Settlements, Power and Transport Networks: A Complex-Systems Approach to Early Urbanisation in Central Italy

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Early urbanisation is commonly investigated through the growth and transformation of individual settlements. Yet settlements do not develop in isolation: they form systems whose organisation depends on mobility, interaction and the infrastructures connecting different communities. From a complex-systems perspective, transport networks are neither a passive background to urbanisation nor a straightforward consequence of geography. They emerge from the interplay between spatial constraints, the distribution and relative importance of settlements, and collective decisions about which connections should be established and maintained. Their structure may therefore preserve information about the social and political organisation of the communities that created them.

We develop this perspective through the study of protohistoric settlement systems in southern Etruria and Latium Vetus between approximately 950 and 500 BC. The initial models represent settlements as spatially distributed agents whose decisions contribute to the formation of terrestrial routes. Alternative rules for generating connections make it possible to explore systems ranging from relatively coordinated regional organisation to configurations in which particular settlements exercise disproportionate influence. Comparing the networks produced under these assumptions with archaeological reconstructions makes it possible to investigate what kinds of geographically constrained social processes could have generated the observed patterns (Fulminante *et al.*, 2017; Prignano *et al.*, 2019; Prignano *et al.*, 2021).

Representing transportation as a single network provides a useful approximation for the study of protohistoric roads, but it necessarily leaves aside other components of regional mobility, including navigable rivers. These early models also start from a set of isolated settlements and generate a single network of terrestrial connections.

A more general mechanistic formulation changes this starting point. Rather than assuming disconnected nodes, it takes a pre-existing high-friction network and models infrastructure development as the creation of lower-friction connections within an already connected system, under geographical, demographic and construction constraints (Prignano *et al.*, 2023). Although transport modes are not represented as explicit layers, the infrastructure under examination no longer constitutes the entire system of possible connections.

A complementary line of research explicitly represents roads and rivers as distinct components of a regional transportation system. A road-only network is compared with a multimodal system combining terrestrial routes and navigable rivers, using a

connectivity measure that balances the availability of alternative routes against cumulative maintenance costs (Prignano *et al.*, 2026). By varying the relative costs assigned to the maintenance of river routes and ports, the analysis identifies the conditions under which the multimodal system provides more robust regional connectivity than roads alone. Rivers reinforce connectivity across a comparatively broad range of cost conditions in Latium Vetus, whereas their contribution in southern Etruria is limited by the scarcity and fragmentation of navigable waterways.

The mechanistic formulation and the multimodal analysis address complementary dimensions of the same problem. The former models infrastructure development within a pre-existing network, while the latter examines the contribution of terrestrial and fluvial routes to regional connectivity.

The longer-term aim of this research programme is to develop a multilayer generative model of terrestrial and fluvial connectivity. This will require a new formulation of how network-formation processes operate across transport layers with different properties and how interactions between them shape infrastructure development. Together, they define the conceptual and empirical basis for investigating the development and organisation of transport infrastructure within multimodal regional systems.

Keywords: early urbanisation; transport networks; generative models; multimodality; roads and rivers

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