Research Article

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Networks of Pots: The Usage of Ceramics in Network Analysis in Mediterranean Archaeology

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Abstract: Pottery studies constitute a core domain in archaeology. The establishment of typo-chronologies forms the backbone of most chronological inferences in Mediterranean archaeology in particular. Computational approaches such as network science can help us expand the interpretative and explanatory power of these material frameworks in our understanding of the past. Network science has increasingly become mainstream in archaeology, yet, its applications in Mediterranean archaeology remain uneven and highly differential in scope and depth. In this article, I explore the potential and limitations of network science using three case studies of network analysis from Mediterranean archaeology. Each case study relates to a different research specialization and covers a different time period. I then show some of the potential of network analysis for pottery studies using an example from my own research on late Hellenistic and early Roman pottery from the eastern Mediterranean. This article outlines a way forward in which material specialists closely collaborate with other specialists such as computer scientists to develop new forms of synergy between computational methods and domain knowledge that can lift research outcomes to a higher level.

Keywords: network science, pottery, Mediterranean archaeology, connectivity

1 Introduction

Pottery studies have been part and parcel of archaeology since its origins as a scientific discipline. Ever since, standardized approaches to pottery analysis have focused on particular sets of observable parameters to assess modes of production (Costin, 1991; Peacock, 1977; van der Leeuw, 1977), classification (Read, 2007), distribution (Brughmans & Poblome, 2016b), technologies (Thér, 2020; van der Leeuw, 1976), and more. Material studies typically entail the establishment of two main components: typology and chronology, often pursued in combination as typo-chronologies to determine the chronological lifespan and variation for a class of objects. For this purpose, endless heaps of material have been amassed, described, and compiled in voluminous catalogues. In recent years, the usage of scientific methods, including among others geochemical analysis, petrography, and isotope studies, to assess provenance and composition of ceramics, has increasingly become commonplace in the field of pottery studies (see, for example Hein, 2018; Hunt, 2017; Irto et al., 2022; Kelepeshi et al., 2024; Roux, 2019; Vannoorenberghe et al., 2020 for overviews and recent applications).

Especially in (Classical) Mediterranean archaeology, traditional studies of material artefacts remain the alpha and omega of the disciplinary practice. The immense merits of these traditional approaches for the development of reliable frameworks of interpretation as the foundation of archaeological reasoning cannot be overstated.

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Yet, the field of pottery studies has not always kept up well with new developments within and beyond archaeology. The recent upsurge in computational approaches in archaeology has produced a fresh breeze invigorating material studies and providing new ways of interpreting material culture. Computational methods such as modelling and network science allow us to move beyond the establishment of types and chronologies and help us explore potential drivers and causal mechanisms underlying observed patterns of production and distribution (Daems, 2021b).

In this article, I will first present three case studies of network science based on ceramics. While it is impossible within the scope of this article to provide a comprehensive overview of network analysis in archaeology, I have selected these case studies to cover a range of different chronological periods and multiple methodological approaches. This way, I aim to provide some snapshots shedding light on the broader current status of the field. For each period and the methodological approach, alternatives could have been chosen. Yet, the current selection serves its purpose of providing a starting point for the broader point I will make in Section 5. The first case study explores the emergence of hegemony in Bronze Age Southern Italy through the lens of the Marxist social theory using shared stylistic features in pottery (Iacono, 2016). The second case study focuses on patterns of trade and economic integration in the Roman Empire based on shared pottery wares and types derived from the *Inventory of Crafts and Trade in the Roman East* (ICRATES) dataset of terra sigillata pottery (Brughmans & Poblome, 2016c). The third case study covers Byzantine trade networks based on shared pottery wares using dynamic and interactive mapping approaches (Yangaki, 2018).

After these three cases, I will present a fourth case study based on my own research to show some of the hitherto untapped or underutilized potential for the usage of ceramics and network science in Mediterranean archaeology. The aim of this article is to show the potential of such network science approaches for the usage of material culture in archaeology in general, and Mediterranean archaeology in particular. I argue in particular for the importance of collaboration between computer scientists and material specialists to obtain the best results. The end goal of the approaches presented here is to develop a disciplinary framework where archaeological and computational approaches mutually reinforce each other through their respective strengths of rich interpretability and analytical tractability. We will only be able to make progress when computational archaeologists make a serious effort to do justice to the works of material specialists, and vice versa, when these specialists approach computational methods with an open mind and readiness to tap into their vast knowledge from new angles. This article aims to provide an outline for a potential path forward in this vein.

2 Interaction, Connectivity, and Networks

Human societies are fundamentally built on interactions and connections. Connections between people allow for communication, the transfer of knowledge, and coordination of activities. It should therefore not come as a surprise that connectivity has long been a major topic in the study of social systems in general, and past social systems in particular (Brughmans & Peeples, 2023; Knappett, 2021; Pitts & Versluys, 2016). This focus on connectivity and interactions is part of a broader relational turn in the humanities with an emphasis on relations and connections, which has even been touted as a new paradigm centred on the concept of interactions in social networks (Kristiansen, 2014).

The Mediterranean as an almost fully enclosed body of water lends itself perfectly to the study of interaction and connectivity between landmasses across and throughout the nexus of the sea (Abulafia, 2012; Broodbank, 2013; Horden & Purcell, 2000; Leidwanger & Knappett, 2018). It is not surprising to see network approaches applied throughout most subdisciplines and chronological specializations in Mediterranean archaeology, with a rich methodological variety. Proximal point analysis was applied to understand centrality in the Early Bronze Age Cyclades (Broodbank, 2000). "Small world" network models have been used to assess the position of marginal island and coastal sites in the central Mediterranean during the Bronze Age (Dawson, 2021). Spatial interaction models have been used in the study of the Middle Bronze Age Aegean (Evans et al., 2009; Knappett et al., 2008), Bronze Age Crete (Bevan & Wilson, 2013), Archaic Greece (Rihll & Wilson, 1987), and

Roman Baetica (Isaksen, 2008). Social network analysis has been used among others to study inter-site connections in the western Mediterranean during the Neolithic period (Freund & Batist, 2014) and to explore Roman perceptions of space through an analysis of transportation routes in the western Roman provinces using the Antonine Itineraries (Graham, 2006). Network modelling has been used in various case studies, including the exploration of urban-rural integration in Bronze Age Crete (Haggis, 2002), cost-surface modelling for Early Bronze Age interaction networks (Jarriel, 2018), and the application of similarity networks to explore diffusion patterns in Hellenistic Italy and Greece (Östborn & Gerding, 2015). Finally, computational modelling techniques such as agent-based modelling have been used to trace economic integration under the Roman empire (Brughmans & Poblome, 2016a, c).

Societies can be considered massive networks of interacting components (individuals, social groups, communities, and so on) generating emergent collective behaviour without centralized control that cannot be reduced to the properties of its constituent parts. Human societies are inherently complex systems. Understanding the complex behaviour, drivers, and feedback loops characterising such systems requires the right conceptual and methodological framework using appropriate tools and theories (Thurner et al., 2018).

Networks are one of the crucial components of the study of complex systems, and network science is one of its main tools. The term network is often used in a colloquial sense as a general shorthand for connectivity. The main advantage of network science, however, is that it allows us to describe and understand the structures and properties of interactive units through the definition of entities (nodes, vertices, or actors) and the connections (links, edges, or ties) between them in a formal and mathematical way (for introductions to network science in general and in archaeology, see among others: Brughmans & Peeples, 2023; Brughmans et al., 2024; Caldarelli & Catanzaro, 2012; Estrada & Knight, 2015; Newman, 2010).

Effective network science requires suitable abstraction and representation of entities in the system of interest (see the figure depicting the typical archaeological network research process in Brughmans & Peeples 2023, p. 11). If we want to understand the causal and generative dynamics of social systems, we need to define the crucial boundaries, elements, and relationships that make up that system. Network science helps us with that as it is extremely suitable, not only to describe but also to analyse and understand system behaviour through the interactions between system components. To unlock the full potential of formal network-based approaches, the network needs to be represented at the right scale and assessed through suitable metrics. Recent advances have resulted in intuitive software programs in which "off the shelf" metrics for analysing networks structures are readily available. While this is a laudable development, it also increases the risk of "push the button" approaches where all kinds of metrics are applied only because they are available, and not because they are relevant for the type of network and kinds of questions the researcher is asking.

Nevertheless, applications of network science have been booming in archaeology over the last decade (Brughmans & Peeples, 2017, 2018, 2023; Collar et al., 2015; Peeples, 2019). In this period, we have shifted from a small, but dedicated, community of early adopters towards network science as another tool in the toolbox of the archaeologist, comparable to the development of Geographic Information System applications in archaeology in the 1990s and early 2000s. Applications of network science in archaeology are generally built on datasets of archaeological sites and transport routes (Graham, 2006; Prignano et al., 2019; Rawat et al., 2021) or material culture (Barge et al., 2018; Brughmans & Poblome, 2016b; Mills et al., 2018). In this article, I will focus on the latter and, more specifically, on the usage of pottery distribution patterns for the creation and assessment of archaeological networks.

3 Pottery Networks

As all archaeologists working in the Mediterranean can testify, there is no lack of (broken) pottery there. One only needs to take a look at the massive Monte Testaccio – an artificial hill near Ostia, the ancient harbour of Rome – composed entirely of Dressel 20 amphorae used to transport olive oil from the Iberian provinces to the capital, to catch a glimpse of the massive amounts of material produced and transported all across the Mediterranean world. Pottery was cheap to produce, relatively durable, and readily discarded in favour of new pots. As a result, pottery is the most ubiquitous class of material culture in most archaeological contexts. It is exactly the massive scale of this production, distribution, and discard that offers a huge potential for archaeologists. It should not come as a surprise therefore that pottery lies at the basis of a lot of our information from the past.

Pottery typologies aim to group artefacts into a class of objects sharing the same or similar attributes related to material, shape, and decoration (Adams & Adams, 1991; Griffiths, 1994; Kafetzaki et al., 2024; Pawlowicz & Downum, 2021; Read, 2007). This type of classification can tell us a lot about the usage of material culture in past social practices. We also use pottery as a (relative) dating tool that helps us understand changes through time. Grouping similar objects, in addition with establishing relative sequences of gradual changes in the shape and composition of these groups, produces pottery typo-chronologies that form the basis of most temporal inferences in archaeology. The movement of physical goods as well as the spread of shared ways of shaping and decorating material culture can be used as proxies for networks of interaction, connectivity, trade, and exchange. Pottery has been a ready source material for the creation of archaeological networks, either through the informal assessment of connectivity or the formal structures of network science.

However, in order to move from the identification of findspots of material (dots on a map) to networks of interaction, connectivity, and trade (lines on a map), some assumptions are needed. First, we must assume that our typology is meaningful. This means that the groupings of material indeed contain elements that are more similar to each other than to the members of other groups. This assumption is necessary to assess whether two findspots share the same types of material in absolute terms or share a certain degree of similarity of material culture in relative terms. Second, we assume that our chronologies are correct, meaning that certain types of materials were produced and used within a certain period of time. This allows us to assess whether the observed similarity is given meaning through contemporaneity. Both assumptions are essential if we want to draw reliable interpretations from our data.

Once established, we can use pottery typo-chronologies to explore patterns of connectivity, interaction, and similarity through material culture. It is one of the basic premises in archaeology that proximity begets similarity, or in other words, as two communities, societies, or cultures are located closer together, they will interact more frequently, influence each other more, and display higher levels of similarity. However, formal social network analysis and similarity analyses based on shared material culture have shown that this premise is only partially supported and that the correlation between proximity and similarity can be highly variable (Hart, 2012; Hill et al., 2015). This should act as a caution for archaeologists interpreting similarity in archaeological networks without exploring the potential drivers and causal mechanisms of this similarity.

An alternative option for reconstructing networks of connectivity and interaction built on pottery data derives from scientific analysis used to establish provenance and raw material usage. In such studies, the idea and terminology of networks have been used to represent flows of materials going from initial raw material exploitation, to production places, to find destinations (Brughmans & Peeples, 2023, p. 32). However, most recent studies explicitly integrating provenance studies and network science have focused on the provenance of materials such as obsidian (Golitko & Feinman, 2015; Golitko et al., 2012). In the few cases where pottery has been used (for example Bernardini, 2007; Phillips & Gjesfjeld, 2013), the case studies have focused on the Pacific and American Southwest. By contrast, even though provenance studies have by now been well established in Mediterranean archaeology, no attempt has been made to incorporate this kind of data into a network science-based approach. Let us therefore now turn to a few case studies in Mediterranean archaeology which have explicitly incorporated pottery data in a network science framework.

4 Pottery Networks in the Mediterranean

While the usage of material culture in formal network analysis is more prevalent in American archaeology (e.g. Borck et al., 2015; Hart et al., 2017; Mills et al., 2018) and Near Eastern archaeology (e.g. Barge et al., 2018; Coward, 2010, 2013; Jayyab & Gibbon, 2022; Meyer & Seland, 2023), applications in Mediterranean archaeology have started to emerge in recent years as well (for some overviews, see Fenn & Römer-Strehl, 2013;

Knappett, 2021; Leidwanger & Knappett, 2018; Malkin et al., 2009; Mazzilli, 2023; Mills, 2018). Providing a comprehensive overview of the usage of pottery as the foundation for archaeological networks would go beyond the scope of the present article. In this section, I will present three case studies of network analysis based on material culture distributions and similarities in styles, wares, and types. Each of these case studies covers a different chronological period to show the breadth of applications in various subdisciplinary specializations. For each case study, I will briefly outline which kind of data is used, which network approach applied, which metrics are calculated, and the results obtained. Finally, I will discuss the potential and limitations of each approach.

The first case study explores the formation of hegemony – the elevation of one social group over the other(s) through a combination of coercion and the institutionalization of power – in southern Italy during the Bronze Age (1750–1000 BCE) (Iacono, 2016). Applications of network science in archaeology are often preoccupied with exploring the structures of archaeological networks by calculating standard network metrics (e.g. centrality measures, degree distribution, modularity), without taking a step further and incorporate these results into a social model to explain the underlying generative mechanisms. Here, the author turns to Marxist social theory to explore how inter-societal interactions create structures of power and how these emergent structures, in turn, shape the conditions of interaction. In this sense, the Marxist social theory follows the core tenets of two-way socialisation in complex social systems posited by the complexity theory (Daems, 2021a, pp. 34–36; Schill et al., 2019, p. 1079). Both frameworks allow for heterogeneity in agent properties and dynamics as a major driver of emergent complex societal behaviour. The Marxist social theory makes this heterogeneity explicit in positing that different social groups or individuals in society have differential access to and control over the means and relations of social and material reproduction (Iacono, 2016, p. 122).

The approach in this case study goes beyond classical Marxism in focusing particularly on interactions and networks of power emerging from inter-societal encounters, rather than intra-societal competition. Such inter-societal encounters are never enacted by all members of society, but only by segments of it. This means that potential benefits of interaction will befall only part of society. Moreover, individuals embedded in a wider network of interactions may have differential access to multiple resources, providing the potential for certain individuals to improve their social position beyond that of the group they belong to. This is where the social network analysis can shine as it provides metrics to trace the structure of the network as a whole, as well as the position of individual nodes within that network.

As archaeologists, we can only infer past interactions through the material remains left behind. The analysis starts from the premise that the co-existence of stylistic features in pottery is a material reflection of the interactions and relationships between communities. The main metric applied here is weighted degree centrality (see Candeloro et al., 2016 for a detailed explanation and application), tracing the number of connections of each individual node and weighing it based on the number of shared features in non-directed graphs (i.e. graphs where the connections between the nodes have no specified direction and the links can thus be read from both sides).

The analyses showed that communities where Aegean pottery was attested, outranked those where such material was absent in terms of degree centrality. Moreover, these central sites were already important in the network preceding the introduction of Aegean materials. In other words, Aegean traders are thought to have tapped into local patterns of connectivity by consciously targeting central sites.

The Bronze Age communities of Apulia were embedded in a network of mutual relations. However, when looking beyond the regional scale, it is suggested that these peer communities were part of an unequal relationship with Aegean sailors coming from Mycenaean and Minoan centres. The latter obtained a hegemonic role in Apulia. The acquisition and spread of Aegean goods in Apulia as part of this hegemonic relationship induced a process of social stratification and inequality formation, redefining social relationships and community structures. It is hypothesized that the process of surplus accumulation by a specific class transformed local communities into tributary societies characterised by the institutionalization of power relations similar to Aegean societies.

In the second case, we move forward over a millennium in time to a study of economic integration based on trade patterns of terra sigillata pottery from the Middle Hellenistic to the Late Roman period (200 BCE–700 CE) across the eastern Mediterranean. This case study is based on the openly available ICRATES

(Bes et al., 2019).[1] This database includes over 30,000 sherds from 275 sites. It provides an invaluable resource for the study of the production, distribution, and consumption of Hellenistic and Roman tableware and the broader economies of their time. It also provides an ideal input dataset for the application of computational methods such as agent-based modelling, network analysis, and Bayesian statistics (Brughmans & Poblome, 2016a, b, c; Carrignon et al., 2020; Daems et al., 2024).

Using computational methods allows researchers to explore the probability of common hypotheses regarding the necessary drivers of large-scale commodity production and distribution, as well as the degree of integration and market knowledge obtained by traders. More particularly, the model aimed to evaluate two highly influential conceptual models of the Roman economy: the bazaar model (Bang, 2008) and the market economy model (Temin, 2012). The former assumed a weak degree of market integration resulting in traders with poor knowledge of prices and the availability of goods, whereas in the latter, a stronger market integration was assumed, allowing for better and more market information to be available. In both models, the role of (social) networks integrating – to varying degrees – actors on multiple scales (traders, communities, regions) within the Roman empire was the crucial backbone of Roman trade and economy.

The MERCURY model is an agent-based model simulating the structure of social networks between traders and outputting the resulting distribution of tablewares. This allows us to compare simulated outputs with observed distributions derived from the archaeological record (Brughmans & Poblome, 2016a). In the standard model settings, traders are created and connected in a social network that derives its structures from the "small-world" network model (Jin et al., 2001), characterised by a high degree of clustering within markets but limited connections between clusters. Connected traders can share information on supply, demand, and prices of tablewares and can decide to trade. The degree of market integration can then be calculated by assessing the actualized proportion of all possible links between traders across different sites. These results under small-world structures are then compared to results generated by random network structures to assess the validity of the proposed network structure.

The results of multiple experiments with the model under various settings show that a number of conditions need to be met to generate patterns comparable to the empirical distributions of various terra sigillata wares. It should be noted that the material record is by definition incomplete and biased and that these biases were not explicitly explored in this study. However, network analysis has recently been used to highlight potential issues and biases in the archaeological record through the assessment of the effects of time averaging (see also the fourth case study below) (Daems et al., 2024). Necessary conditions identified by the modelling process include an unequal amount of traders per production site, strong degrees of market integration, and high availability of commercial information that allows traders to cater to high local demands as well as assess business opportunities elsewhere. It is also demonstrated that the intra-community structures corresponding to individual markets within the overall network are considerably less important than the degree of integration between markets. These results lend stronger credence to Temin's market economy model of high market integration, over Bang's bazaar model of economic fragmentation.

The third and final case study uses pottery of the Byzantine period (fourth to fifteenth c. CE) to map trade networks in an interactive digital environment (Yangaki, 2018). Building on traditional systematic mapping exercises, the Institute of Historical Studies of the National Hellenic Research Foundation initiated a research project titled "*Kyrtou Plegmata—Convex Grids. Networks of economy, power and knowledge in the Hellenic space from prehistory into the modern age: analytic documentation—interpretive mapping—synthetic approaches*." The aim of the project was to build a spatial relational database accessible through a digital interactive interface that compiles archaeological evidence for both specialists and the general audience.

Through this resource, the author of the study uses pottery imports to trace trade networks connecting sites on Crete during the twelfth and early thirteenth centuries. However, the author immediately notes the limited availability of quantitative data, stating that only the material from a handful of sites (Herakleion, Gortyn, Chania, Eleutherna, and Vrokastro) provide sufficient evidence to be used in a network analysis.

1 https://archaeologydataservice.ac.uk/archives/view/icrates_lt_2018/, accessed on March 14, 2023.

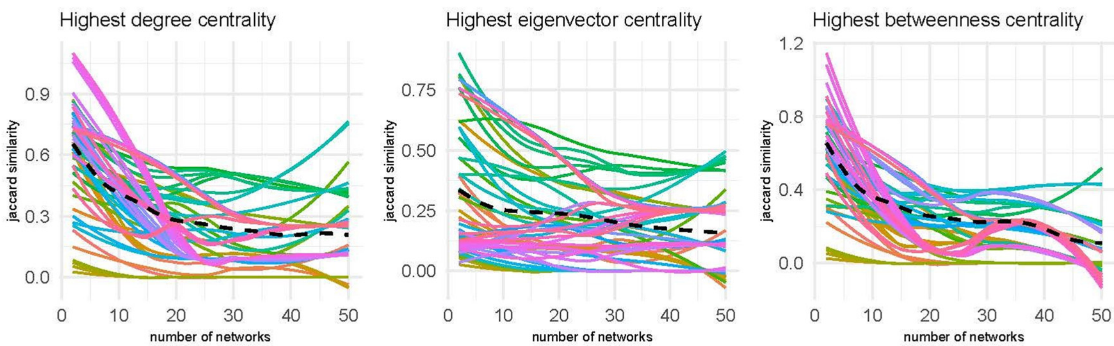

Figure 1: Similarity of centrality values for increasingly time-averaged networks in the ICRATES dataset (figure adapted from Daems et al., 2024, p. 489).

The network analysis presented in this article remains restricted to a visual representation of networks and connections between sites and does not offer any analytical approach – using the standard quantitative metrics of social network analysis – to explain potential underlying drivers of trade and exchange. Network visualizations entail first the connections in a geographical network with links between sites based on shared pottery wares. Second, a two-mode network representing the shared presence of 11 imported pottery wares is displayed. This graph shows that while almost all wares are found across more than one site, only the Fine-Sgraffito ware obtains a somewhat central position in the network as it is attested at all five sites. A final, one-mode network shows the links between the five sites weighted by the degree of connections in the previous networks. From this graph, it is concluded that Heraklion constituted the most central node in the network and that the connection between Heraklion in the centre of Crete and Chania in the west was particularly strong.

By the admission of the author, the study is a only preliminary first step outlining the potential of network approaches using their digital interface rather than their actual application.

It should be clear from these three case studies that network analysis has been applied across specializations in Mediterranean archaeology. While these kinds of studies are gaining ground, there is still a lot more to be done. In the next part, I will present an example of my own research to outline some of the potential new applications of network analysis using pottery data in Mediterranean archaeology.

5 Potential Ways Forward for Network Analysis in Mediterranean Archaeology

In a recent article, my coauthors and I use three archaeological datasets (including the ICRATES dataset used in the second case study earlier) to explore potential temporal biases in the study of social and economic networks in the past (Daems et al., 2024). This study explores how time-averaging, which refers to the mixing of artefacts from different time periods into a single layer, impacts the interpretation of archaeological network data. It is shown that time averaging reduces the accuracy of interpretations by altering network properties such as size, centrality, and path length. This reduction in fidelity can lead to overestimations in the importance of nodes (e.g. settlements) and their connectivity within networks. This means that common metrics such as centrality measures, often used to infer the relative importance of nodes within a network, are particularly susceptible to bias due to time averaging (Figure 1). This can result in misleading interpretations regarding social, political, and economic hierarchies within the studied archaeological context.

From the graphs shown in Figure 1, we see that the similarity between the centrality values for the original networks goes down (as indicated by the Jaccard similarity on the *y*-axis) as time-averaging increases (i.e. as the number of networks displayed on the *x*-axis increases). The dotted line on each of the graphs represents the averaged Jaccard similarity values between the node sets across all the time-averaged graphs and thus indicates the average trend. While the impact of time-averaging appears to stabilize after some time, the overall effect is highly significant for the interpretation of these metrics.

A second major conclusion of this study was that the effects of time-averaging are highly dependent on the original structure of the network. This variability makes it challenging to apply a one-size-fits-all approach when interpreting time-averaged networks, highlighting the need for context-specific analyses. It is clear therefore that it is highly important for archaeologists to be aware of the potential biases introduced by time-averaging. It suggests that practitioners should carefully evaluate the reliability of their data and consider the potential distortions caused by time-averaging, not only when conducting network analysis but also when evaluating and interpreting archaeological data in general.

In this methodological study, we used network science to assess one of the core purposes of archaeological data: its ability to gauge temporal patterns of human activity. We thus provided a clear handle for assessing potential temporal biases in archaeological data. One of the most important accomplishments of the article is that it offers a methodological pipeline, consisting of time slice creation, time-averaging, and sensitivity analysis, which can be used by others to assess the effects of time-averaging in their own data through openly available code scripts.[2] Conducting such analyses will allow others to assess the reliability of their inferences from archaeological datasets. This is but one example of how network science can be used to advance our understanding of the past through a better handling of our empirical datasets.

6 Discussion

The case studies presented in this article are all built on solid premises. The Bronze Age case study focuses on the co-existence of stylistic features as a proxy for connections between communities. The usage of average weighted degree offers a good metric to explore these connections. The usage of social theory is then necessary in the next step if we want to provide contextualization and explanatory power to our network metrics. At the same time, the Bronze Age case study shows how difficult it is to apply these theories in a way that conclusively proves the hypothesis. Here, the Marxist social theory is used as an interesting lens of interpretation; however, its application is not operationalized. That is, there are no empirical handles provided with which one can assess its validity.

The observation that average weighted degree is higher in communities with an established presence of Aegean material is by itself unsurprising given that well-connected sites are more likely to engage in inter-regional relations. Yet, it is interesting to test this assumption and further explore the nature of these connections. The lack of operationalization, however, becomes problematic as it means that we have no way of linking higher or lower values of this metric to any of the assumptions or explanations posited by the theory.

The Byzantine case study starts from the premise that the presence of imported pottery wares is a material reflection of trade and the participation of this community in broader trade networks. Its main caveat pertains to the realization that such presence only reflects the consumption of goods, rather than its production or full scope of distribution. Both assumption and caveat are inherently reasonable given the data at hand. More problematically, the presented study uses networks solely as an informal visual tool to represent connections between sites, without exploring its potential as an analytical tool to formally assess the structures and properties of these networks. Even though the author rightly points out the limitations of the available data for an encompassing application of network analysis, her self-imposed restrictions take away any potential new insights that might be generated by looking at the data through a new lens.

The Roman case study, by contrast, goes deeper and shows how the usage of formal approaches such as computational modelling and network analysis can help rigorously test hypotheses and assumptions. They offer a complementary set of tools to the more prevalent application of conceptual models in archaeology,

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2 Available at: https://github.com/cocoemily/time-averaged-networks and https://osf.io/5ca2u/.

which often use ill-defined concepts that remain un-operationalized and can therefore not be validated and tested against the available empirical data.

Formal computational approaches force us to recognise the limitations of the archaeological data, particularly in its scope and resolution (Perreault, 2019). The kinds of questions we can endeavour to answer using the ICRATES dataset are effectively constrained by its very resolution, which is defined by the unevenness of the publication record, the limitation of published materials often focusing only on the diagnostic material, and the usage of particular typological and chronological frameworks (Brughmans & Poblome, 2016c, p. 396). To continue the way forward, we need to improve on two levels:

(1) We need more well-defined and formal models with explanatory power and empirical operationalization that allow them to be quantitatively tested against available archaeological datasets.
(2) Better and larger datasets need to be compiled using standardised data structures – ideally in a linked open data system – that allow stronger data integration transcending the efforts of individual researchers and groups.

Only by this way can we explore the vast landscape of probability that envelops our knowledge of the past. The assessment of particular models and hypotheses allows us to map areas of high probability and exclude others through falsification. Still, the availability of ICRATES as an open-access dataset is already valuable in its own right as it allows others to (re-)use it for their own work, as is clear from the re-use of the dataset in our own work. Digital tools can help us on this trajectory. For example, the digital interface built as part of the Byzantine case study could potentially allow users to access datasets and build networks in an interactive (and hopefully intuitive) manner. However, this case also immediately shows us some of the limitations and dangers as the links provided in the article are broken and the interface can therefore not be reached directly. While the website was easily tracked through a search engine, further exploration made clear that the interactive mapping tool showed its data sources only in Greek, even though the rest of the website had an English version. This poses strong restrictions on the utility of this data source for the international research community. Moreover, the actual functionality and data availability offered by the website appear much more limited compared to what is presented in the article.

The part of the solution here is to make sure that when building such a database, we make it part of the linked open data ecosystem (Schmidt et al., 2022). This way, we can transform a stand-alone resource like this one into a node of an ever-growing network of information and knowledge. This greatly enhances the searchability, accessibility, and utility of each individual database.

Finally, I want to stress the importance of establishing routine collaboration between material specialists and computer scientists. The works of material specialists are valuable and still offer the necessary (and often also the only) backbone for archaeological inferences in many archaeological studies. We absolutely need to continue building new typo-chronologies, as well as refining existing ones, and conduct more material analyses studies to gain better chronological and geographical precision and resolution. However, pottery specialists must also remain self-critical and look for new ways to tap into the rich potential of the data at their disposal. Advances in 3D modelling, algorithmic classification, linked data querying, and deep learning pattern recognition provide for new and exciting opportunities in the documentation, classification, and interpretation of pottery (Karl et al., 2022).

As has been the case in other instances where cutting-edge approaches have been applied in archaeology – for example in the usage of deep neural networks to restore and attribute ancient texts (Assael et al., 2022) – the best results are obtained when computer scientists or other programmers directly collaborate with disciplinary specialists. Such instances show that new developments such as artificial intelligence do not replace the material specialist, but that the synergy between computational methods and domain knowledge can lift research outcomes to a higher level.

Network science has been around for some time. Its application in archaeology is no longer considered cutting-edge. It has rather become one of many tools in the toolbox of the archaeologist. Yet, this article has aimed to show that there are still a lot of differences between applications. Mediterranean archaeology in particular still has a long way to go before it can claim network science as a prevalent tool. This is a shame given the enormous amounts of material data we are sitting on. The tools and the data are there. The potential for application is enormous. All we need are pottery specialists and computer scientists to start talking to each other and explore the vast areas of what is currently possible. Who knows, we might even venture into new and unforeseen avenues of research. What a wonderful world that would be.

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