



Low-Density Urbanisation: Prestate Settlement Growth in a Pacific Society

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Abstract

The recognition of low-density urbanisation has been important in documenting how diverse human settlements generated enduring social and economic change. In tropical regions, the key challenges to studying low-density urbanisation have been the difficulty in acquiring past built environment data and integrating the frameworks that illuminate the social behaviours intrinsic to urbanisation. The introduction of lidar mapping and urban science methods has proven revolutionary in our understanding of low-density urbanisation as demonstrated by emerging research on settlements and states in Mesoamerica and Southeast Asia. These studies draw on urban theory to highlight patterns in the built environment associated with profound societal changes including the rise of social institutions, agglomeration effects, and ongoing settlement growth. Here, we present an approach that combines lidar survey and archaeological fieldwork with recent developments in urban science to understand the built environment of Tongatapu; the location of an archaic state whose influence spread across the southwest Pacific Ocean between the thirteenth and nineteenth centuries A.D. Quantitative results show—for the first time—that settlements on a Pacific island were urbanised in a distinct low-density form and that the processes of urbanisation began prior to state development. This study highlights the potential contribution of Pacific landscapes to urban science and the low-density settlement phenomena given the presence of large populations, hierarchical societies, and vast distributions of archaeological built remains on many island groups.

Keywords Lidar · Urbanisation · Tonga · Settlement scaling · Low-density urbanisation · Institutional development

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Introduction

When groups of people come together to live in larger groups, they experience similar challenges in deciding where they will locate the growing populations and how they will manage increasing social interactions. The empirical diversity of settlements across time and space—from the moveable cities of the Golden Horde (Favereau, 2021:120–125), to the mega cities of Rome and China (Noreña, 2015), and the low-density agrarian settlements of the tropical world (Evans et al., 2013; Isendahl & Smith, 2013)—masks the underlying similarities of these settlements that make them recognisable as a part of a larger, urban, phenomenon. The structural similarities among urban settlements, in part, derive from the solutions societies adopt to take advantage of the benefits of people living closer together, while managing the negative effects generated by increased social interactions. The outcome of these decisions can have effects on a society as it continues to grow.

Low-density urbanisation appears as an outlier in many narratives of compact urbanisation; however, recent advances employ emerging urban science methods to illuminate the core processes of settlement growth (Bettencourt, 2021; Scott & Storper, 2015; Smith, 2023). These place renewed importance on social interactions as the drivers of social development and agglomeration (Ortman et al., 2014; Smith, 2023), and are an important approach that bridges the diversity of urban forms as well as untangling competing processes, such as the emergence of territorial states (Jennings, 2016). Despite their promise, these new approaches to urbanisation are data-intensive and capturing the settlement information necessary for analysis remains a challenge—particularly for low-density settlements. The expansion of lidar based surveys is rapidly increasing settlement data with recent research in the low-density settlement systems of Mesoamerica (Smith et al., 2021) and Southeast Asia (Klassen et al., 2022) able to use large geospatial databases and urban science methods to investigate ancient settlement dynamics.

In this research, we further develop research on low-density urbanisation by integrating data recorded from airborne lidar survey and archaeological investigations with recent developments in settlement scaling and growth theory to understand the built environment of Tongatapu in the Kingdom of Tonga. The Pacific is a region where archaic states and complex chiefdoms developed outside of continental influences (Hommon, 2013; Kirch, 1984, 2010) and the island of Tongatapu, first occupied by people from 900 B.C. (Burley et al., 2012), was the seat of power for a dynastic polity whose influence extended across the south west Pacific (Fig. 1) (Aswani & Graves, 1998; Clark, 2017). Archaeological evidence and vernacular literature indicate that the Tongan polity flourished from A.D. 1300, and its growth is associated with the construction of monumental architecture, expansive regional trade networks, and complex sociopolitical institutions (Clark, 2016; Clark et al., 2008, 2014). The polity collapsed in the early nineteenth century, in part, because of the impact of introduced diseases (Parton & Clark, 2022), although the modern nation state of Tonga incorporates many elements of the traditional Tongan political systems (Lātūkefu, 1974, 1975).

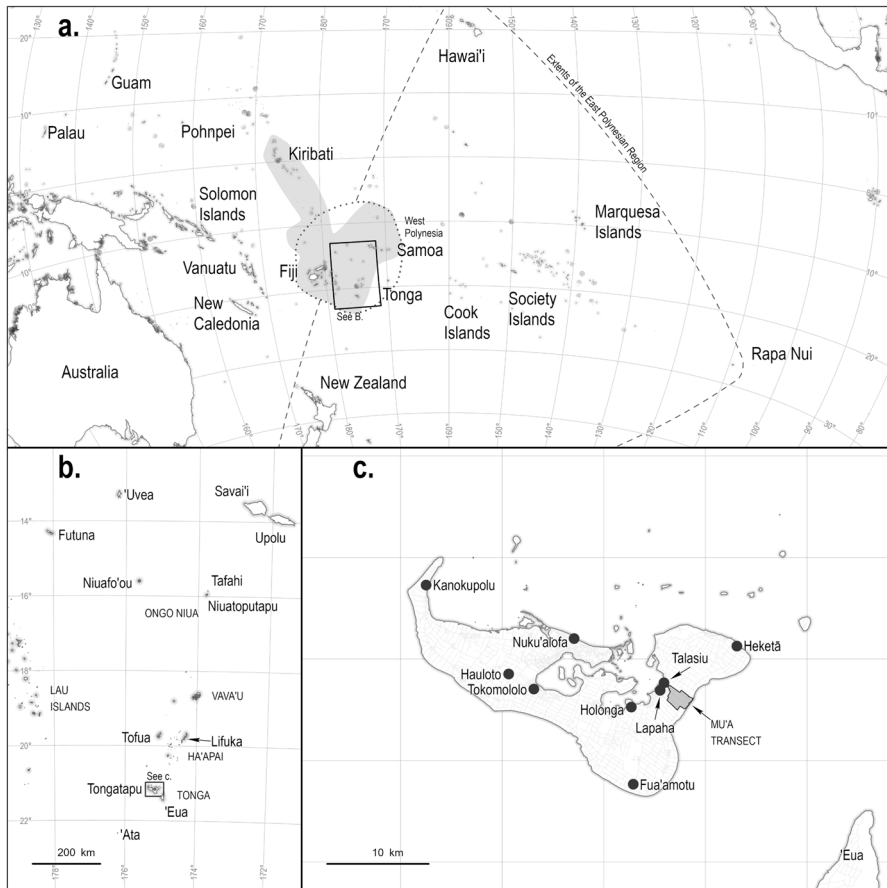


Fig. 1 **a** Islands of the Pacific Ocean. Shaded area identifies islands known to Tongans recorded in A.D. 1777 (Geraghty, 1994), and lines indicate the extents of the Fiji-West Polynesia (dotted) and East Polynesia (dashed) areas. **b** The Tongan islands and important neighbouring locations. **c** Tongatapu and locations mentioned in the text

Pacific archaeology has yet to combine the vast settlement information available in lidar datasets with the theoretical advances in our understanding of urbanisation that have emerged elsewhere in the world. Throughout the Pacific, island landscapes—like that of Tonga—are characterised by extensive remains of past built environments, and traditional, terrestrial-based methods of archaeological survey have identified dense concentrations of architectural remains in Micronesia (Liston, 2009), Melanesia (Parry, 1977; Walter & Sheppard, 2000), and Polynesia (Frimigacci, 2016; Green, 1967; Jennings et al., 1982). The recent proliferation of lidar based research has produced new records of the built environment that were previously unachievable (Bedford et al., 2018; Comer et al., 2019; Freeland et al., 2016; Jackmond et al., 2018; Jalandoni et al., 2022; Ladefoged et al., 2011; Quintus et al., 2015a). Importantly, these surveys document often overlooked domestic remains

(house sites, agricultural terraces, field boundaries) alongside examples of monumental architecture. As definitions of ‘urban’ have expanded to examine the fundamental processes of urbanisation (Bettencourt, 2021; Scott & Storper, 2015; Smith, 2023), it is now appropriate to investigate the possibility that some Pacific societies were not only complex but also urbanised and were able to harness social interactions to generate economic and political change.

Below, we present the first evidence that settlements on Tongatapu were urbanised and they had developed many of the characteristics and traits of urban settlement systems identified in other parts of the world. We find that Tongan settlements produced agglomeration effects that stimulated the development of new social institutions that drove settlement growth and social change. Importantly, the settlement growth occurred within a low-density settlement morphology and our quantitative data contributes new perspectives on how low-density settlements grow. Our chronological data indicates that settlement growth and social development occurred several hundred years prior to the emergence of the territorial state institutions that integrated much of the western Pacific under Tongan influence. This has important implications for longstanding debates on the relationship between urbanisation and state formation (Childe, 1950; Fletcher, 1996:189; Jennings, 2016; Smith, 2023; Smith, 2003b:11–16), as well as demonstrating that the built environments of Oceania can be used to investigate social development over millennia. We anticipate that further research into Pacific settlements that focusses on the role of social interactions and how societies managed change through the development of new social institutions will advance understanding of how urban settlements form, grow, and decline.

Settlement Patterns and Urbanisation in Polynesia

Roger Green, a student of the pioneer of settlement pattern analysis Willey (1953), introduced the approach to Pacific landscapes (Green, 1967), and his work has been influential to understanding how Oceanic communities interact with each other and their environment. Settlement patterns continue to be the dominant paradigm for understanding built landscapes in the Pacific with recent research published from Sāmoa (Quintus et al., 2015b), Society Islands (Kahn, 2005; Kahn & Kirch, 2011), Hawai‘i (Kirch et al., 2004; Ladefoged et al., 2011), and Cook Islands (Campbell, 2003) to reference a small sample of active areas of research. The settlement pattern approach has also been applied across Tonga with research conducted in Niuaotupapu (Kirch, 1988), Ha‘apai (Burley, 1994), and Tongatapu (Spennemann, 1989a, 1989b). Freeland et al. (2016), Freeland (2018), and Parton et al. (2018) have used recently acquired lidar data and a settlement pattern approach to understand the distribution of mounds and fortifications on the landscape of Tongatapu.

The vast quantities of data produced by lidar presents a unique opportunity to incorporate built environment data with approaches that are inclusive of all sectors of past societies, not just the social and political elite. The introduction of lidar as a tool to understanding built environments of the past has been transformative for

tropical regions resulting in a reappraisal of our understanding of settlements in these landscapes (Chase et al., 2011; Evans et al., 2013; Freeland et al., 2016).

Here, we present a new approach to Oceanic built environments that conceptualises settlements as lying on an arbitrary continuum towards urbanisation (Trigger, 2008:55; Smith, 2023:Chapter 1). This perspective takes advantage of the new built environment data generated from lidar and aims to provide a more inclusive view of the past by integrating the surviving built structures constructed by a society. The approach expands the breadth of social interactions we consider when interpreting relationships between past communities by centring the aggregate actions of individuals and their social networks to investigate how these decisions affected the development of society and the built environment (Raja & Sindbæk, 2020).

Urban Theory

Urbanisation as Social Interactions and Their Cost/Benefits

The last decade has seen renewed interest in the origins, development, and functions of past settlements that has foundations in decades of theoretical development (Table 1). Advances in data collection (Lobo et al., 2020a:12–14) and analysis capability (Rey et al., 2023), as well as volumes by Smith (2003a) and Marcus and Sabloff (2008), have seen archaeologists re-engage with contemporary urbanists to conceptualise ancient settlements as the flows of people, information, and goods across social and physical networks (Batty, 2013; Bettencourt, 2013). Archaeological data have made important contributions to these new developments by demonstrating that the increasing intensity and diversity of social interactions in settlements are important drivers of innovation, and economic and social development (Ortman et al., 2014; Smith, 2023).

The movement of people, information, and goods across networks incur costs that limit the range that they can effectively traverse. For example, transporting people and goods incurs energetic and time costs that can vary according to the development of transportation infrastructure and the size of loads to be moved, and information degrades as messages are communicated longer distances and to more people. The residents of a settlement are faced with a number of decisions that they must address to minimise the cost of participating in the social life of society while balancing the need to allocate space in, or near, the settlement for subsistence and other activities. These trade-offs result in a ‘spatial equilibrium’ (Alonso, 1964) that produces the recognisable clustering of people and their ‘social networks embedded in space’ (Bettencourt, 2013; Ortman et al., 2014:2).

The coming together of different groups of people as settlements grow has effects caused by the concentration of social interactions (Fig. 2). First, coming together produces agglomeration economies, or economies of scale, that make the settlement more productive as it becomes larger. Second, the concentration of social interactions in space causes interaction stresses that a settlement needs to manage to continue to take advantage of the productivity gains from agglomeration economies. The complex interplay between the benefits to society

Table 1 Summary of the key advances in the development of urbanisation theory of ancient settlements

Year	Key contribution	Reference
1826	Analysis of the distribution of agricultural and residential land around a central node	von Thünen (1966 [1826])
1938	Definition of cities focussing on sociological characteristics such as size and heterogeneity	Wirth (1938)
1950	Archaeological traits that define ancient cities	Childe (1950)
1961	Description of cities as organised complexity	Jacobs (1961)
1964	Models the spatial equilibrium that emerges based on how people organise themselves in space	Alonso (1964)
1966	Cities as central places within a hierarchical network of smaller places	Christaller (1966)
1969	Argues that the benefits of city living derive from concentrated social interactions	Jacobs (1967)
1971	First application of scaling research from biology to settlements	Nordbeck (1971)
1972	Institutional approach to settlements and the areas they service within hierarchical network	Trigger (1972)
1977	Recognition of the major functions that settlements perform	Fox (1977)
1990	Advances institutional theory identifying how social institutions promote growth by providing structure to society	North (1990)
1996	Identification of low-density settlements in ancient and modern contexts	Fletcher (1996)
1999	Modelling of the economic benefits of aggregated living and how spatial structure emerges	Fujita et al. (1999)
2011	Review of urban theory of modern settlements and discussion on its utility for ancient settlements	Smith (2011)
2013	Conceptualisation of cities as flows of information, goods and people embedded in space	Batty (2013); Bettencourt (2013)
2014	Reorienting the study of modern urbanisation to identify foundational concepts understand urbanisation	Scott and Storper (2015); Storper and Scott (2016)
2014	Application of scaling methods ancient cities	Ortman et al. (2014)
2016	Identification of functional archaeological dimensions to measure ancient settlements	Smith (2016, 2020)
2016	Evidence for the separation of urbanisation and state concepts	Jennings (2016)
2020	Linking of agglomeration models to scaling in ancient settlements	Ortman et al. (2020a)
2021	Unification of the urban science approach	Bettencourt (2021)
2021	Urban science methods to measure returns to scale in ancient settlements	Smith et al. (2021), Klassen et al. (2022)
2023	Energised crowding and social interactions as drivers of settlement growth	Smith (2023)

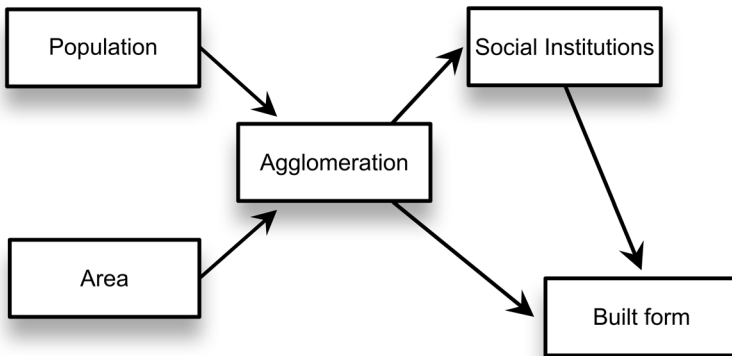


Fig. 2 Causal diagram of the process of urbanisation in Tonga. Increasing population within bounded settled areas generates agglomeration effects within the settlement. Agglomeration effects cause changes in the built form of a settlement as residents begin to use space more efficiently and balance movement and interaction costs. Larger agglomeration effects stimulate the development of social institutions as settlements adapt to increasing social interactions. Social institutions also cause changes to the built form of a settlement by competing against other land uses, such as residential, subsistence, and other production related land uses, for settlement space to perform their functions

derived from agglomeration and the stresses caused by larger populations is key to understanding the urbanisation process (Scott & Storper, 2015). How a society resolves these interlinked phenomena is responsible for much of the empirical diversity and similarity found among urban settlements.

Agglomeration

Agglomeration economies are the costs and benefits generated by groups of people living together in concentrated space (Brueckner, 2011; Fujita et al., 1999). When larger groups of people can interact with each other more frequently by living closer to each other, there are more opportunities to share common resources to solve collective action problems, pool labour, and learn and transmit knowledge (Duranton & Puga, 2004). Agglomeration economies have long-term effects on settlement growth and societies, and these effects are only now beginning to be studied in ancient settlements (Klassen et al., 2022; Ortman & Lobo, 2020).

Agglomeration forces can be difficult to measure with archaeological data and require large amounts of information from a settlement system. Lidar-derived data is suitable if the record extends across an interacting settlement system. Because agglomeration economies are an aggregate property of settlements—that is they are the outcome of thousands of interactions within the settlement system—the effects of structure contemporaneity, which is a challenge to settlement pattern research (Morrison & O'Connor, 2015:463), are reduced (Betten-court et al., 2020; Ribeiro et al., 2020).

Low-Density Urbanisation

Agglomeration economies have many positives for the growth of settlements. However, this growth causes interaction and communication stresses due to the increasing concentration of social interactions that residents need to manage. Failure to properly manage these stresses may lead to negative outcomes such as poor health, increased violence, and inequality, or the decline of the settlement (Algaze, 2018; Hassett, 2017; Thompson & Prufer, 2021). In our model of urbanisation in Tonga, there are two ways that these interactions can be managed: through the built environment with planning and architectural innovations, and through the development of new social institutions.

Low-density agrarian urbanism is a concept developed by Fletcher (1996, 2009, 2020) based on a comparative analysis of settlement sizes and densities in a global sample. Fletcher identifies limits to how much a settlement can grow before interaction and communication stresses constrain settlement growth. To grow beyond these limits, a settlement has two options: (1) to develop a series of material innovations to settlement structure that manages the increase in interactions and allows the settlement to maintain high population densities or (2) to adopt a low-density settlement morphology that separates interactions by distances that are manageable for the settlement.

Social Institutions

As social interactions within the settlement intensify and become more complex, it becomes harder for interactions to be mediated by the built environment alone. The development of institutions structure social interactions with ‘rules of the game’ (North, 1990:3). The new rules for society provide the necessary legibility and predictability in social interactions that can manage and support settlement growth by solving collective action problems that arise from containing more people in limited space (Carballo et al., 2014; Smith, 2010, 2011:179–180). Importantly, the new social institutions do not need to benefit all the residents of a settlement to successfully manage social interactions. In modern societies, inclusive social institutions are associated with higher living standards (Koyama & Rubin, 2022; North et al., 2009). However, in the past, many social institutions excluded large sectors of society based on gender or social background (Blanton & Fargher, 2008; Johnson & Koyama, 2019). Social institutions also change and institutions that were initially developed inclusively, such as trade guilds (Ogilvie, 2019) and political institutions (Stasavage, 2020), can be captured by elite sectors of society for their own benefit.

Social institutions, like people, require physical space to perform their functions: political elites require space for their residences, to govern from, and for their burial; communities require space for meeting and ceremonies; and religious organisations need land to construct temples and ritual sites (Smith, 2016, 2020). Institutional land uses also look to minimise the costs of performing their functions by seeking the same advantages generated from agglomeration economies. The need for space and desire for proximity for institutional land uses often places them in direct competition with other land uses in the settlement, primarily residential and production related land uses.

For Scott and Storper (2015), the conflict between land uses is a key component of the urbanisation process. When the infrastructural power of institutions (Mann, 1984, 1986) is sufficient to win the competition for the most desirable space in the settlement, the relationship between residents, institutions, and the built environment is fundamentally different than before and the settlement can specialise, developing recognisable—yet different—institutions that perform distinct sets of ‘urban functions’ (Fox, 1977).

Many archaeologists will notice several theoretical lines of overlap between our theory of urbanisation and how settlement pattern research is currently applied in the Pacific, for example, how concepts such as centralisation (agglomeration), connectivity, and the distribution of features support interpretations of elite-commoner relationships (see Quintus & Kahn, 2023 for a recent example). Our model of the urbanisation process (Fig. 2) is centred on the benefits that residents of a settlement gain from living in larger settlements and how they manage the increase of social interactions either through material or social innovations. The advantage of this model is that the range of interactions now considered is wider because we can now access spatial datasets that capture the full diversity of the built environment. We now examine the types of built features found on the Tongan landscape before analysing how these features contribute to an urbanising Tongan society.

Lidar Data and the Tongan Built Environment

Lidar Data and Settlements in Tonga

When Europeans arrived in Tongatapu in A.D. 1773, they described an intensively developed landscape with a transport network that connected residences across the island (Cook, 1967, 1969). In 2011, some 238 years after Cook, a lidar survey carried out over the island of Tongatapu (see AAM Pty Ltd, 2011; and Parton et al., 2018:12–13 for survey specifications) revealed an archaeological landscape mirroring the one described in his account. The built environment identifiable in lidar include large clusters of earth mounds (Freeland et al., 2016) that are often bounded by defensive infrastructure (Parton et al., 2018, 2022). The clusters of mounds are linked by a transport network, and recent analysis suggests that the island was home to 50,000 to 60,000 people (Parton & Clark, 2022). From A.D. 1300, the island was home to the Tu‘i Tonga dynasty whose territorial political institutions spread to other Pacific Islands (Aswani & Graves, 1998; Clark, 2017). The high accuracy lidar data provides unprecedented data on the built environment of Tongatapu that permits new analyses of the built environment.

Mounds

Mound Function Categories

Archaeologists in Tonga have long recognised the importance of the numerous earth mounds to understanding past Tongan society (Davidson, 1964:15). In the absence

of modern mapping technologies like lidar, it has been difficult to develop repeatable typologies of mound form and function. McKern (1929) used information from informants to identify mound function; however, later researchers found it difficult to replicate his work due to the loss of traditional information that the classification was based on (Davidson, 1971; Kirch, 1988). Later researchers examined the morphological characteristics of mounds and identified two broad types of mound function (Davidson, 1969; Kirch, 1988). First, burial mounds are primarily identifiable through concentrations of beach sand which was used to fill the burial excavation (Davidson, 1969:279; McKern, 1929:30–33; Parton & Clark, 2022:4–5; Poulsen, 1987; Spennemann, 1989b:65) and non-burial mounds are characterised by an absence of beach sand (Clark et al., 2024; Groube, 1971; Parton & Clark, 2022:4–5; Poulsen, 1987; Spennemann, 1989c:159–162).

Recent and existing archaeological evidence along with observations made by early European arrivals indicate that many of the mounds constructed on Tongatapu had a domestic function and were used as house foundations. Data from a transect survey performed in areas adjacent to Lapaha and Talasiu at Mu'a with an auger was used to identify mound function. The survey found that 87.4% of mounds did not contain evidence of burial and were therefore likely to be residential structures (Parton & Clark, 2022:4). Coring also identified a series of constructed 'floors' in many mounds, similar to those described by Spennemann in excavations at nearby Beulah (Spennemann, 1989c: 159–162) and by Groube (1971:299) and Poulsen (1987) at Ha'ateiho. The cores also recovered domestic debris in some mounds such as shells, lithic flakes, and oven stones.

Mound Clusters

We adopt a recently developed 'bottom up' approach from urban economics to define settlement areas on Tongatapu based on the distribution of built features (Arribas-Bel et al., 2021; Bellefon et al., 2021; Rozenfeld et al., 2011). Burley (1994:396) and Kennedy (1958:163) describe clusters of settlements around local centres and a visual analysis of mound distributions from lidar on Tongatapu suggests that mounds were constructed in large groups that resemble bounded settlements. Analysis by Freeland et al., (2016:72) with a Getis-Ord statistic indicates that these clusters are statistically significant and the authors link the clusters to local political organisations. Density based methods to define settlement areas relate to our theoretical expectations of settlements being containers of interacting populations and mitigate against retrodicting ethnohistoric descriptions of settlement organisation too far into the past.

To define settlements, we use the Density Based Spatial Clustering of Applications with Noise (DBSCAN) algorithm (Ester et al., 1996) adopted in Parton and Clark (2022). Two parameters are required in the ArcGIS 3.0 implementation of the DBSCAN algorithm, an 'Eps distance' and the minimum number of points in a cluster. The 'Eps distance' defines the separation distance between points to be considered a cluster. The value of 150 m was determined by nearest neighbour analysis and matches the culturally important measurement of *ofa 'e teau*, one hundred arm spans (*tofifatafata*). 'MinPts' was left at the lowest permitted value as large values

can remove points on edges which can create overly compact clusters. Spatial joins connect the number of mounds in a group to the settlement cluster.

Mound Chronology

Built environments in west Polynesia, for the past 50 years, are thought to have been built after A.D. 1000 followed by the construction of monumental architecture (Davidson, 1979:82; Freeland et al., 2016). However, new evidence that a large earth mound was built around A.D. 400 (Clark et al., 2024) demonstrates that the built environment of Tonga dates to the first millennium A.D. A longer record of earth mound construction is supported by a coring program at Lapaha and Talasiu that recorded stratigraphic information from 143 mounds and charcoal samples from five mounds. The dating samples were recovered from contexts where there was a clear distinction between original ground surfaces and mound construction layers. Charcoal samples from these interfaces have been used to date construction of other built structures and to posit a first outline of architectural development in Tongatapu. The calibrated age of the mound samples indicate that earth mounds were likely being constructed in Tongatapu by A.D. 250 to A.D. 360 (90% HDI) (Fig. 3).

Current evidence suggests that the Tongan built environment was continuously used for settlement by people. Parton and Clark (2022:6), and others (Clark et al., 2024; Groube, 1971; Poulsen, 1987; Spennemann, 1989c:159–162), describe how mounds were regularly refurbished and reoccupied with new floors, suggesting long-term occupation of dwelling sites (Kirch & Green, 2001:201–207). Additional data from burial mounds also indicates that they were in continuous use for centuries up to the reconfiguration of land in the nineteenth century (Fenner et al., 2015:646; 2021:Table 2). Tongan vernacular literature (Kaeppler, 1967) and toponyms (Clark, 2010; Gifford, 1923) combine to demonstrate that the Tongan built environment was continuously used and that variation in mound occupation rates (Parton & Clark, 2022:6) would be offset by the number of residences not constructed on mounds (Parton & Clark, 2022:9). We also note that once constructed, the ongoing occupation of settlements is a common characteristic of urban environments (Kearns, 2015:19). While preliminary in nature, the radiocarbon results suggest mound construction was a persistent settlement phenomenon spanning almost two millennia—characteristics that make mounds an appropriate archaeological feature to analyse the Tongan built environment.

Flat-Topped Mounds

Morphological analysis of mound data suggests an important category of mounds exists between the monumental mounds at the Mu'a core and the numerous smaller mounds. These mounds are rectangular in plan with a large and flat surface forming the top of the mound. Figure 4a shows that these mounds form a separate size category from other mounds as they become taller at a slower rate to other mounds, emphasising the design decisions made to make the mound larger in plan, rather than taller.

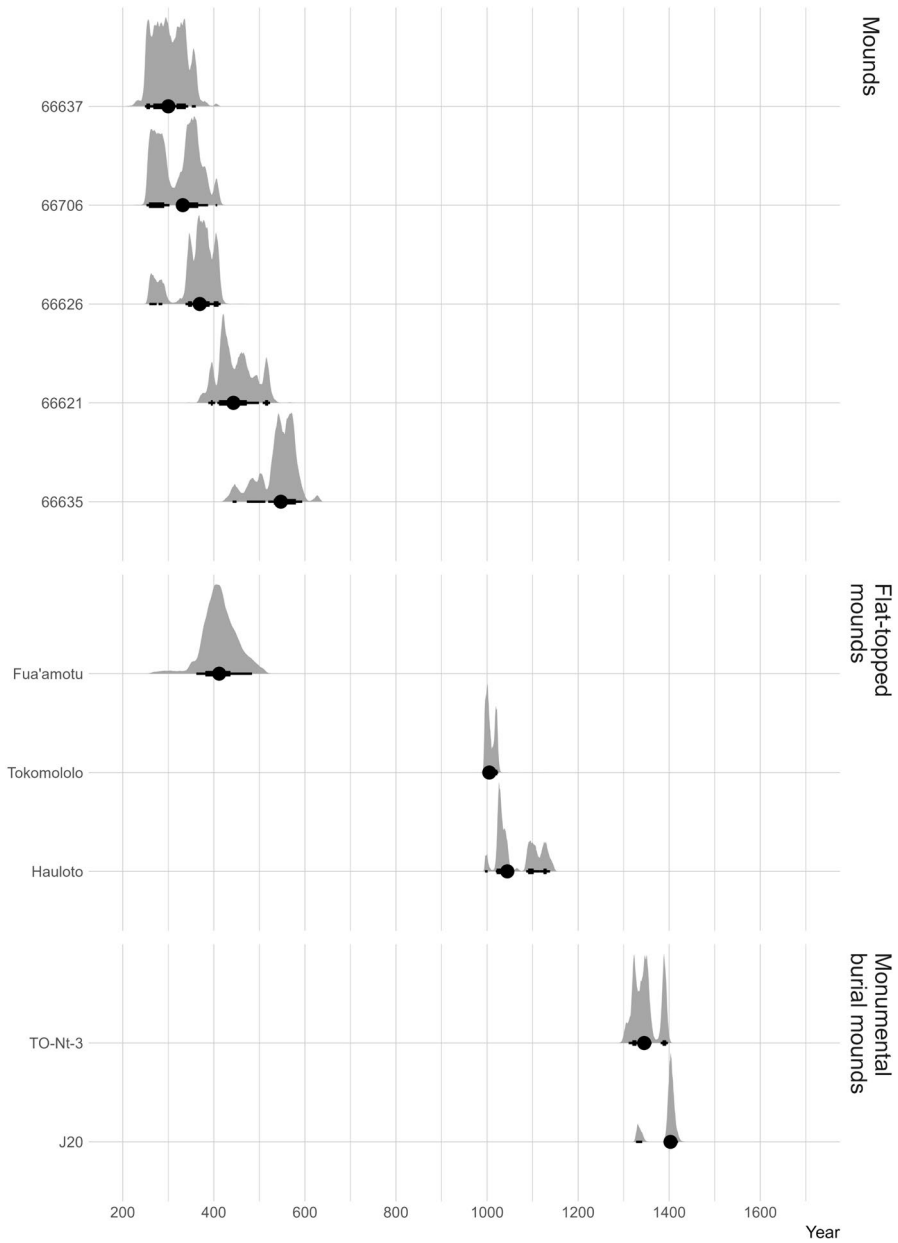


Fig. 3 Calibrated radiocarbon ages (median, 60% and 90% HPDI) for built environment features on Tongatapu

Linguistic and ethnohistoric observations suggest that these flat-topped mounds were the site of important community facilities and were the foundation for large meeting halls approximately 30 m long (McKern, 1960:91) called *falehau*. Some

Table 2 Parameters for scaling analysis and robustness check

Parameter	Observations	Exponent (90% CI)	Intercept (90% CI)
Settled area	299	0.917 (0.904–0.929)	0.130 (0.379–0.439)
Robustness check			
130 m DBSCAN	426	0.922 (0.910–0.934)	0.281 (0.105–0.157)
170 m DBSCAN	216	0.907 (0.891–0.922)	0.644 (0.606–0.683)

observers noted that these halls were constructed on mound foundations (Guthrie, n.d. 30 May 1830; McKern, 1960:80–93) and William Mariner describes their prominence in the northern islands of Vava‘u in the early nineteenth century (Martin, 1991:77). The earliest Europeans in Tonga noted an association between public open spaces (*mala‘e*) about 1 ha in area, roads (*hala*), and community meeting halls (*falehau*). Burley’s (1994) research in the Ha‘apai group suggests that bathing wells (*vaikaukau*) and burial places (*fa‘itoka*) can sometimes be included in these complexes. Figure 4c shows the distribution of these complexes on Tongatapu and in Fig. 5 examples are mapped in detail to highlight common configurations of open space (*mala‘e*), the adjacent roads (*hala*), bathing wells (*vaikaukau*), and the large mound foundation for the *falehau*. In A.D. 1643, near Kanokupolu in western Tongatapu, Isaac Gilseman produced an illustration of this complex of features (Fig. 4b) and depicts at ‘K’, a ‘hall of audience’ alongside an open space, a bathing place (‘L’), and a road connecting the complex to the shoreline (Anderson & Pond, 1999:22). Linguistic data indicates that such complexes were important landscape features in formative Polynesian culture dating to the first millennium A.D. (Kirch & Green, 2001:249–256).

Recently, published radiocarbon results from a large, flat-topped mound in south east Tongatapu, near Fua‘amotu, indicate that these structures were being constructed as early as A.D. 360 to A.D. 480 (90% HDI) (Clark et al., 2024). The early flat-topped mound has an association with ancient roads and open space located at the base of the small hill the mound was built on. In Fig. 3, we include radiocarbon determinations for an additional two large, flat-topped mounds found in association with roads and open space. The mounds at Hauloto (A.D. 1000 to A.D. 1140 90% HDI) and Tokomololo (A.D. 990 to A.D. 1020 90% HDI) are located in the central areas of Tongatapu and alongside the Fua‘amotu mound, provide support for the emergence of social institutions predating the first evidence for territorial political institutions at Heketā and Mu‘a.

Monumental Burial Mounds—*langi*

Some of the most comprehensive chronological data for built remains in Tonga comes from the monumental burial tombs of the ruling lineages of Tonga called *langi*. These structures are earth mounds, often rectangular in plan with a facing of highly prepared beach rock, sometimes involving multiple tiers (Burley, 1998; Clark & Parton, 2020), and *langi* appear on the landscape almost contemporaneously at

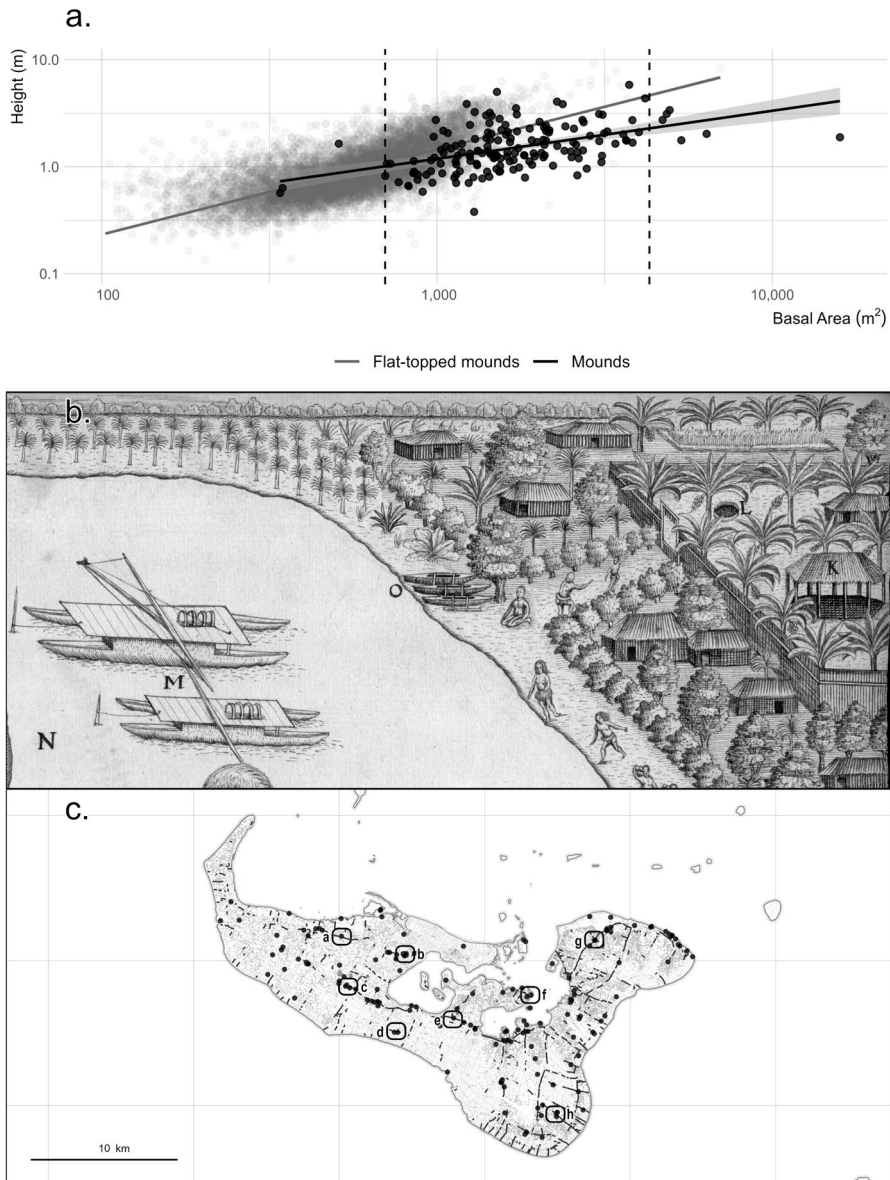


Fig. 4 **a** Different mound size trajectories of flat-top mounds (black) and other mounds (grey) on Tongatapu. Note the difference the slope of the lines indicating flat-topped mounds grow in their basal dimensions faster than their height. The vertical lines indicate the range of mound sizes needed for *falehau* construction, from the smallest mound required to accommodate a *falehau* based on dimensions recorded by McKern (1960), to the largest mound measured by McKern (1929:10) as the foundation of the *falehau* constructed by the Tu'i Kanokupolu at Mu'a. Small, flat-topped mounds are difficult to identify because of the overlap with other types of mounds. **b** Illustration of a central place by Gilseman, near Kanokupolu, in A.D. 1643, highlighting the association between meeting places ('K'), and connections to terrestrial and maritime transport infrastructure. Image from the collections of the Nationaal Archief Nederlanden and is licensed under CC0. **c** The distribution of roads and flat-topped mounds with zoomed in areas in Fig. 5 outlined

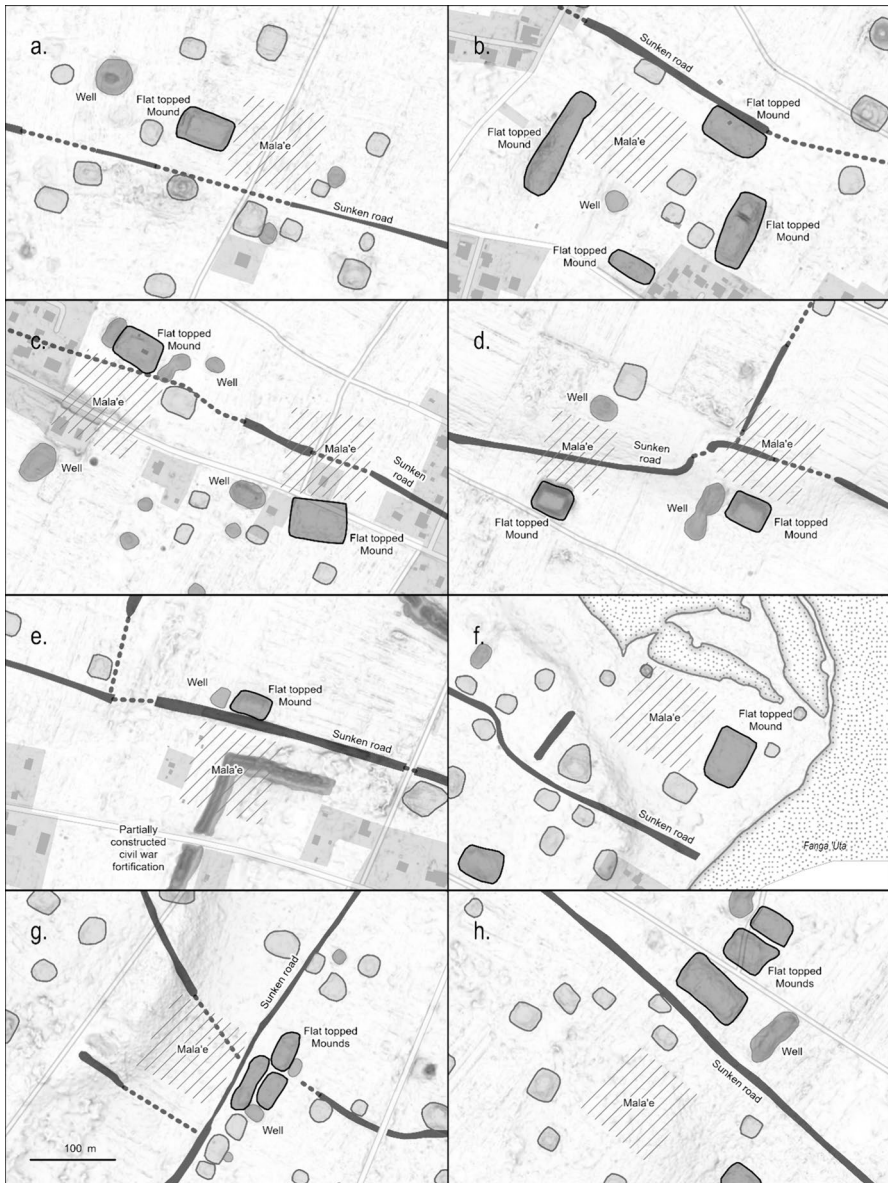


Fig. 5 Selected areas (identified in Fig. 4c) highlighting the common association of flat-topped mounds (and *falehau*), roads (*hala*), wells (*vaikaukau*), and open space (*mala'e*). Fieldwork is necessary to identify burial locations within these complexes

Heketā and Mu'a at A.D. 1350 and A.D. 1300 to A.D. 1400 respectively (Clark & Reepmeyer, 2014:1252; Clark et al., 2016:1044). *Langi* construction continued throughout the period of the Tongan Maritime State (Clark et al., 2008) with the final *langi*, *Tuo-teau* (J01), likely constructed around A.D. 1760 to A.D. 1775 (Clark, 2016:338).

Roads, Fortifications, and *sia heu lupe*

Lidar imagery reveals traces of a terrestrial transport network that appear as long and shallow depressions connecting groups of mounds or linking the groups to coastal zones. These depressions were described as ‘sunken roads’ by early archaeologists (McKern, 1929:89) and missionaries complained that they collected water after rain (Thomas, 1828:35). Limited archaeological investigation on sunken roads suggests that, like hollow ways in Mesopotamia (Altaweel & Palmisano, 2019; Wilkinson et al., 2010), they were formed from repeated foot traffic that compacted soil and rainwater erosion. Approximately 110 km of the road network is visible in lidar imagery with a main trunk connecting eastern and western Tongatapu that passes through most of the major settlement clusters. This trunk road was described in historic sources as measuring ‘six or seven yards wide’ (approximately 6 m) (Wilson, 1799:285) in the east and ‘about [16] feet broad’ (approximately 5 m) (Cook, 1969:252) in the west. Historical descriptions of the road match measurements made from lidar point clouds. Arterial roads, described as 6 to 12 ft wide (approximately 2 to 3 m) (Wilson, 1799) branch from this trunk to connect inland locations and neighbourhoods with each other and to the wider maritime transport networks maintained by Tongans (Clark et al., 2014, 2020; Geraghty, 1994; Hermann et al., 2019; Kaeppler, 1978).

Fortifications (*kolotau*) are common built environment features in Tongatapu, and many can be linked to a period of intense warfare during the nineteenth century (Parton et al., 2018). A small selection of fortifications may have been constructed long before the nineteenth century. In Lapaha, unpublished radiocarbon ages reported in Parton et al., (2022:160) from the fortification of Olotele indicate it was likely constructed between A.D. 1400 to A.D. 1500 with the adjacent Fisi Tea fortification wall constructed shortly after between A.D. 1400 to A.D. 1600. The smaller, Lapaha Kolotau was constructed A.D. 1310 to A.D. 1410 (Clark et al., 2018:414), and these early fortifications hint at multiple episodes of warfare in the Tongan past.

The final category of built environment features are large mounds called *sia heu lupe* that were constructed for the sport of pigeon snaring and are characterised by their large size and a central depression (Pond, 2016). *Sia heu lupe* are found in all island groups of the Tongan archipelago (Davidson, 1971:35; Kirch, 1988:44–63; McKern, 1929:19–27) with substantial clusters found in Ha’apai (Burley, 1996) and at least 47 on Tongatapu (Burley & Freeland, 2022). While *sia heu lupe* are important culturally (Burley, 1996), little is currently known about their chronological development. A single *Gafrarium* shell collected by Spennemann (Wk-1417, 1989d:429) recalibrated with the MARINE13 curve dates between A.D. 1210 to A.D. 1410 (90% HDI) although issues with the reliability of shell dates are explored by Petchey and Clark (2011). In Ha’apai, Burley (1995) uses vernacular literature to propose a mid-fifteenth century A.D. construction date for *sia heu lupe*.

Archaeological Correlates of Urbanisation

Measuring Agglomeration

To model agglomeration economies in Tongatapu settlements, we use the settlement scaling framework set out by Ortman et al. (2020a) that simplifies models of agglomeration effects making it suitable to analyse archaeological data. The variables used to model agglomeration via settlement scaling are derived from lidar data and include the number of mounds in a settlement cluster derived from DBSCAN as a proxy for settlement population, and the area of the settlement cluster. Scaling models are fit using the ‘rstanarm’ package in R using the default weakly informative prior (Goodrich et al., 2023). To recap, if a settlement was experiencing agglomeration effects, then we would expect to see a settlement become denser as it become larger as residents manage the costs of growth with the benefits of proximity.

In Fig. 6, we see that Tongan settlements did become denser as they became larger with the scaling exponent for settlement densification below one (Table 2). The result indicates that settlements on Tongatapu experienced agglomeration effects at rates comparable to those identified for structured settlements (5/6 Bettencourt, 2013; Ortman et al., 2015:2) rather than amorphous settlements (2/3 Bettencourt, 2013; Ortman et al., 2015:2) or mobile bands (Lobo et al., 2022). A scaling exponent consistent with structured settlements elsewhere in the world reflects both lidar mapping of mounds and European descriptions of Tongatapu indicating a highly organised built environment underpinned by an expansive transport network. Cottineau et al. (2017) and Arcaute et al. (2015) both note that

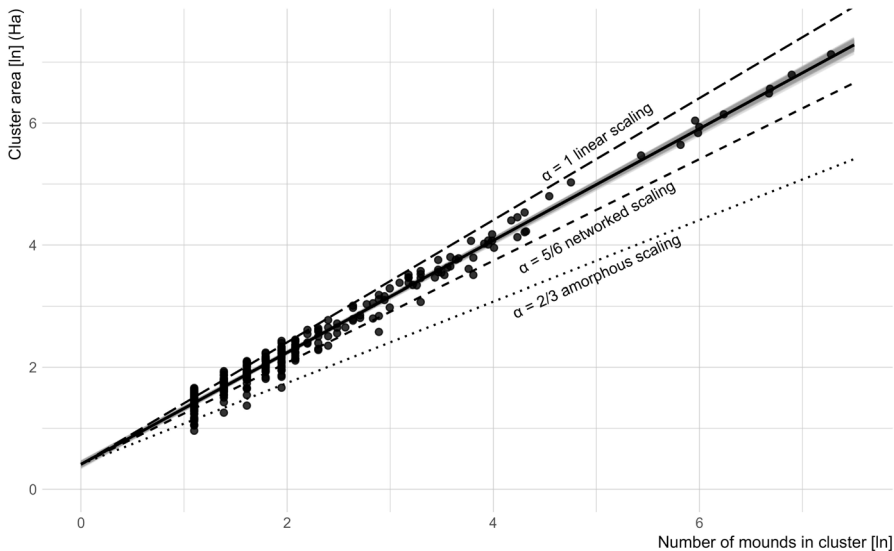


Fig. 6 Scaling analysis of Tongan settlements. Amorphous, networked, and linear scaling regimes shown for comparison

scaling exponents can be sensitive to settled area definitions. We demonstrate that our results are robust to changes in cluster size by making adjustments of 20 m to the ‘Eps distance’ parameter in DBSCAN. The sensitivity analysis produces scaling exponents that lie within the 90% credible interval of our main result (Table 2).

Managing Social Interactions

Low-Density Urbanisation

The increasingly denser settlements formed by agglomeration effects cause an increase in social interactions as residents interact more frequently. We first look at how settlements managed these interactions through settlement morphology and architectural innovations.

In Table 3, we calculate the population of settlements with an area greater than 100 Ha on Tongatapu by using the modified house count method used by Parton and Clark (2022). The largest settlement on Tongatapu, at Mu’a, was home to an estimated 6700 to 7600 people (90% CI) over 1170 ha. The settlement density at Mu’a was 6.16 people per hectare, and the density of settlements larger than 100 hectares varied between 3.80 and 6.47 people per hectare, and in Fig. 7, we plot the Tongan settlements to Fletcher’s interaction-communication matrix (Fletcher, 1996) to demonstrate that settlement sizes and densities are comparable with other low-density settlements in a global sample. By operating at these low densities, Tongan settlements were able to space out the increasing social interactions generated by agglomeration and incorporate agricultural land uses into the settlement milieu.

Table 3 The number of mounds, area, population (median), and density (people per hectare) of settlements in Tonga with areas larger than 100 hectares. Settlements mapped in Fig. 8

Cluster number	Cluster name	Number of mounds	Area (Ha)	Population (90% CI)	Density
1	Mu’a	1446	1170	7210 (6720–7630)	6.16
2	Kolonga	988	862	4920 (4570–5230)	5.71
3	Fua’amotu	799	665	3980 (3700–4240)	5.98
4	Folaha	792	609	3940 (3660–4210)	6.47
5	Tatakamotonga	511	446	2550 (2350–2730)	5.71
6	Malapo	403	365	2010 (1850–2160)	5.50
7	Holonga	397	322	1980 (1820–2130)	6.15
8	Ha’amea	387	399	1930 (1770–2070)	4.83
9	Heketā	336	275	1670 (1530–1810)	6.08
10	Pangai	229	231	1140 (1030–1240)	4.94
11	Nukunuku	116	152	580 (510–640)	3.80
12	Vaotu’u	94	121	470 (410–530)	3.87

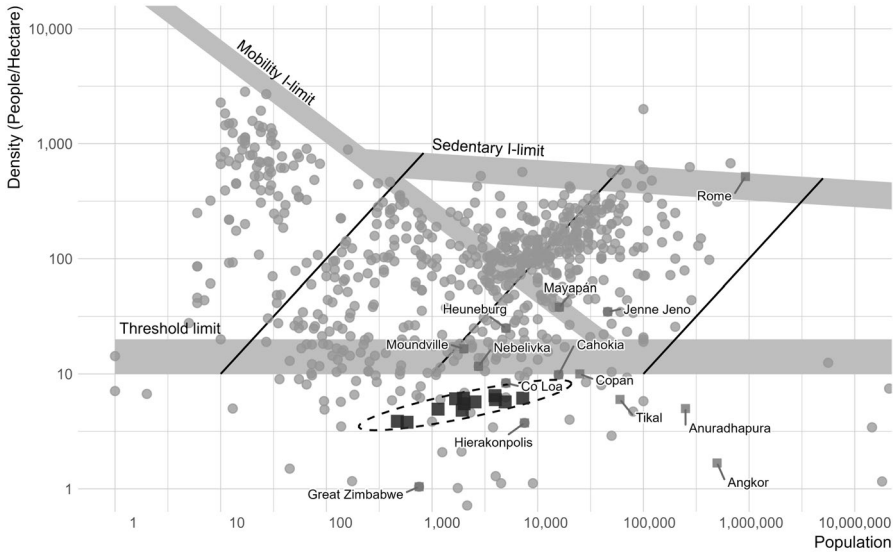


Fig. 7 Tongan settlements plotted to interaction-communication matrix (see Fletcher, 1996 for derivation). Settlements at, or below, Fletcher’s Threshold limit of 10 to 20 people per hectare are considered low-density, using settlement morphology to mitigate social interactions stresses. Tongan settlements (black squares) from Table 3 fall within the low-density area and are comparable to labelled settlements that have similar densities and institutional arrangements. Data for background settlements sourced from Cesaretti et al (2016), Fletcher (2012), Fletcher et al. (2022), Hanson and Ortman (2017), Hutson et al. (2023), Klassen et al. (2021), Smith (2005), and White (2022).



Fig. 8 Location of mound clusters in Table 3 (1 to 12) on Tongatapu

Settlements in Tongatapu also mediated the increase in social interactions generated by agglomeration in other ways. Several architectural innovations identified as important by Fletcher (1996:134–151) as material prerequisites for settlement growth are present in Tongatapu: durable materials, baffles and barriers, elevation, route hierarchies, rectilinear forms, and large linear dimensions that provide legibility in settlement structure by creating recognisable spatial scales for residents. The earliest European accounts all document rectilinear living compounds surrounded by tall fences that prevented unwanted access and reduced visibility from the street (Cook, 1969:246 & 252; Tasman, 1642–1643). While Tongan residences were open sided for comfort, their elevated position on top of durable earth mounds broke street level site lines to further manage settlement stresses and improve amenity during rain and breezes. The well-developed road hierarchy that crossed Tongatapu provided routes for the movement of goods that minimised interaction stresses on minor roads. Finally, large linear dimensions are observed in the regular spacing of mounds by culturally important measurement units like the *ofa 'e teau* (approximately 150 m).

Institutions

As the social interactions stimulated by growing populations increased, the built environment was increasingly unable to manage social interactions alone. In response, residents looked to new social institutions to structure and manage life. Historical linguistics suggests that political and religious institutions existed in Pacific societies since the arrival of Lapita people in Tonga 2850 years ago (Burley et al., 2012; Kirch & Green, 2001). However, the key milestone for settlements becoming urbanised is how these institutions grew in power to occupy settlement space. We compare these developments at the settlement of Mu'a, which was the political capital of the Tongan Maritime State, and a related but smaller centre at Holonga. These two locations show how the competition for space within settlement cores was influenced by the infrastructural power of the social institutions (Norwood & Smith, 2022; Pugh, 2018).

The settlement of Mu'a was the capital of the Tongan Maritime State and the home to many territorial political institutions of the polity. Vernacular literature situates the establishment of Mu'a as the political centre in the thirteenth century A.D. when the sons of Tu'i Tonga Tu'itātui, Talatama, and Tala'iha'apepe, relocated their residence from Heketā to provide better anchorage for storing vessels (Thomas, 2013:29). However, Lapita age remains at Talasiu (750 B.C. to 650 B.C. Valentin et al., 2020:3) and the radiocarbon results presented in Fig. 3 demonstrate that the area has known some form of settlement since people first arrived in Tonga.

Many of the architectural features associated with urban institutions (Smith, 2016, 2020) are found in the central area of the Mu'a core. McKern (1929:92–101) documented traditions identifying the location of large open spaces, connective infrastructure, and the residences of political elite and their monumental burials in the modern settlement of Lapaha (Fig. 9a). McKern also recorded the location of residences and burials of the lower elite that filled positions within administrative

and religious institutions. Fortifications and gates separated land uses and social classes, and a wharf and harbour infrastructure connected the settlement to the Polynesian world. The missionary, the Reverend Walter Lawry, described the settlement at Mu‘a in 1822 as the ‘Metropolis of Tonga’ (Lawry, n.d:90).



Fig. 9 Layout of institutions in the core location of Mu‘a (a) and at neighbouring Holonga (b)

The spatial configuration of social institutions at Mu‘a as described by McKern is the result of some 500 years of development and competition between the residents of the settlement and the growing social institutions. Shortly after the arrival of the brothers, Talatama and Tala‘iha‘apepe, in Mu‘a, important infrastructure linked to emerging political institutions begins to be constructed: a royal tomb, J20 *Paepae-otelea*, (A.D. 1300 to A.D. 1400 Clark et al., 2016:1044) and a fortification (A.D. 1310 to A.D. 1410 Clark et al., 2018:414). The position of the tomb on reclaimed land and the fortification on the fringes of the settlement, both marginal environments, indicate that the new institutions in Mu‘a were unable to compete with existing land uses and institutions already occupying central spaces. However, the situation rapidly changed as subsequent tombs were constructed along main thoroughfares and new fortifications enclosed central spaces.

A second reconfiguration of space to accommodate expanding social institutions is recorded in Tongan vernacular literature that describes a spatial division in the fourteenth century A.D. following lineage segmentation. The creation of the Tu‘i Ha‘atakalaua line to administer the secular institutions of government divided the central area of Mu‘a between the secular *kauhalalalo* (people of the lower side of the road) and the ‘sacred’ institutions of the Tu‘i Tonga of *kauhala‘uta* (people of the landward side of the road) (Bott, 1982:79–80). Further lineage segmentation in the sixteenth century A.D. saw continued reconfiguration of space, this time with the new governing institutions associated with the Tu‘i Kanokupolu line occupying land in the adjacent Tatakamotonga settlement (Clark, 2016).

At the nearby settlement cluster of Holonga (Fig. 9b), lidar data reveals a similar configuration of the central areas of settlement, albeit at a smaller scale than at Mu‘a. The smaller settlement permits the identification of three core components of Tongan settlement centres: open space, transport infrastructure, and large flat-topped mounds oriented towards the road and open space. The settlement at Holonga lacks the elaborate stone architecture found in Mu‘a, which suggests that the competition for institutional land uses was directed to local institutions rather than elite and territorial institutions. Radiocarbon dates for flat-topped mounds indicate the emergence of this configuration was early and it may have been the initial land use pattern at Mu‘a that was later displaced.

Importantly, the layout of settlement cores and the association of large flat-topped mounds with adjacent open space and roadways appear repeatedly across Tongatapu (Figs. 4 and 5; Clark et al., 2024). The widespread presence and early emergence of this configuration highlight the importance of highly connected places in managing social interactions within and between settlements. These central locations served as community nodes that facilitated social interactions and connected residents to neighbouring settlements, and from A.D. 1300, the larger territorial institutions developing at Mu‘a.

Discussion

The settlements of Tongatapu developed many of the characteristics and traits of urban settlement systems identified in other parts of the world. Tongan settlements produced the agglomeration effects that are key to supporting settlement growth,

and they developed the social institutions that structure interactions for residents. The increased social interactions stimulated by the agglomeration effects were initially mitigated through built environment innovations like mound construction, regular spacing of structures, and a low-density settlement morphology. Eventually, these innovations needed to be supported by social institutions to continue settlement and social development. The social institutions that were developed are typical of those common to urban settlements and include elite residences and burial structures, civic architecture, fortifications, public space, and connective infrastructure. The combination of agglomeration effects and the development of social institutions presents strong evidence that Tongan settlements were urban.

As settlements continued to grow and more mounds were constructed, nascent social institutions began to vie for space within the settlement. The first evidence for social institutions influencing the development of the built environment occurs at a recently described large, flat-topped mound in south east Tongatapu that was constructed around A.D. 400, and occurs in configuration with roads and open space (Clark et al., 2024). By A.D. 1000, social institutions were transforming the central areas of settlements across Tongatapu by displacing earlier land uses with planned configurations of mounds, roads, and open space (Figs. 4c and 5), suggesting that these settlements were on a trajectory to urbanisation. The increasingly urban character of Tongatapu settlements was then able to be incorporated into the growing state apparatus from A.D. 1300 onwards by taking advantage of the concentrated labour pools and specialised workers in urban settlements to construct fortifications, monumental architecture, and project territorial institutions across the region.

Since Childe (1950) and Adams (1966), urban settlements are commonly used as evidence for how territorial states project their power to citizens. The Tongatapu data supports growing evidence separating the processes of urbanisation from the expansion of state political institutions over a territory (Fletcher, 1996:189; Jennings, 2016; Smith, 2023; Smith, 2003b:11–16), although this view remains controversial (Yoffee, 2009). In the latter view, rather than urbanisation being an invention of the state, the causality is reversed, and the political institutions later implemented across territories are developed and honed within aggregated settlements as a result of the generative effects of people coming together (Ortman & Coffey, 2017:678; Smith, 2019, 2023). In Tongatapu, territorial political institutions were preceded by several hundred years of social development providing a clear distinction between urbanisation and state formation. Linguistic reconstructions place the development of several of these social institutions to Ancestral Polynesian Society 2850 to 1000 years ago (Kirch & Green, 2001), and it is likely that nascent forms of these institutions existed for a time before they reached sufficient infrastructural power to compete for settlement space and construction on durable foundations.

The Tongan data outlined above has important implications for our understanding of the development and expansion of Polynesian societies in the region. Kirch (1984) used logistic growth equations to identify the first millennium A.D. as an important period of growth and expansion in Western Polynesia. This is a period marked by limited archaeological evidence (for example Rieth & Addison, 2008), and historical linguistics has been used to model growing social complexity (see Burley & Clark, 2003; Kirch & Green, 2001). Our analysis of the built environment

on Tongatapu provides the first archaeological evidence for settlement growth and institutional development in the first millennium A.D. The new results show that earth architecture was being constructed approximately A.D. 300, some 700 years earlier than previously thought (Burley & Clark, 2003; Davidson, 1979:94–95), demonstrating that architecture can now be used to investigate social development in the Pacific over millennia.

The development of the Tongan built environment is also earlier than in neighbouring islands which has implications for later episodes of population expansion. In the eastern Sāmoan islands, the first evidence of a growing built environment emerges at A.D. 800 followed by a substantial surge of construction growth after A.D. 1200 (Quintus et al., 2020:14). Macrocharcoal analysis of sediment cores from the neighbouring island of Upolu presents similar evidence of landscape alteration at approximately A.D. 750 (Gosling et al., 2020:67) and built environment growth at A.D. 1025 to A.D. 1400 (Wallin et al., 2007:77). Our data suggests that West Polynesia, and Tongatapu in particular, had structured built environments and emerging community focussed social institutions centuries prior to sustained settlement of East Polynesia about A.D. 1125 (Sear et al., 2020; Table 1). The trajectory of Tongan urbanisation presented here is informative for understanding the social conditions in West Polynesia prior to Polynesian migration and has implications for interpreting architectural features in early East Polynesian sites (Wallin & Martinsson-Wallin, 2022).

Research on agglomeration and scaling in low-density settlements is new, and there is currently little published comparative quantitative research. An analysis by Smith et al. (2021) in Mesoamerica identified scaling coefficients that encompass the range of scaling regimes (0.820 to 1.711), and other studies from the northern Maya lowlands also present results ranging across scaling regimes (0.889 to 1.087 Hutson et al., 2023). Our results show a sublinear scaling regime operated in the low-density settlements of Tongatapu, and these results are robust to the modifiable areal unit problem by varying parameters in the DBSCAN algorithm and estimating similar scaling coefficients. A review by Ribeiro and Rybski (2023) highlights the importance of connectivity to the Bettencourt model of settlement scaling, adopted here and by other archaeologists, so that the benefits of social interactions can outweigh their costs. Because many Mesoamerican cities have discontinuous ground plans that are shaped by complex topography (Thompson et al., 2022), settlement and transport networks are restricted to suitable terrain on ridges and valleys that increase the cost of social interactions and produce the variable scaling regimes noted above. In contrast, there are few topographical constraints to the growth of Tongatapu settlements allowing the realisation of expected scaling coefficients. We agree with Smith et al. (2021) that the question of scaling regimes in low-density settlements remains an open question and new data from other settlement systems is needed.

If the settlement organisation of Tongatapu was in fact organised as an urban system (such as Leeds, 1980), then why has this idea not been explored previously? Intensively developed built environments are often described by archaeologists in the Pacific and are supported by early historic accounts by Europeans who described Tongatapu as ‘wholly laid out in Plantations’ (Cook, 1969:261) and parts of Sāmoa

‘filled with houses from the hilltops down to the edge of the sea’ (LaPérouse, 1995:412). In Tonga, indigenous descriptions of past built environments, such as *fanongonongotokoto*, relate a built environment that was so densely occupied that news could be transmitted while lying down (Gifford, 1929:4). Because Pacific Island landscapes were largely empty in modern times due to depopulation following introduced diseases (Parton & Clark, 2022; Sand, 2023), few have considered an indigenous Pacific urban tradition. Historians and geographers regard urbanisation as a foreign introduction (Buchholz, 1983:1) and a reconfiguration of ‘traditional’, rural ways of life (Cocklin & Keen, 2000; Connell, 2017). Similarly, Spennemann (1993) sees Tongan urbanisation as a nineteenth century phenomenon in response to episodes of warfare that was later codified in the 1875 constitution (Lātūkefu, 1975) as a preference of local elites and their European supporters.

Archaeologists too have been dismissive of urban frameworks to analyse the development of built environments (although see Bulmer, 1993). In Hawai‘i where an archaic state is argued to have developed, researchers argue that low population densities were the primary reason for the absence of urbanised settlements (Hommon, 2013:129; Jennings & Earle, 2016:482–484; Kirch, 2010:75). Other explanations for the absence of urbanisation in Hawai‘i include a lack of wheeled or animal based transport, tuber crops that defied long term storage (Kirch, 2010:75), the absence of market based specialisations in the economy, and active resistance to population aggregation by common people (Jennings & Earle, 2016:483–485).

However, as Fletcher’s (2019:4–5) model shows, the traits and institutions associated with urban settlements can, and do, develop in settlements with low overall population densities, and as Smith (2012) notes, the explanations above would preclude many non-European settlements. We note that population densities in Hawai‘i and Tonga are comparable. Estimates of population densities in Kirch (2010:Table 4.2) indicate that the equivalent dryland agricultural systems of Hawai‘i had similar population densities to Tonga, 2.62 people per hectare compared to 2.05 to 2.46 people per hectare in Tonga. Archaeological evidence from Hawai‘i suggests that many of the social institutions associated with urbanisation were also manifested in the built environment of sixteenth and seventeenth century A.D. ‘royal centres’ (Hommon, 2014; Kirch, 2010:166–173). At the royal centre Hōnaunau, archaeological remains associated with political institutions include residences of rulers (Emory, 1986; Stokes, 1986) and their mausoleum—Hale o Keawe (Ladd, 1985). Nearby are the residences and burials of lower ranking elites, and those who supported the settlement (Ladd, 1969, 1986). The settlement also contained important religious infrastructure and was the central location for tax collection (McCoy, 2018) with connectivity to the wider archipelago (Reith et al., 2013) and the nearby Kona field system (McCoy et al., 2022).

A reviewer asked how investigating Pacific settlements through the lens of urbanism helps us to understand the diverse societies of Oceania? To put this question in context, we reiterate that until now the Pacific societies of the past have never been identified as being urbanised nor have the processes of urbanisation been analysed despite remote sensing and archaeological surveys documenting extensive built remains and evidence of larger populations prior to European contact (Bedford et al., 2018; Comer et al., 2019; Freeland et al., 2016; Jackmond

et al., 2018; Jalandoni et al., 2022; Ladefoged et al., 2011; Quintus et al., 2015a). As the Pacific is a new area to apply urban science methods, we believe that the benefits of employing urbanisation approaches include the following. Firstly, urbanisation is an important approach to analyse Pacific landscapes because it can distinguish how residents, settlements, agricultural zones, and built infrastructure interacted with each other over large areas (Bettencourt, 2021; Leeds, 1980). Secondly, when combined with the growing chronological record of built environments, urban methods can track the growth of settlements and their built institutions to examine, for example, the relative strength of collective versus exclusionary systems through time (Carballo et al., 2014; Green et al., 2023). Thirdly, urban theory increasingly focusses on using built environment data to obtain measurable indicators of social agglomeration, interaction, density, prosperity, equality, and sustainability (Crawford et al., 2023; Kohler & Smith, 2018). These and other quantitative indicators will inform on longstanding questions in the Pacific, such as, why did Tonga form a long-lasting primary state or ‘maritime empire’ when neighbouring Fiji and Samoa did not? Quantitative approaches permit explicit comparisons that will provide new insights and testable hypotheses of oceanic social development (Smith, 2017), including how variation in settlement trajectories influenced Polynesian culture. Finally, a key strength of many Pacific societies is the continuation of traditional cultural and economic systems that govern the use of space (Bennardo, 2000; Francis, 2006; Refiti, 2015), along with extensive oral histories that document the role of social and political institutions and their place in the landscape (see above). In short, urban frameworks and models provide a new and powerful approach to understanding Pacific landscapes and uncovering what Roger Green (1991:19) has described as Oceania’s ‘real historical complexity’.

Conclusion

Theories of urbanisation have advanced considerably by identifying and modelling the key processes underlying both ancient and modern settlements (Lobo et al., 2020b; Ortman et al., 2020b). At the same time, remote sensing technologies have transformed how we capture the archaeological remains of built environments (Chase et al., 2012). New methods of spatial analysis, such as those presented here, now permit us to advance remote sensing technologies beyond site prospection (Horn & Ford, 2019) to understand how past societies developed.

The urbanisation process outlined here has focused on the generative effects of social interactions in space that presents several opportunities to Pacific archaeologists. First, the full range of social interactions can be considered in the model (agglomeration) as well as the effects these aggregated interactions have on the development of society (social institutions)—both intentionally and unintentionally. As settlements grow, we can now learn how communities changed because of increased social interactions. Characterising the ways that social interactions manifest on the built environment is important to understanding demographics, landscape and environmental change, agricultural development, and political evolution.

Settlements in the Pacific have considerable potential to inform global debates on settlement formation, urbanisation, and sustainability. As outlined here, the early commencement of settlement growth in Tongatapu indicates that urbanisation in the Pacific, like state formation (Hommon, 2013; Kirch, 2010), is an indigenous innovation that developed without the influence of continental complex societies. Locations in the Pacific with dense built remains similar to Tonga, and where the fundamental processes behind settlement growth can also be examined with lidar data, include the built environments of Sāmoa (Jackmond et al., 2018; Quintus et al., 2015a), and the centre of Nan Madol in Pohnpei (Comer et al., 2019). Locations such as Vanuatu (Bedford et al., 2018) and the eastern Torres Strait islands (Wright et al., 2022) where the built environment remains are predominantly agricultural present contrasting and striking examples of settlement growth trajectories that seemingly did not result in urbanisation. Further advances in our understanding of Pacific societies and their settlement diversity can be generated by additional studies of the type we have outlined here, particularly when combined with Indigenous knowledge, historical observations, and a robust chronological record of a society's built structures. We anticipate that these studies are likely to identify diverse settlement systems that will further contribute to our knowledge of urbanisation and the development of complex societies.

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Declarations

Competing Interests The authors declare no competing interests.

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