also, Figure 4 and Figure 7). Ground plans evolved from single-square-room houses in the late 8th century to the pastas house, which—with minor variations—became the canonical layout from the early 7th century BC onward. While plot sizes varied across different sectors, an average of approximately 120 m^2 can be established.

At first glance, scenario 1 seems more advantageous in that it would cost 9 p-d less to construct the house. This is largely due to the nearness of the raw material, as we consider here that it could come from the cliffs topping the river Cantera, some 100 m away[35] (the nearest sections of the ditch being some 250 m away). Yet, it would seem reasonable to assume that the ditch material was reused somehow[36], as it provided thousands of cubic metres of already extracted stone (see footnote 34). Besides, while the bedrock could conveniently be quarried

[25] Distances are calculated from open-source GIS software QGIS (https://qgis.org). Volumes and areas in constructions are calculated from Blender (see second paragraph).

[26] Adapted from Devolder, 2013. Digging rate in soft sediments = 0,104 p-d/ m^3.

[27] Adapted from Pakkanen, 2021. Digging rate in mixed sediments = 0,245 p-d/ m^3.

[28] Adapted from Pakkanen, 2013. Digging rate in soft bedrock = 0,3475 p-d/ m^3.

[29] Loose rubble used to build the embankment. Adapted from Lancaster, 2019: removal rate for rubbles = 0,225 p-d/ m^3 on a distance d = 25 m. Here, I consider d = 10 m, hence division of the output by 2,5.

[30] Rubble stones used to build the retaining wall. Same as note 28, with d = 5 m.

[31] Adapted from Pakkanen, 2013. Rate for backfilling/constructing embankment = 0,09625 p-d/ m^3.

[32] Adapted from Lancaster, 2019. Building rate for rubble masonry = 1,25 p-d/ m^3.

[33] Adapted from Pakkanen, 2023 (after Pegoretti 1863–64). Rate for rough dressing = 0,3 p-d/m^2.

[34] Given the frangible nature of the bedrock, which belongs to the "Panchina" type (see footnote 26), we make the reasonable guestimate that only half of the extracted material there could be used as rubble stones (hence 7350 m^3, see Table 1). Once the wall of the agger-wall was built, the leftover material usable for construction was around 5550 m^3. Out of this, 125 houses like the one on plot 113W4 could be constructed (see Table 2), offering accommodation for 625 people, therefore more than Megara's whole population at this time (see Table 3).

[35] We suggest that suitable locations may have included the cliffs surrounding the urban area on the northern side (along the Cantera River), on the eastern side (above the sea, as already proposed by Vallet, Villard, and Auberson 1976, pp. 249–250), or possibly the cliffs flanking the small valley known as the "Arenella," situated in the centre of the urban area. Even today, these cliffs crumble into boulders and smaller stones, which could have been conveniently split into rough ashlars. Given the geology of Megara's bedrock and the type of material required here (rubble stone), these locations were more opportunistic collecting sites rather than stone quarries stricto sensu.

[36] The hypothesis of the ditch being used as rubble supplying locus had first been put forward in Gras, Tréziny, Broise, 2004, p.460.

Table 2. Architectural energetics calculations for the 7th century BC house on plot 113W4 in Megara Hyblaia.

House on plot 113W4	Person-days (p-d)	Comments
Stone (walls)		Volume = 44,29 m3
scenario 1: extraction[37]	28,79	
scenario 1: transport	25,3	On back of men[38]
scenario 2: transport	63,27	On back of men[39]
Wood		
beams, door, door frame[40]	27,11	Volume = 4,28 m3
east side enclosure	5,11	Volume = 0,73 m3
pastas props and beams	2,92	Volume = 0,46 m3
transport	5,25	One oxen yoke, with driver[41]
loading/unloading carts[42]	0,82	
Foundations levelling[43]	0,44	Depth = 0,05 m; Volume = 1,26 m3
Walls construction[44]	55,36	
Backfilling + floor foundation[45]	1,18	Thickness = 0,1 m; volume = 12,3 m3
Roofing (framework)[46]	8,38	
Pastas		
wood processing[47]	0,61	Squaring, cutting
posts setting[48]	1,25	
roof framework[49]	0,625	
Roofing (flat roofs)[50]	8,71	Surface = 85,42
Openings		
wood processing	2,79	Squaring, cutting
door construction[51]	4	
door and doorframe setting[52]	3	
Enclosure		
wood processing	3,02	Squaring, cutting
construction	2	
TOTAL (scenario 1)	**186,67**	
TOTAL (scenario 2)	**195,85**	

[37] Adapted from Lancaster, 2019. Extraction rate for rubbles = 0,65 p-d/m^3.

[38] For scenario 1, I have considered: max load/person = 25 kg (stone density = 2,5), round-trip to/from quarrying source = 200 m, max distance/day = 33,6 km, therefore 1,75 m^3/day.

[39] For scenario 2, I have used the same calculation than above and considered the distance between the ditch and the houses on plot 113W4: round-trip = 500 m, so rate = 0,7 m^3/day.

[40] Adapted from Pakkanen, 2013. Soft wood timbers costs (felling, trimming, seasoning) converted in p-d according to size = 3,51 p-d/m^3 (L<4,1 m); 7,01 p-d/m^3 (4,1<L<6,5 m); 10,52 p-d/m^3 (L>6,5 m).

[41] Adapted from DeLaine, 1997. Considering here: max load/carriage = 500 kg (stone density = 2,5), round-trip to/from quarrying source = 13,36 km, max distance/day = 13,36 km. The quarrying source distance (6.68 km) is tentatively estimated based on the maximum range an oxen yoke could travel in one working day, while also aligning with a plausible distance for acquiring construction wood (the Hyblean mounts could be convenient that for). This figure is expressed in p-d (driver) as well as in "oxen-day" (though the latter is not explicitly noted). Research in Megara confirms the presence of oxen by at least the early 7th century BC (see in particular Gras *et al.*, 2004, p.232–235).

[42] Adapted from Lancaster, 2021. Rate = 0,08 p-d/m^3.

[43] Adapted from Pakkanen, 2013. House walls in Megara and Selinous were generally founded directly on a previously levelled ground. Rate for digging in stone solid ground = 0,35 p-d/m^3.

[44] Adapted from Lancaster, 2019. Rate for rubble masonry up to 2 m high = 1,25 p-d/m^3.

[45] Adapted from Pakkanen, 2013. After construction, wall bases were reinforced with backfilling outside and inside. Considering here that most of raw materials for backfilling (earth, pebbles) were available on the construction site after levelling. Rate = 0,1 p-d/m^3.

[46] Adapted from Lancaster, 2021, considering here that beams were primary beams that had to be set with quite simple gear. Rate = 1,66 p-d/beam.

[47] Adapted from Lancaster, 2021. The so-called processing involves operations like squaring the timbers and cutting them into planks (door, lintel) or posts (doorframe, pastas and enclosure). Rate for sawing = 0,18 p-d/m^2.

[48] Adapted from Lancaster, 2021. Rate = 0,31 p-d/post.

[49] Adapted from Lancaster, 2021, considering here that beams were secondary beams, hence rate = 0,31 p-d/beam.

[50] Adapted from Lancaster, 2021. Rate = 0,1 p-d/m^2.

[51] Adapted from Lancaster, 2019. Flat rate for a single door = 2 p-d.

[52] Flat rate for a single door's doorframe setting = 0,5 p-d.

on-site for the few first 8th-century houses[53], it appears problematic to extract on the plateaus' surface the 4429 m^3 required for a hundred 7th-century houses, like the one on plot 113W4, thus leaving several parts of the urban space with large diggings[54].

Be that as it may, the 186–196 p-d range for the house on plot 113W4 falls within the range of comparable figures found in the archaeological literature. For Megara, Fitzjohn, 2015 (Table 1, p.138) gives 324 p-d for House 23,5 (walls volume: 49,5 m^3), albeit with a five-hour working day. A little further afield, in Syracuse, Lancaster, 2019 (Table 5.1, p.100) proposes a broad range of 27–76 p-d, with a ten-hour working day, for a typical one-room house with all-stone walls (14,38 m^3). In Archaic Kasmenai, a house with a flat roof and all-stone walls could be built on a standard plot (12,5 m × 12,5 m — very similar to the dimensions of plot 113W4) within a ten-hour working day, in 225–720 p-d (Lancaster, 2021, Table 4.1, p.59). The figures here are substantially higher, even when considering only the lowest number[55]; this can be explained by the higher input values for transportation (Kasmenai is located on a steep hilltop) and wall construction (more complex ground plans), which account for an extra ≈ 70 p-d. Finally, although in a different geographical and chronological context, Pakkanen, 2021 (Table 2, p. 67; Table 3, p.68) gives 350 p-d for a Hellenistic flat-roofed house in Salamis, built on a 280 m^2 surface, with a ten-hour working day. The ground-plan surface is roughly double that of the house on plot 113W4 and more complex, though with mudbrick walls; all things considered, the figure cited above remains broadly comparable to that of Megara.

Demography and workforce in early 7th-century BC Megara

Estimating workforce availability in early construction projects is particularly challenging, especially for early periods such as archaic Sicily. The figures presented here can only be properly interpreted within the broader context of ancient demography and the resulting labour force capacity. The time period here considered are the first decades of the 7th century BC in Sicily, namely the time of the second generation of settlers, roughly 50 years after the foundation. Assessing the impact of construction programs on a community depends entirely on the number of individuals available for labour—the implications differ significantly if 100 people, rather than 1,000, could be allocated to building activities. Moreover, as previously noted, agricultural cycles played a critical role in workforce distribution. Certain periods of the year were dominated by food production, while other essential tasks—such as the manufacture of pottery, textiles, and furniture—demanded year-round attention (for instance, Brysbaert, 2023). To accurately estimate the available labour force, it is therefore essential to consider the agricultural calendar and seasonal labour constraints. Various demographic estimates for ancient Mediterranean populations have been proposed, often yielding significant variations. Although inherently theoretical, even when supplemented with archaeological data, the models developed by M.H. Hansen within the Copenhagen Polis Centre remain the most comprehensive[56]. Following Hansen's methodology, we would have a 7200–9600 population figure for Megara Hyblaia[57]. Nevertheless, these are only rough average mathematical estimates, which may only correspond to a certain period of each city's urban development, namely the urban development's heyday. They surely cannot apply to the first and even second generations contexts, as defined here for our purpose. We use a different approach here, based on: population estimates in Megara by the late 6th/early 5th centuries BC, population estimates upon foundation time and a fixed annual growth of 2%[58]. It must be underlined that this

[53] The 8th century BC houses used around 15 m^3 of stone. About their most characteristic masonry (the so-called "orthostate type" or type 1), see Vallet, Villard, Auberson, 1976, p.250–251 and Vallet, Villard, Auberson, 1976, Table 2.

[54] Same remark in Fitzjohn, 2015, p.136.

[55] See discussion in Pakkanen, 2021, p.64.

[56] For an application to archaic Sicily, see Lancaster, 2021, p. 85–91 and De Angelis, 2016, p. 137–145. Appropriately called "The Shotgun Method" (Hansen, 2006), this approach is based on intramural area and population density. Although the figures may seem overestimated or somewhat imprecise, the methodology was revised in Hansen, 2008, where it was found that the estimates were actually low in most cases.

[57] For calculation details, see Hansen, 2006, p.60–63. The figures here result from applying Hansen's methodology to the intramural areas of Megara (60 ha), with an adjustment for the proportion of space available for housing. This was calculated using QGIS, by subtracting public and religious areas (e.g., roads, agoras, sanctuaries) from the total intramural area. The estimated maximum urban space available for housing was 80% in Megara.

[58] In Megara, this period is thought to represent the peak of urban development and, consequently, demographic expansion. The calculations are based on an estimated 8,000–10,000 inhabitants by the late 6th century BC (Gras *et al.,* 2004, p. 569–571). The 150–200 colonists at the time of foundation are derived from a reasonable assumption, supported by other relatively precise estimates, which suggest 225–450 inhabitants by the late 8th century BC (De Angelis, 2003, p. 40–45; De Angelis, 2016, p. 137–145).

Table 3. Population estimates (min and max) at different periods in Megara Hyblaia.

	Years			
	0 (foundation)	**+25 (1st generation)**	**+50 (2nd generation)**	**+200 (late 6th c.)**
Population	150	246	**404**	7873
	200	328	**538**	10497

annual growth rate is theoretical and can by no means reflect a natural demographic increase, especially over a span of two centuries. One would rather expect a natural rate within the range of 0,25% to 0,45%, as convincingly put forward by Scheidel, 2003 (p.122–123; see also p.128). That being said, W. Scheidel also acknowledges that natural demographic increases could have occurred at significantly higher rates, though only in limited geographical and chronological contexts (Scheidel, 2003, p.128–129). Nevertheless, the 2% annual growth rate adopted here represents an average intended to reflect the very nature of Megara in the first decades: a remote foundation likely to be continually supplemented by new arrivals. These arrivals may have consisted of a few dozen individuals each year (perhaps 20 to 40), especially during the first generations (colonists, natives, and possibly slaves in later periods)[59]. The following results are presented on two lines corresponding to the two possible population estimates at the beginning (see Table 3).

Demography, however, serves only as a baseline for estimating potential workforce availability. Not all members of a community could engage in the physically demanding tasks of construction. Nonetheless, we challenge the conventional assumption that only able-bodied adult males (aged 18–50) participated. These estimates are thus generally based on army figures, then adapted to workforce by taking into account the wealthiest classes which were probably exempted from these duties, resulting in a 22,5% of the whole population[60]. While activities such as stone extraction or heavy transport were likely performed by adult men, women and older adolescents could have contributed to other construction-related duties[61]. Based on these assumptions, we will rather consider a workforce average of 50% of the total population[62] hence, after Table 3, between 202 and 269 people.

Finally, ancient agricultural practices are well-documented in Hesiod's writings, which provide invaluable insight into the daily rhythms of agrarian communities in the 8th-century BC Greek world. This unique source allows for the reconstruction of a realistic agricultural calendar, helping to determine periods of workforce availability (Brysbaert, 2023; Fitzjohn, 2013; Ingold, 1993). Based on this framework, we estimate that labourers could be available for 150–180 days per year, corresponding to 5–6 months during which they were relatively free from other obligations. From the previous figures, we can deduce that the total of person-days under the worst-case scenario (lowest population x lowest availability) is 30300 and under the best-case scenario (highest population x highest availability) is 48420.

Dividing the number of person-days available yearly for construction by the energy expenditures required to build a house yields the number of new houses that could be constructed within a year (under both worst-case and best-case scenarios). Then, assuming an average household size of five people[63], we can estimate the number of individuals that these newly built houses could accommodate (see Table 4).

Conclusions

This short essay sets out to assess, for the first time, the feasibility of two critical and interrelated construction projects undertaken by an early Greek Sicilian community. In doing so, we have remained acutely aware of the limitations and uncertainties inherent in both architectural energetics calculations and ancient demographic estimates. Taking these constraints into account—and with due caution—our findings suggest that the second generation of inhabitants at Megara Hyblaia, living approximately in the first quarter of the 7th century BC, possessed sufficient human resources to construct both the initial fortification and an adequate number of houses to accommodate the entire population. Notably, these foundational undertakings for communal development could likely have been completed within a single year, without compromising agricultural production or the performance of other essential tasks. Future research will need to refine estimates of both energetic expenditures and demographic structures, in order to more precisely evaluate the costs and labour demands associated with each aspect of the construction programmes. These analyses should also extend to include civic and religious architecture, as well as critical infrastructure such as roads and water management systems. To provide a more comprehensive picture, the inclusion of food and artifact production is essential. Finally, it would be valuable to apply this methodology to other significant periods in the history of Megara Hyblaia—particularly the 6th century BC, when major construction projects such as temples, civic buildings, and fortification walls were undertaken. This later phase should be examined with reference to its evolving sociopolitical

Table 4. Number of new houses and their occupants (min and max), during the 2nd generation in Megara Hyblaia.

New houses	146
	233
Occupants (persons)	730
	1165

[59] Lancaster, 2021 (p.88–89), for instance, applies a global rate of 1% to Kasmenai for its whole Archaic phase, which includes additional immigrated individuals. These considerations and calculations concerning ancient demography in Megara should be further clarified and explained in a forthcoming dedicated article.

[60] Synthesis and explanation in Lancaster, 2021, p. 42–44, 90–91.

[61] Turner, 2021, p.197, expresses the same opinion.

[62] The population pyramid presented in De Angelis, 2003 p. 46 allows for a 55% of the total population estimate aged 15–55. Hence around 50% if we apply the minus 10% of exempted people.

[63] This 5 people figure is the average number of a household in the ancient Greek World according to Hansen, 2008, p. 61.

context, marked by a more structured society and the emergence of labour specialisation.

Besides, this study has demonstrated the potential of 3D modelling and BIM tools in the analysis of ancient architectural structures, despite certain known limitations. While BIM's defined framework offers significant advantages, it can struggle to accommodate the complexity and irregularity of heritage subjects, especially non-standard elements like the agger-wall. Nevertheless, the capacity of these tools to integrate visualization, analysis, and data makes them highly valuable. Future developments will focus on incorporating 4D and 5D modelling into the models, generating automated estimations of construction time and cost based on detailed input data. In this way, it will be possible to further enhance the scope and utility of digital heritage models.

Data availability

The data that support the findings of this study are openly available:

In Datarepository Unive (Ca' Foscari University of Venice)

At https://doi.org/10.71731/DATA_UNIVE/XU7LS1 (MeGE, 2025)

Data are available under the terms of the Attribution-Non Commercial-NoDerivatives 4.0 International (CC BY-NC-ND 4.0).

References

Abrams EM, Bolland TW: **Architectural energetics, ancient monuments, and operations management.** *J Archaeol Method Theory.* 1999; **6**: 263–291.
Publisher Full Text

Arayici Y, Counsell J, Mahdjoubi L, (eds.), *et al.*: **Heritage Building Information Modelling.** London, Routledge, 2017.
Publisher Full Text

Brysbaert A: **'Forces of the hands, forces of the lands': an awareness of physical and social multi-tasking in the agrarian and economic landscape of the Late Bronze Age Argive Plain.** *Groniek.* 2020; **223**: 59–82.
Reference Source

Brysbaert A: **Labour and its cost during the Aegean Late Bronze Age.** In: Barker, S.J., Courault, C., Domingo, J.Á., Maschek, D., *From Concept to Monument. Time and Costs of Construction in the Ancient World. Papers in Honour of Janet DeLaine. Proceedings of a conference held in Wolfson College, Oxford, 16–18 January 2020*. Archaeopress, Oxford, 2023; 233–265.
Reference Source

De Angelis F: **Archaic and classical Greek Sicily: a social and economic history.** Oxford University Press, Oxford, 2016.
Publisher Full Text

De Angelis F: **Megara hyblaia and selinous. The development of two Greek city-states in Archaic Sicily.** Oxford University School of Archaeology, Oxford, 2003.
Reference Source

DeLaine J: **The baths of Caracalla: a study in the design, construction, and economics of large-scale building projects in imperial Rome.** *Journal of Roman Archaeology.* Portsmouth, Rhode Island, 1997.
Reference Source

Delpozzo E, Balletti C: **Bridging the gap: an open-source GIS+BIM system for archaeological data. The case study of Altinum, Italy.** *Int Arch Photogramm Remote Sens Spatial Inf Sci.* 2023; **XLVIII-M-2**: 491–498.
Publisher Full Text

Devolder M: **Construire en Crète minoenne. Une approche énergétique de l'architecture néopalatiale.** Peeters, Louvain, Liège, 2013.
Reference Source

Fitzjohn M: **Bricks and mortar, grain and water: tracing tasks and temporality in Archaic Sicily.** *World Archaeol.* 2013; **45**(4): 624–641.
Publisher Full Text

Fitzjohn M: **The economics of house construction and the temporality of daily life: quantifying construction practices to understand economic organisation, time and space in archaic megara hyblaea.** In: Di Castro, A.A., Hope, C.A. (Eds.), *Housing and Habitat in the Ancient Mediterranean. Cultural and Environmental Responses*. Peeters, Louvain, Paris, Bristol CT, 2015; 133–142.

Fusaro D: **Note di architettura domestica greca nel periodo tardo-geometrico e arcaico.** *Dialoghi di Archeologia.* 1982; **1**: 5–30.

Garagnani S, Gaucci A, Gruška B: **From the archaeological record to ArchaeoBIM: the case study of the Etruscan temple of Uni in Marzabotto.** *Virtual Archaeol Rev.* 2016; **7**(15): 77–86.
Publisher Full Text

Gras M, Tréziny H, Broise H: **Mégara Hyblaea 5. La ville archaïque. L'espace urbain d'une cité grecque de Sicile orientale.** EFR, Rome, 2004.
Reference Source

Guerrero Vega JM, Pizzo A: **Análisis arquitectónico y aplicación de metodología BIM en el santuario extraurbano de Tusculum.** *Archeologia e Calcolatori.* 2021; **32.1**: 99–116.
Publisher Full Text

Hansen MH: **An update on the shotgun method.** *Greek Roman Byzantine Stud.* 2008; **48**(3): 259–286.
Reference Source

Hansen MH: **The shotgun method. The demography of the Ancient Greek city-state culture.** University of Missouri Press, Columbia, Londres, 2006.
Reference Source

Ingold T: **The temporality of the landscape.** *World Archaeol.* 1993; **25**(2): 152–174.
Publisher Full Text

Lancaster J: **Virtually reconstructing the past.** L'Erma di Bretschneider, Rome, 2021.
Reference Source

Lancaster J: **To house and defend: the application of architectural energetics to southeast Archaic Greek Sicily.** In: McCurdy, L., Abrams, E.M. (Eds.), *Architectural Energetics in Archaeology*. Routledge, Oxon, New York, 2019; 95–113.
Publisher Full Text

MeGE F: **Megara_House 113W4 + Agger wall.** Datarepository Unive, V1, 2025.
http://www.doi.org/10.71731/DATA_UNIVE/XU7LS1

Mège F, Belfiore C, Monaco C, *et al.*: **Premier bilan des recherches préliminaires sur la pierre de construction à Mégara Hyblaea.** *Mélanges de l École française de Rome Antiquité.* 2020; **132–2**: 339–357.
Publisher Full Text

Pakkanen J: **Building accounts, monumental construction projects, and labour rates in the classical and hellenistic periods.** In: Barker, S.J., Courault, C., Domingo, J.Á., Maschek, D., *From Concept to Monument. Time and Costs of Construction in the Ancient World. Papers in Honour of Janet DeLaine. Proceedings of a conference held in Wolfson College, Oxford, 16–18 January 2020.* Archaeopress, Oxford, 2023; 266–285.
Reference Source

Pakkanen J: **Building big and Greek classical and hellenistic houses? Estimating total costs of private housing in Attica.** In: Pakkanen, J., Brysbaert, A. (Eds.), *Building BIG – Constructing Economies: from Design to Long-Term Impact of Large-Scale Building Projects*. Propylaeum Heidelberg University Press, Heidelberg, 2021; 59–75.
Publisher Full Text

Pakkanen J: **The economics of shipshed complexes. Zea, a case study.** In: Blackman, D.J., Rankov, B., Baika, K., Gerding, H., Pakkanen, J. (Eds.), *Shipsheds of the ancient Mediterranean*. Cambridge University Press, New York, 2013; 55–75.
Reference Source

Scheidel W: **The Greek demographic expansion: models and comparisons.** *J Hell Stud.* 2003; **123**: 120–140.
PubMed Abstract | **Publisher Full Text**

Trézíny H: **Mégara Hyblaea.** *Mélanges de l'école française de Rome.* 2008; **120/1**: 256–260.
Reference Source

Turner D: **Comparative labour rates in cross-cultural contexts.** In: Pakkanen, J., Brysbaert, A. (Eds.), *Building BIG – Constructing Economies: from Design to Long-Term Impact of Large-Scale Building Projects*. Propylaeum Heidelberg University Press, Heidelberg, 2021; 195–217.

Vallet G, Villard F, Auberson P: **Mégara Hyblaea 1. Le quartier de l'agora archaïque.** EFR, Rome, 1976.
Reference Source

Open Peer Review

Current Peer Review Status: ? ✓ ? ✓

Version 2

Reviewer Report 06 January 2026

https://doi.org/10.21956/openreseurope.23598.r65629

© **2026 Kocaman İ.** This is an open access peer review report distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

✓ **İrfan Kocaman**
Erzurum Technical University, Erzurum, Turkey

Reviewer Comments

The manuscript presents an original and interdisciplinary approach to evaluating early construction capacity through architectural energetics supported by 3D modelling and BIM-based volumetric estimations. The study is clearly structured, well-documented archaeologically, and contributes valuable quantitative insight into early Archaic urban development. Overall, the paper is suitable for publication after **minor revisions** aimed at improving clarity and methodological transparency, particularly from an engineering-oriented perspective.

1. While the architectural energetics framework is well applied, it would be beneficial to more explicitly clarify that the proposed dimensions of the agger-wall (e.g., wall thickness and height) are interpretative reconstructions rather than performance-based engineering designs. A short clarification acknowledging this distinction would help avoid possible misinterpretations by readers from engineering disciplines.
2. The discussion of construction materials is archaeologically sound; however, briefly indicating typical ranges of material properties reported in the literature (e.g., for dry rubble masonry or local stone) would strengthen the transparency of the assumptions without requiring additional analyses.
3. The use of BIM as a tool for geometric reconstruction and volumetric estimation is well justified. It may be helpful to explicitly state that BIM is employed here primarily as a quantitative modelling aid rather than for structural or performance-based analysis, in order to clearly frame its methodological role.
4. The labour and productivity rates adopted are reasonable and well referenced. A short statement acknowledging that these values represent average estimates—and that minor variations would not significantly affect the overall conclusions—would further reinforce the robustness of the results.
5. The conclusions are coherent and well aligned with the presented data. A brief reminder that the findings represent a feasible scenario under favourable conditions would appropriately contextualize the results while preserving their significance.

The paper is scientifically sound, methodologically innovative, and clearly written. The suggested revisions are minor and primarily intended to enhance clarity and interdisciplinary readability

rather than to request additional analyses. After these small adjustments, the manuscript will be well suited for publication.

Is the work original in terms of material and argument?
Yes

Does it sufficiently engage with relevant methodologies and secondary literature on the topic?
Yes

Is the work clearly and cogently presented?
Yes

Is the argument persuasive and supported by evidence?
Yes

If any, are all the source data and materials underlying the results available?
Yes

Does the research article contribute to the cultural, historical, social understanding of the field?
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Structural and earthquake engineering; seismic performance assessment of masonry and historical structures; numerical modelling (FEM); dynamic analysis of heritage buildings; strengthening and conservation of cultural heritage structures.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Reviewer Report 30 December 2025

https://doi.org/10.21956/openreseurope.23598.r65633

© 2025 Gil-Ozoudeh I. This is an open access peer review report distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

?

Ifechukwu Gil-Ozoudeh
Enugu State University of Science and Technology, Enugu, Enugu, Nigeria

The manuscript explores how digitalisation and intelligent technologies—such as BIM, IoT, AI, VR, and smart systems—are transforming environmental design. It presents a broad literature review and a detailed case study of Chongqing Lijia Smart Park, using hierarchical analysis and fuzzy

evaluation to assess the effectiveness of digital-intelligent integration in environmental design. The article concludes with projected trends, including human-centred design, sustainability, interdisciplinary integration, and enhanced user participation.
Overall, the topic is timely and relevant, especially in the context of smart cities and data-driven environmental design. The case study is well chosen and aligns with the article's objectives.

Major Comments (Points that Must Be Addressed)
1. Originality of the Argument — *Partly*
While the manuscript covers important themes, its originality is moderate. Much of the discussion reiterates established knowledge (e.g., BIM benefits, IoT sensing, AI-enhanced UX). The article would benefit from a clearer statement of **what is new** about the proposed "innovation paths."
Required Improvement:
Add a distinct contribution statement clarifying what novel insight or framework the paper adds beyond existing literature.
2. Engagement with Secondary Literature — *Partly*
The literature cited is extensive but not always critically synthesised. The review occasionally becomes descriptive rather than analytical.
Required Improvement:
Strengthen the literature engagement by comparing differing scholarly perspectives, identifying gaps, and highlighting where the authors' argument intervenes.
3. Methodological Rigour — *Partly*
The hierarchical analysis + fuzzy evaluation approach is sound, but more methodological transparency is needed.
Must Clarify:
- How the evaluation indicators were selected and validated
- The criteria for expert selection
- Potential biases in the questionnaire (sampling, demographics, representativeness)
- Limitations of a single-site case study

Without these clarifications, the robustness of the findings remains uncertain.
4. Clarity and Coherence — *Partly*
The manuscript is readable but contains:
- Long, repetitive sentences
- Occasional grammatical inconsistencies
- Paragraphs with overlapping ideas
- A need for clearer transitions between major sections

Required Improvement:
A full language and structure polishing is recommended. Streamline repeated content in the introduction and discussion.
5. Persuasiveness of the Argument — *Partly*
The empirical results are well presented but the analysis is somewhat descriptive.
To strengthen persuasiveness, please:
- Explain *why* certain indicators performed better or worse
- Discuss unexpected findings
- Connect the results more explicitly to the theoretical claims
- Reflect on how the findings advance environmental design practice as a discipline

Minor Comments (Recommended Enhancements)

1. Consider adding diagrams or conceptual figures summarising:
    - The integration framework of digital + intelligent + environmental design
    - The evaluation model
2. The conclusion would be stronger with:
    - A clearer articulation of global relevance
    - More specific future research directions
3. Some references appear region-specific; include more international comparative works if possible.
4. Ensure consistent terminology (e.g., “environmental design,” “environment design,” “environmental art design”).

Overall Assessment

The manuscript addresses an important topic and demonstrates significant effort in both theoretical synthesis and empirical evaluation. However, revisions are needed to improve the originality, analytical depth, clarity of methodology, and coherence of argumentation.

My recommendation:

Revision Required (Moderate to Minor)

Once the issues above are addressed, the article has the potential to make a meaningful contribution to discussions on digital and intelligent transformations in environmental design.

Is the work original in terms of material and argument?

Partly

Does it sufficiently engage with relevant methodologies and secondary literature on the topic?

Partly

Is the work clearly and cogently presented?

Partly

Is the argument persuasive and supported by evidence?

Partly

If any, are all the source data and materials underlying the results available?

Yes

Does the research article contribute to the cultural, historical, social understanding of the field?

Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Architecture, Renewable Energy, Sustainability Urban Housing, Materials

Engineering

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Version 1

Reviewer Report 14 October 2025

https://doi.org/10.21956/openreseurope.22202.r60915

© 2025 Palieraki V. This is an open access peer review report distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Vasiliki Palieraki
Civil Engineering, National Technical University of Athens Ship Design Lab, Zografou, Attica, Greece

The current study is very interesting. Adding some additional information regarding the research, could be helpful for the readers.
1. In page 5, in the paragraph "3D modelling workflow" you are writing about the information regarding the materials. You are suggested to add some information in the paper, regarding the materials as well as the height of the remainings.
2. You are suggested to describe in more details the model shown in Figure 4, and based on which information the model has been constructed.
3. According to the reviewer, the width of the wall (0,6m) seems rather limited, while on the other hand the height, in case it refers to the initial height, is again small for such a structure.
4. Please, explain how the walls have been constructed, and if there is information about the use of mortar and not only stones.

Is the work original in terms of material and argument?
Yes

Does it sufficiently engage with relevant methodologies and secondary literature on the topic?
Yes

Is the work clearly and cogently presented?
Partly

Is the argument persuasive and supported by evidence?
Partly

If any, are all the source data and materials underlying the results available?
No source data required

Does the research article contribute to the cultural, historical, social understanding of the field?
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Civil Engineering, Ancient Monuments, Behavior of monuments, experimental testing, analysis

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Author Response 04 Nov 2025

Frédéric Mège

Dear colleague, Thank you for taking the time to read our article and for your valuable comments. Your remarks have certainly helped improve the quality of our study. Most of your comments (points 1, 2, and 4) have been taken into account and had, in fact, also been raised by the first reviewer, Felat Dursun. Regarding point 3 specifically, we understand that the dimensions of the wall may appear somewhat limited from a defensive perspective. However, this type of wall formed only part of a broader system: it was preceded by a large ditch and followed by a relatively wide embankment. Moreover, such a structure also had a symbolic purpose: to delineate the boundaries of the urban space (asty) in relation to the suburb (proasteion) and the territory (chôra), while signalling to outsiders the presence of a “civilised” settlement. Indeed, after some fifty years, the Megarians felt the need to construct a more substantial fortification built with large ashlar blocks (2nd and 3rd phases). As for the dimensions, we deduced the wall’s width (0,6 m) from sections drawn in the poorly preserved southern and eastern parts of the agger-wall, while the 2 m height is an informed estimate based on the extant remains (around 1,5 m) and on the likelihood that the wall was built without scaffolding, as was the case for domestic walls, on such an early period. We hope that we accordingly answered to your questioning and we would like to thank you again for your review.
With best regards, Frédéric Mège and Eleonora Delpozzo.

Competing Interests: No competing interests were disclosed.

Reviewer Report 01 September 2025

https://doi.org/10.21956/openreseurope.22202.r57321

© 2025 DURSUN F. This is an open access peer review report distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

?

Felat DURSUN
Department of Conservation and Restoration of Cultural Heritage, Izmir Institute of Technology, Urla,, İzmir, Turkey

Review on
The Ditch and the House. Megara Hyblaia by the early 7th c. BC.

This study aims to assess whether the Megarian community of the period had the workforce and time needed to meet the costs of the construction projects under consideration. For this purpose, the authors focused on Architectural Energetics calculations for two case studies: the agger-wall fortification and the house located on plot 113W4. The article provides useful data and serves as an important example of applying Architectural Energetics. However, the basis and accuracy of the calculations, as well as the integration of BIM applications, should be supported with more concrete evidence. Adding visual materials would help readers better understand the site and link the interpretations to the context. It would also be valuable to compare the results with similar studies to give a wider perspective and highlight the importance of the findings.

Below the author can follow my notes and recommendations,

Considering the title of the manuscript, it is recommended to make it more specific and revise it so that it clearly reflects the aim and focus of the study. In its current form, the title does not adequately reflect the concept or purpose of the research.
Abstract:
The structural format of the abstract is generally acceptable; however, it is recommended to revise the results and conclusion subsections so that the results focus on the actual findings rather than interpretations (particularly in the results section). the conclusion section, on the other hand, some points are repeated from the introduction, which should be avoided. Instead, it would be more effective to emphasize the core results and the main conclusions of the study.
Intro:
-please provide supportive images of the study area, overall view, the mentioned ditch, the dimensions of the stone, and agger-wall, etc.
-please provide additional references, especially on reconstruction of ancient lands and the use of local materials in ancient dwellings. (see p4: 3D modelling and BIM for archaeological reconstructions)
-Figure 1. Schematic plan of archaic Megara Hyblaia.
Here it would be better to provide some images from the site to grasp the overall view of the site.
-Table 1. Architectural energetics calculations for the 7th century BC agger-wall in Megara Hyblaia.
Please be more specific regarding the bases of your estimated person-days calculations

Architectural energetics calculations
-Regarding the following statements: (p7)
Statement1: “Yet, it would seem reasonable to assume that the ditch material was reused

somehow, as it provided thousands of cubic metres of already extracted stone (see note 17)."

To reach such a statement it is recommended to evaluate the stone layers. without assessing the discontinuity sets and their relationship to the bedding plane, thickness, etc. it is not possible to conclude whether a stone layer is suitable for cut stone production. A proper building stone suitability assessment combines discontinuity analysis (often done via scanline surveys or mapping), laboratory testing, and quarrying feasibility studies. yes, they can be used as aggregate for mortar and plaster production, however as a cut stone, it is essential to evaluate their block size and shape. for insantce, if discontinuities are too closely spaced, the stone will break into small fragments rather than yielding large blocks. If they are too far apart or poorly oriented, the extraction process becomes costly or impossible.

Statement2: "Scenario 1: the stone was extracted ad hoc. Scenario 2: the construction stone (rubble stones) came from the material extracted when the ditch was dug. (P7-8)"
In both scenarios, the approach applied in the calculations appears open to discussion. Esp., the observations in Scenario 1 involve considerable uncertainties. Could you please clarify the rationale for assuming that the raw material originated from cliff toppings and indicate the basis for this assumption? If any quarry has been identified, it would be helpful to provide supporting explanations and relevant visual documentation.

- The discussion of the results, particularly in relation to studies conducted in the close vicinity or within a similar archaeological period, is lacking. Including comparisons with such studies would strengthen the discussion and provide valuable context for the findings.

Conclusions

Here, there is a strong emphasis on the study's limitations and suggestions for further research. When considered within the framework of Architectural Energetics, this "short essay" lacks certain detailed analyses and findings that could significantly influence the calculations. However, as the present study holds substantial value on its own, it may be beneficial to characterize it as a preliminary study.

Is the work original in terms of material and argument?

Yes

Does it sufficiently engage with relevant methodologies and secondary literature on the topic?

Partly

Is the work clearly and cogently presented?

Partly

Is the argument persuasive and supported by evidence?

Partly

If any, are all the source data and materials underlying the results available?

No source data required

Does the research article contribute to the cultural, historical, social understanding of the field?
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: stone conservation, geoheritage, geoarchaeology, material characterization, site selection

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Author Response 04 Nov 2025

Frédéric Mège

Dear colleague, Thank you very much for taking the time to read our article and for providing your valuable comments. Your remarks have certainly helped us improve the quality of our study. We would nevertheless like to respond to some of your points and explain how we have addressed them in the revised version. As you rightly suggested, the title of the manuscript has been modified accordingly. In addition, the *Results* section of the abstract now lists only the main findings, as is appropriate. Following your recommendation, we have added three new figures to better support the text and help readers visualize the site and the structures under investigation. The calculations in Table 1 are now described in greater detail, which was indeed missing in the original version. Finally, as per your suggestion, the architectural energetics results for the house are now compared with similar data, allowing readers to place our findings in a broader context. Regarding the construction materials in general, and stone in particular, we have worked to clarify our hypotheses and the evidence on which they are based. However, as often happens in Classical archaeology, the type of detailed data you requested—such as fine characterisations determining the suitability of specific stones for construction—are unfortunately lacking. One of us has, however, carried out a separate project that included petrographic analyses of the main stones used in Megara, and some of these results are now incorporated into the article. It should be emphasized that the stones used for the retaining wall of the agger-wall and the house were small ashlars, possibly roughly dressed, or even rubble stones. Neither of these structures employed the large ashlar blocks used in Megara's monumental buildings (such as the second and third phases of the Archaic fortifications, temples, and civic buildings of the late 7th and especially 6th centuries BC). Those large blocks were extracted from more distant quarries that provided suitable stone for major construction projects. Therefore, we have maintained our initial hypothesis—supported by geological observations and investigations—that the rubble stones used for the 7th-century fortifications and houses were locally sourced, in some cases simply collected. The reuse of material extracted from the bedrock during ditch excavation to build houses remains, in our view, highly plausible. The cliffs bordering the plateaus where the urban area was located also appear to have been suitable places from which builders could obtain the rough ashlars they required. We hope that these

clarifications and the revisions made to the article will help you gain a clearer understanding of our study. Once again, we sincerely thank you for your time and for your thoughtful and constructive feedback. With best regards, Frédéric Mège and Eleonora Delpozzo.

Competing Interests: No competing interests were disclosed.