

Putting Space Syntax to the Test: Digital Embodiment and Phenomenology in the Roman House

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While space syntax analysis has been widely applied to archaeological sites (including Pompeii), it is fundamentally limited by its isolation within the social sciences and its omission of decoration from the analysis of human cognition and movement within structures. At the same time, phenomenology in archaeology has typically arisen from the physical experiences of a limited number of professional archaeologists in a landscape, with little interest in digital embodiment in virtual spaces. The Virtual Pompeii Project has produced an updated version of space syntax which combines network measures common in the social sciences with visibility graphs to produce predictive models of movement within a set of three ancient Roman houses in Pompeii. These predictive models are tested through the navigation of virtual models of the houses by human subjects, demonstrating the significance of decoration in shaping movement, and, through quantitative and qualitative data, the value of digitally embodied phenomenology. This points ahead to the use of crowd-sourced, web-based global testing, diversifying the subject pool far beyond the narrow bounds of professional classicists or archaeologists.

Key words:

Pompeii, space syntax, wayfinding, digital phenomenology.

SDH Reference:

David Fredrick and Rhodora G. Vennarucci. 2021. Putting Space Syntax to the Test: Digital Embodiment and Phenomenology in the Roman House. *SDH*, 4, 2, 185-224.

<https://doi.org/10.14434/sdh.v4i2.31521>

1. INTRODUCTION

Since the publication of *The Social Logic of Space* more than 35 years ago [Hillier and Hanson 1984], space syntax analysis (SSA) has become widely diffused as an interpretive approach in New and Old World archaeology to explore the correlation between spatial configuration and social phenomena. Its diverse applications include, for example, a 4th-century CE Mesoamerican residential compound [Robb 2007], a 10th-12th century CE Chacoan Great House in the American Southwest [Van Dyke 1999], a 14th-century pueblo in New Mexico [Shapiro 2005], Bronze Age palaces on Cyprus [Fisher 2009a and 2009b], the Roman imperial harbor city of Ostia [Stöger 2011 and 2015], and the Roman provincial town of Pompeii [e.g. Anderson 2004 and 2005; Grahame 1999 and 2000; Laurence 1994; von Stackelberg 2009]. SSA has been widely adopted because of its promise to allow the space of an archaeological site to speak in its own discrete terms: we may have little material or textual evidence from the culture that produced the site, and the walls may be little more than ankle-high, but nonetheless the

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structure of the space, in the relationships of one room to another as part of a network, can carry meaningful cultural implications. As Jason Shapiro puts it, "A cornerstone of the theory is the assumption that the configuration of any network of built spaces is the spatial expression of the social relations of the group responsible for creating the network" [Shapiro 2005:7].

Traditional SSA has two primary methodologies, the justified plan graph, used primarily for building interiors, and the axial line map, used primarily in the analysis of exterior urban space. The justified plan graph of a structure treats each room as a node, and then groups the nodes (rooms) in sets based on their depth from the entrance. Based on the justified plan graph, if a given culture consistently builds structures of comparatively shallow depth and high integration (most rooms cluster close to the entrance, and are similarly positioned within the network), this suggests that the culture is not deeply stratified by class and status. Conversely, if a given culture consistently builds structures with significant depth and low integration (many rooms located quite far from the entrance, with significant asymmetry in their connectivity), we might assume that the highly stratified nature of the space reflects a deeply stratified social hierarchy. As an example of the former, in applying SSA to Arroyo Hondo Pueblo in central New Mexico, Shapiro observes, "The syntactic pattern of roomblock 16 is essentially symmetrical and distributed, meaning that there is a relatively high degree of accessibility among its spaces...This spatial pattern has been associated with less hierarchical forms of social organization. In the case of Arroyo Hondo, these findings are consistent with relatively egalitarian tribal models..." [Shapiro 2005:70]. Conversely, Matthew Robb concludes of the spatial syntax of the Aztec site of Zacuala, Teotihuacan, "The apparent symmetry of the compound's design does not promote equal access to its similarly structured patio groups. Instead, access is increasingly controlled and limited, and the subtly rising numbers for integration suggest that a great deal of attention was paid to ensuring correspondingly precise social differences" [Robb 2007:7; in traditional SSA, the higher the integration number itself the more segregated the space, and the lower the number, the more integrated the space].

Along with justified plan graphs, SSA includes analyses based on axial line maps. For a given built environment, a set of lines is produced corresponding to direct, unbroken paths of visibility and movement, starting with the longest and moving down to the shortest, generating an axial map that consists of the fewest possible lines [Hillier and Vaughan 2007; Jiang and Claramunt 2002]. With the lines as nodes and their intersections as links, the axial map is assessed using network measures similar to those found in the justified plan graph: connectivity, control, depth, and integration. As Sonit Bafna noted, if justified plan graphs help explain the spatial syntax of a given environment, axial line maps help explain movement within it [Bafna 2003:23]. In practice, axial line analysis has found widespread use in research on outdoor urban space rather than inside buildings, which has a certain basic logic, since a street is far more like a line than is a room. Indeed, "Space Syntax" in urban studies primarily means axial map analysis, and in the form of the Urban Network Analysis Toolkit, it has become part of ArcGIS [Sevtsuk and Mekonnen 2012]. To move from the insides of buildings to the streets outside is thus often to move between "flavors" of SSA, from justified plan graphs to axial line maps. There are consequently few applications of axial map SSA to building interiors, but this method has been used on urban spaces in archaeology and history [Craane 2007 and 2013; Haciguzeller and Thaler 2014, who use it in combination with justified graphs and VGA; Weilguni 2011].

At Pompeii, for instance, Steven Ellis incorporated the analysis of street patterns and isovists into his assessment of the placement of bars along city streets [2004; 2008]. Eric Poehler's discussion of the street network of Pompeii [2016] is particularly interesting for its combination of SSA concepts with a GIS, metrically based analysis of path segments articulated by nodes corresponding to each door, rather than long axial lines defined by the run of the streets. This approach leads to productive questions about the notion of the optimal (likeliest) path for street traffic. While Poehler uses an algorithm that measures this metrically by the shortest path, he recognizes that cognitively the "simplest path," with the fewest turns but longer metrical distance, may be preferred – the guiding premise of the axial map [Poehler 2016:201-202]. Indeed, human navigators will often avoid the shortest metrical path because of the risk of getting lost posed by its many turns. Instead, they may follow an alternative to Dijkstra's shortest path algorithm, including hierarchical paths and paths that minimize route complexity and/or mitigate risk [Vanclooster et al. 2013]. A study performed by Bill Hillier and Shinichi Iida [2005] on vehicular and pedestrian movement in four separate areas of London confirms this proclivity. The study found that of the three path variables, topological (fewest turns), geometric (least deviations in angle) and metrical (shortest path), metrical was the least significant in determining route choice, and geometric the most [see also Sadek and Shepley 2016:117]. It would also be possible to explore the influence of local subnetworks (modularity) on traffic flow, while Poehler relies on the single, global measure of the overlap of all the shortest paths from each door to every other door. This is essentially a measure of betweenness centrality, although this term itself is not used. Although he recognizes explicitly that his work is provisional and invites further questions and research, Poehler's analysis remains a valuable starting point for a nuanced, flexible, and data-driven approach to Pompeii's urban network.

While the axial map method itself has seen only limited use for building interiors, its emphasis on lines of sight as drivers of movement led to the development of visibility graph analysis (VGA), which has shown significant value in modeling movement within structures. VGA offers a way of quantifying the relative visibility of spaces within a structure, given the interference of the structure itself. Like SSA, if a given structure has a high degree of visual integration, and a comparatively low number of visually isolated spaces, it has high intelligibility, implying a relatively egalitarian social structure. Conversely, if visual integration is low and a significant set of spaces are visually isolated, this would suggest a more elaborate social hierarchy. For instance, a comparison of Frank Lloyd Wright Prairie style houses with late Victorian houses led to this conclusion: "Regarding the visual aspect of these relationships, one should expect that the undesirable service zone was hidden away from the eyes of the visitors and daily social life of the owner-habitants. In the space syntax context, this 'hiding' is represented by higher visual depths between the service and social spaces (in comparison to the rest of the house)" [Behbahani et al. 2017:8]. Taken together, SSA and VGA propose that a structure shapes movement by articulating distance (both physical distance and network distance, the number of turns/choices encountered on the route), and visual access (how much of the structure the visitor can see at given points in the space). In general, if many of a culture's structures include long routes with a wide range of integration values in room and visual access, it can be assumed to have a serious investment in hierarchy. Using a nuanced toolbox that combines SSA with isovist analysis (akin to VGA) and Edward Hall's proxemics [Hall 1969], Kevin Fisher concludes of Bronze Age palaces on Cyprus: "Ultimately, the Ashlar Building at Enkomi and other Late Cypriot monumental buildings were aimed at producing meaningful contexts for social

interactions during which various facets of individual and group status and identity could be displayed, negotiated or reinforced. Whatever their practical functions, these structures reified the establishment of social boundaries through which wider social structures were reproduced or transformed" [Fisher 2009b:454].

Despite the capacity of SSA (taken now to include VGA) to formulate hypotheses about movement and social hierarchy in a given culture and across cultures, several decades of use have exposed limitations of the traditional application of the theory. These limitations are partly conceptual and partly practical, as the software to perform SSA continues to age. Conceptually, SSA is a radically abstract approach to space. Once the justified plan and visibility graphs have been produced, SSA is no longer interested in any other characteristics of the built environment. As Hillier succinctly put it [1996], "space is the machine." Daniel Montello points out that this single-minded focus on space makes SSA inadequate as a comprehensive approach to human environmental psychology: "Either explicitly, by theoretical claim, or implicitly, by omission of emphasis, space syntax underplays the role of particular physical characteristics of environments that are, in fact, relevant to human psychology" [Montello 2007:6]. Further, SSA is totalizing in its assertion that space as machine will drive circulation patterns in predictable ways across all contemporary and past human cultures. At the same time, the methods and measures used by SSA to produce the justified plan graph have been criticized for their opaque jargon, inconsistency, and insular separation from network analysis as applied more broadly across the social and hard sciences. As Ostwald put it, "...while it is possible to construct a full and complete (if not consistent and transparent) explanation of the Justified Plan Graph method from published materials, it requires...an extensive investment of time and energy" [Ostwald 2011:447]. Very few scholars outside of SSA (or archaeology) will have a working sense of what "real relative asymmetry" is, but many scholars have first-hand familiarity with social network measures like betweenness centrality and eccentricity. This is reflected in the fact that the Space Syntax program at University College London seems to have abandoned justified plan graphs, and the software to produce them is no longer readily available. Meanwhile, DepthMapX, the application for VGA provided by the Space Syntax program at UCL, receives only intermittent updates, and is often unstable.

The Virtual Pompeii Project has therefore fundamentally reworked the assumptions, measures, and software workflows for an SSA-like approach to the ancient city. Pompeii is obviously unlike many other archaeological sites in that there are standing walls up to six meters or more, densely covered with mosaics and frescoes, many of which remain in situ or are recorded in photographs, drawings, watercolors, and lithographs. These architectural and decorative elements, essential to the choreography of movement in Pompeii, cannot simply be suppressed or abstracted down to their foundations because "space is the machine." Somewhat paradoxically, the rich artistic heritage of Pompeii is why the combination of network topology with visibility graphs remains fundamental to our approach: rather than a space syntax that would explain spatial cognition and movement patterns based strictly on the network statistics of the spaces, this project's methodology provides the context of spatial and visual data necessary to begin to understand which artwork is where in Pompeii, and why. While traditional SSA argues that surface decoration is beside the point, we argue to the contrary that space and decoration, in Pompeii at least, are inherently intertwined, and what is needed is a data-driven analytical framework to explore their relationship. This includes the

critical question of how they might work together to drive movement. For our project, the promise of SSA is clearly predictive: the value of the Justified Plan Graph and Visibility Graph together lies in their ability to forecast where people in the structure might be likely to go, along which paths, and where they might linger. However, it also seems to us that SSA is more comfortable if these predictions are unlikely to be tested, since actually putting humans in a real built environment means confronting them with all kinds of visual, auditory, and somatosensory stimuli that SSA insists do not matter. Indeed, SSA has often been presented as if it were declaring truths rather than proposing hypotheses about space and behavior. In its traditional form, SSA does not have an explanatory framework or method to address the combination of space and decoration, and this may explain why the Space Syntax program at UCL has gradually shifted away from the interpretation of space and movement within buildings and toward the analysis of traffic patterns in larger urban environments, where one could argue that spatial configuration carries significantly more weight than building textures. This has been reflected in studies of Roman urbanism (e.g., Van Nes 2014, Kaiser 2011), as part of a welcome growth of interest in the analysis of Roman streets and shops. In SSA itself, the shift to urban environments has been accompanied by a gradual shift away from the nodes and edges of the Justified Plan Graph in favor of axial map analysis (as discussed above).

It is in fact difficult in practical terms to test the predictions of traditional SSA against the movement of people in actual contemporary environments, especially at "micro" scales: the pedestrian street, shops, and houses. When SSA is applied to past environments, this difficulty becomes an impossibility for most archaeological sites. Even in Pompeii, it would be quite difficult to construct a test of movement patterns in the physical space, because the pressures of tourism and the imperative need to protect the site require that visitor itineraries be tightly and artificially constrained. Thinking beyond the actual, physical space, most archaeological sites are not preserved well enough to allow 3D virtual reconstructions that are both finished sufficiently for navigational testing and well-grounded in the evidence. On this score, Pompeii is different. Its high level of preservation and documentation allows the construction of reasonably complete digital models that can be navigated virtually using game engine platforms. The use of a game engine means that "player" movement through the models can be captured, and this data can be compared to what was predicted through network and visibility graphs of the space. A methodology that combines network and visibility graphs (an updated SSA) with player tracking data from the navigation of 3D digital models has rarely, if ever, been applied to an archaeological site. However, video game designers commonly use an approach like this to understand and predict player behavior, in a feedback loop with player testing.

While surface decoration is simply dismissed in traditional SSA, the use of 3D models in a game engine means that the impact of decoration, an essential aspect of the way movement is choreographed in built space, can be assessed. By toggling decoration in a given house model off or on, A/B testing is possible, raising fundamental questions about how decoration impacts player movement. Are there computationally identifiable consistencies and patterns to the articulation of space and decoration in Pompeii? Do these consistencies and patterns point to a shared strategy for shaping movement? To explore these questions, it became evident that the project would need a framework to track the distribution of artwork across the city, evaluate it for similarity and level of complexity, and compare this to the definition of spaces through network and visibility graph

analysis. This would enable us to ask what kind of artwork is found in what kind of space, where the space is defined by its network scores (betweenness, closeness, eccentricity, eigenvector centrality, hub, authority) and visual integration within a given structure. This means setting aside, at least temporarily, the traditional nomenclature for rooms in Pompeii (*fauces*, *atrium*, *tablinum*, *oecus*, *cubiculum*, etc.), as these terms are too imprecise and loosely defined for meaningful data-driven analysis. The project is in the process of developing a comprehensive analytic tool for art in Pompeii, the Pompei Pitture e Mosaici Explorer (PPMx) [Roullet et al. 2019, forthcoming 2021]. This tool uses the digitized eleven volumes of *Pompei: pitture e mosaici* (PPM), the single most important resource for artwork in Pompeii, to train convolutional neural networks (CNNs) to recognize similarities among its plates, and it uses natural language processing (NLP) to parse its Italian captions. By combining these two strategies recursively back and forth between the images and the text, PPMx aims to allow overall image similarities, as well as specific themes and motifs, to be tracked with a high degree of accuracy across the entire corpus. Since PPM provides precise spatial information for the location of most plates, this can be cross-referenced, through a shared GIS map and database, with the network and visibility graph scores to develop a picture of which types of spaces (defined statistically) receive which kinds of decoration, also defined statistically. This essentially predictive methodology can then be compared to the emerging assessment of the combined effect of space and decoration on player movement through the virtual 3D models. In this respect our project looks to build on the pioneering work of Andrew Wallace-Hadrill on the "articulation of the house" and the impact of decoration on attracting movement toward "grand" spaces while turning it away from "humble" spaces [Wallace-Hadrill 1994; cf. Clarke 1991 for the correlation of decorative complexity and simplicity with static and dynamic spaces]. As we incorporate the data from PPM, we intend to map out decorative content and elaboration against room type in a more granular way than possible for Wallace-Hadrill, with a quantified understanding of visual complexity and interest. The project will then test the impact of different content and style in decoration through player data.

The CNN and NLP methodologies for PPMx are still under development by the project team, most importantly as the dissertation work of Cindy Roullet, a recently graduated doctoral student in Computer Science at the University of Arkansas, and this aspect of the project will not receive much additional discussion here. Rather, the main body of this piece will focus on the feedback relationship between network and visibility graph analysis on the one hand, and data captured from playthroughs of the 3D virtual spaces on the other. This discussion will focus on three houses from Pompeii, the House of the Ara Maxima (VI.16.15-17), the House of the Prince of Naples (VI.15.7, 8), and the House of Paquius Proculus (I.7.1). Although the discussion confirms in a general way the fit between the predictions of network and visibility graph analysis and where the human subjects ("players" in the 3D virtual houses) actually went, there were definitely surprises. One of these we might call "the lure of the unbeaten path," as players fairly often chose to explore the equivalent of network and visual "back alleys" in these houses. Another, perhaps less surprising result was that turning on the decoration definitely impacted player movement, at the scale of the room and the structure. It is very clear even from this initial round of experiments that space is not the whole machine.

Our project thus moves between the predictive (an updated form of SSA) and the experiential, what people actually do in the environment, even if the environment of these houses is virtual. While it is not a matter of interest for traditional SSA, for our project this cannot be separated from how the

subjects feel as they navigate these houses. Consequently, the project administered pre- and post-experiment questionnaires to the subjects in order to gain a sense of their emotional reactions to various aspects of the experience of exploring these virtual houses. This qualitative data is as important as the quantitative capture of their movements, and it bears upon a frequent concern expressed to the authors at conference presentations: your human subjects (thus far, primarily students at the University of Arkansas) are not Romans, and therefore the data produced by their navigation of these digital spaces cannot really tell us much, if anything, about how Romans would have navigated their actual spaces. Our response to this objection forms the final part of this discussion, where we introduce and outline the concept of "diverse proxy phenomenology." To us, there is considerable theoretical and social interest in the fact that this objection was not brought forward as long as the predictions made by SSA remained untested – the universal applicability of SSA across cultures and time was taken for granted, as if it were an objective exercise in statistics, until one threatened to test it. The numbers, after all, could not fail the test of being Roman. We also feel compelled to point out that we contemporary scholars are not, in fact, ancient Romans, and no amount of archaeological or philological training could make us so. Archaeologists, philologists, and historians of ancient Greece and Rome are, however, an extremely narrow and culturally specific slice of human beings. Our training may bring us closer to the Romans in conceptual, interpretive, and imagined ways, and indeed this training is invaluable in informing what Eleanor Betts [2017] has called "the sensory turn" over the last decade of ancient Mediterranean archaeology and history. At the same time, as a way of exploring how "Romans" (a very diverse set of people) might have moved through and behaved in their environments, it seems *a priori* a good thing to test outside the demographic slice of our discipline.

While the predictive side our approach seems abstract and numbers-driven, which it is, the experiential side aligns quite closely with the expanding interest in the archaeology and history of the senses, with its roots in phenomenology and a critical emphasis on the concept of "embodiment" [Betts 2017; Day 2013; Hamilakis 2014; Howes 2005; Robb and Harris 2014; Toner 2014]. As Betts notes, "Sensory Roman histories and archaeologies must include the evidence afforded by textual sources, material culture and embodied spaces, ideally beginning with the recording of sensory data through experimentation (whether that is in the field or via modelling) in order to understand the affordances of the material...Only then can the personal experience and cultural meaning of these data be explored" [Betts 2017:3]. From our perspective, updated SSA and player data from the digital reconstructions together form two halves of a coherent modeling approach, with a feedback loop between them. As Betts observes [2017:3], "there are sufficient parallels between the modern and Roman body to investigate how particular sensory stimuli may have been physiologically, and perhaps emotionally, perceived, something which cognitive neuroscience may enable us to explore further." As our project moves forward to crowd-sourced testing using browser-based 3D models, the diversity of a global player pool will become a vital check on those parallels between the modern and Roman body. While our experiment design is kinaesthetic in that it captures player responses as they move through the virtual environment, it reproduces the visual emphasis of SSA. Since game engines can model the behavior of sound in 3D environments with a high degree of precision, we look forward to incorporating soundscapes into player testing, producing a more holistic view of how space, decoration, and sound shaped the experience of Pompeian houses as places.

2. EXPERIMENT OVERVIEW

For our project, "Experimental Design" refers to both the hypotheses about space and movement generated through our updated form of SSA, and the testing of these hypotheses through the navigation of the Pompeian houses by human subjects on a desktop computer. The experiments were carried out May 1-11, 2018 on 45 subjects in the Behavioral Business Research Lab of the Walton College of Business on the University of Arkansas-Fayetteville campus. Each subject was presented with 1 of 4 scenarios for navigation of the 3 houses: free exploration with decoration off or on, and task-oriented exploration with decoration off or on. Each subject was given a pre-session form to track demographics, knowledge of ancient Greece and Rome, experience with video game play, and wayfinding preferences, and a post-session form to track their recollections of the house plans, their memory of specific moments in their navigation of the houses, and their own sense of the impact of the decoration on their ability to find their way. Each aspect of the experimental design will be presented in further detail below.

2.1 Updating Space Syntax: Network Topology

As a first step, this project set aside entirely the Justified Plan Graph and associated graph calculations (Total Depth, Mean Depth, Relative Asymmetry, etc.) of traditional SSA in favor of those found in social network analysis (SNA). SNA assumes that the flow of people through a spatial network is fundamentally comparable to the flow of information through a social network, and offers us a widely shared and well understood set of network measures, accessible through a range of software packages. However, developing a workflow for generating and representing network nodes and edges for the houses was not entirely straightforward. Rather than a detached graph placed beside the building, as in traditional SSA, we wanted to represent the nodes directly on top of the house plans, indicating changes in the network score of a given room on a given measure by varying the size of the circle representing the node. To accomplish this, we have established a workflow that moves back and forth between ArcGIS and Gephi, an open-source network graphing and analysis software. Initially, in ArcGIS, each house is divided into rooms (shapefiles), using the map of Pompeii provided in *The World of Pompeii* [Dobbins and Foss 2007]. This process is automated but must be manually checked against other published maps of Pompeii, especially the maps produced by Eschebach [Eschebach and Müller-Trollius 1993], the RICA maps [Van der Poel 1984], and the maps found in PPM. Nodes are generated for the rooms, and edges are generated for doorways where the rooms touch. The set of nodes and edges is then exported as an Excel file, and imported into Gephi, where a layout of the network graph is generated and a series of network calculations are performed, for both directed and undirected forms of the graph. When the graph is viewed as directed, a primary direction is established at the main entrance of the house, and this flows across the house from "front" to "back." This very roughly corresponds to the outside-in orientation of a visitor passing into the house from its main entrance. The undirected graph calculates these measures with each room as a potential starting point, corresponding roughly to the movement-within orientation of a household member.

Along with replacing the traditional SSA graph with an SNA approach and measures, this project also reconsidered the common treatment, in earlier uses of SSA, of atria and peristyles as single nodes. As these rooms typically impose changes of directions around their central water or garden feature,

it seemed to us far more accurate and nuanced to split these rooms into four nodes (typically), with an edge drawn from each corner of the *impluvium* or garden diagonally across to the corresponding outer corner of the atrium or peristyle, as shown in Fig. 1. This revealed, in network analysis and player navigation, that these rooms often have an "on" side which carries much of the traffic, and an "off" side that is used much less frequently. As a visitor to the house (or a player of the digital recreation) would have no way of knowing that one side of the atrium has a much higher betweenness value than the other, their choice to go one way or the other around the *impluvium* must be largely driven by visual cues – and indeed the "on" side of the atrium frequently has significantly higher visual integration than the "off" side.

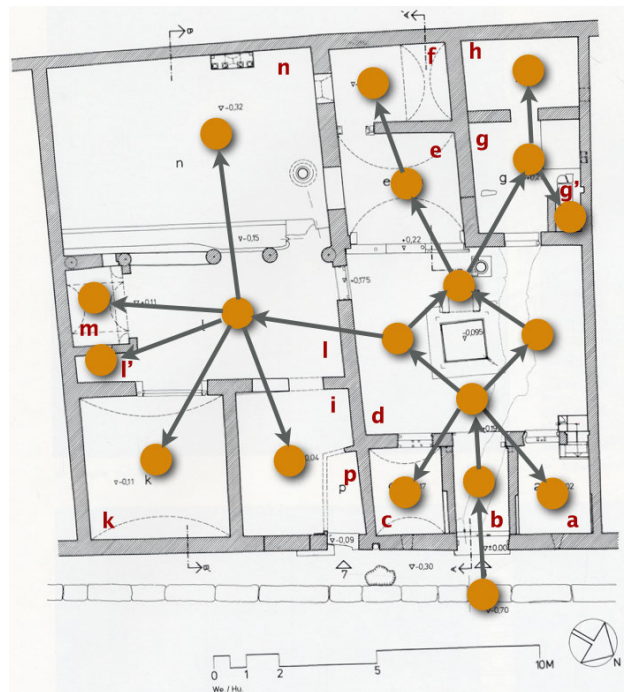


Figure 1. House of the Prince of Naples, directed graph with four nodes for the atrium.

Once the graph of a house has been exported from ArcGIS into Gephi, a standard set of network calculations is performed, summarized in Table 1. This network approach to space assumes that as people move through the houses, so does information: the social network of people has a meaningful, reflective relation to the social network of space. Thus, a room with high authority and eigenvector scores is likely a location where significant encounters took place and important information was exchanged. This is fundamentally different from traditional SSA, where rooms with high integration (roughly corresponding to betweenness and closeness) were assumed to be the most important rooms for the social life of a structure.

In our analysis of houses in Pompeii, the betweenness and closeness scores of a space may be quite low, while its eigenvector and authority scores are high, indicating that it likely had significant social value in the flow of information.

Table 1: Summary of network measures and their definitions

Network Measure	Definition
Betweenness Centrality	Measures how often a node appears on the shortest paths between nodes in the network
Closeness Centrality	The average distance (in network nodes) from a given starting node to all the other nodes in the network
Eccentricity	The distance from a given starting node to the farthest node from it in the network
Hub	Measures the quality of a node's links to other nodes with high authority values (the node is a distributor to valuable nodes)
Authority	Measures how valuable the information stored at a given node is, where "value" means the node is fed by links from nodes that are strong distributors.
Eigenvector Centrality	A measure of node importance based on the quality of a node's connections. For instance, a node may have only few or one incoming edge, but if that edge is at the end of a path that leads through several well-connected nodes, the eigenvector score is high.

This has allowed us to develop a working hypothesis: complexity in mosaic and painted decoration will tend to track together with high eigenvector and authority scores, as complexity in decoration equals cost, a value that silently points to the social (and financial) value of the information passed back and forth in these spaces. A simple example of this is provided by the House of the Prince of Naples (VI.15.7,8), where the betweenness scores of the left side of the atrium and the portico are high, while their eigenvector scores are very low (see Fig 2).



Figure 2. House of the Prince of Naples: a) directed betweenness values; b) directed eigenvector values.

The high betweenness values of the front, left, and back portions of the atrium (room d) and the portico (room l) are clear (sub-figure a), and these values suggest that these rooms experienced significant traffic, as they are on the short paths connecting many of the rooms (room letters can be found in Fig 1). Meanwhile, the right-hand portion of the atrium has a quite low betweenness value: it is the "off" side, a nuance that treating the atrium as simply one large node would erase. Conversely, all of the rooms at the ends of paths have low betweenness values. This does not mean that they are unimportant to the circulation of people/information in the house. When we look at the eigenvector values for the house (sub-figure b), the nodes that were once large in betweenness now become small, while nodes with small betweenness values (e.g., rooms e, f, g, h, k, and m) suddenly loom large, especially rooms e, f, g, and h. This suggests that these rooms, all with only 1-3 edges to other nodes, are significant as high value destinations.

2.2 Updating Space Syntax: Visibility Graphs

In order to produce a predictive model for movement patterns, it is necessary to consider not only network topology and the relative influence of hubs and destinations, but also the visual integration of the spaces. In the example of the House of the Prince of Naples from above, rooms e, f, g, and h share very high eigenvector scores, but they are far different in decorative quality and apparent function. With its high, broad doorway, room e is often identified as the *tablinum* in the house (the primary room for reception of clients) and room f as its most upscale *cubiculum* (a small room for sleeping or intimate social interaction). Both rooms are finely decorated in the 4th Style and have ample windows out on to the small garden of the house. Accessed through a low, narrow doorway, g and h are roughly decorated, with room h used for storage and room g used for cooking and a latrine (Fig 3).



Figure 3. House of the Prince of Naples, view from the atrium into room sequences e-f (left) and g-h) right.
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Because VGA focuses on visual rather than physical connectivity between rooms, it can shed some light on these differences that are not expressed in network topology but are likely to influence movement. Again, VGA works by splitting the plan of a structure into a set of very small squares and calculating which squares can be seen the most by the other squares, given the interference of the architecture. This could be rephrased to say that the architecture is not "interference," but rather constructive, shaping patterns of intervisibility that reinforce (and sometimes conflict with) network topology, and definitely contribute to directing movement. Using DepthMapX, VGA yields a heat map, with the hottest colors identifying the most visually integrated parts of the plan, and cool colors the least (see Fig 4).

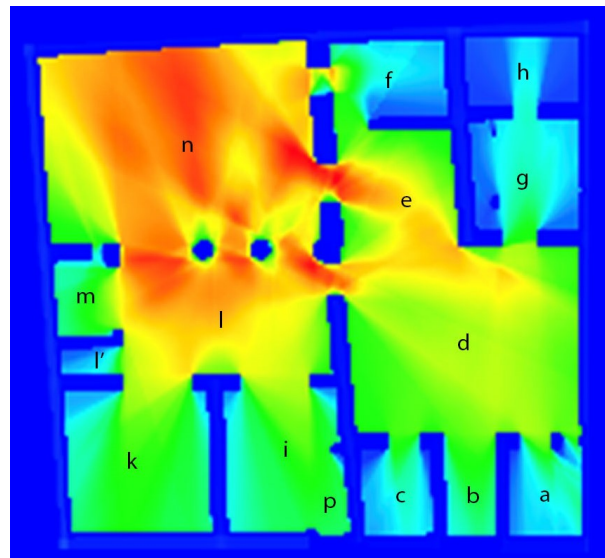


Figure 4. House of the Prince of Naples, VGA produced using DepthMapX.

It is immediately evident that rooms e and f are fairly well integrated visually, especially room e, with its wide door on to the atrium and window on to the garden. Meanwhile, rooms g and h are comparative backwaters, visually the least integrated rooms in the plan. As a general rule in environmental psychology, when navigating a built structure or urban setting humans tend to go where they can see the most, as this will yield the quickest understanding of the building plan. However, this is only a general rule, and obviously will change if a threat is sensed in the environment, or if (for personal or social reasons) the human in question would rather not be seen, since to move along the most visually integrated path in the environment is to make oneself most visible. Granted these exceptions, which may be very significant for a deeply stratified society that includes enslaved people, the general rule of attraction to visually integrated spaces remains, and the VGA heatmap is thus a blunt starting point for predicting the heatmap of actual movement in the structure. The example of the House of the Prince of Naples, however, makes an essential point about using network topology (NT) and VGA together as a predictive methodology: they do not always agree. In this instance, NT assigns equivalent eigenvector scores to rooms e-f and rooms g-h, suggesting that they will receive equally high traffic. VGA suggests the opposite, that rooms e-f will indeed receive significant traffic (especially room e), while rooms g-h, with their very low visual

integration, will receive very little traffic. Paradoxically, in player testing both turn out to be partly right, as will be discussed below. Conflict between NT and VGA points to tension and complexity in the visitor's navigational choices; this mixed messaging between the two components of space syntax is surprisingly common and meaningful in Pompeian houses, which do not univocally command "go there," and "do not go there." In practice, space syntax's mixed messaging drives the visitor to look for further environmental clues to solve the conflict, constructing for the visitor a kind of test or game. As John Clarke notes, Roman houses often present the visitor with a view-through, a visual connection, to a destination that they do not know as yet how to reach physically [Clarke 1991.14-16]. With the updated SSA presented here (NT + VGA), we can begin to quantify how these spatio-visual puzzles work, as well as establishing the more obvious predictions for movement patterns when NT and VGA agree. We would stress, however, that these predictions in any case require player testing.

2.3 Updating Space Syntax: Software for Visibility Graphs

Through most of the project to date, we have relied on DepthMapX for VGA. However, stability and efficiency have remained persistent problems, as the software is updated infrequently, runs slowly, and often crashes. We therefore are currently working to reproduce the functionality of DepthMapX through an application written for the Unity3d game engine. For game developers, the concept of a visibility graph is familiar because games face their own challenges in performance around what the player can see and when. For a game to run smoothly, with a consistently high framerate, it is important that the game render only what the player can see in each frame. Therefore, solutions have been implemented that calculate what the player can see from each point within the playable game space, and then remove from the render everything they cannot.

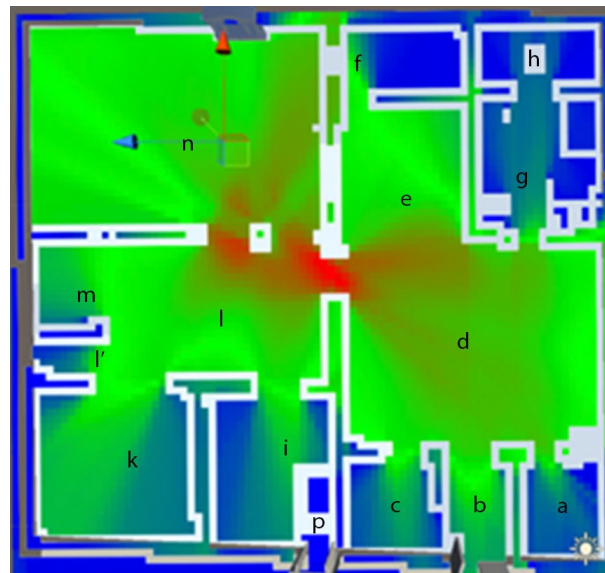


Figure 5. House of the Prince of Naples VGA produced in Unity.

This concept is called "occlusion culling," and the calculated solution for optimizing the render is called an "occlusion bake." Once an occlusion bake is implemented, as the player moves through a game level, parts of the environment are continuously swapping off and on to reflect only what the player can see from any given point in the space, as X pieces of the environment are occluded by Y pieces. By adapting the programming for occlusion culling, we have been able to produce VGA outputs in Unity for several houses that approach DepthMapX in quality, with far greater speed and stability (see Fig 5).

A critical difference between the VGA in Fig 5 (produced in Unity) and the VGA in Fig 4 (produced in DepthMapX) is that the latter includes window and door openings, while the Unity VGA includes only door openings, because it is restricted to the level of the floor. The DepthMapX version depends on a vectorized plan of the house, produced in Adobe Illustrator, which represents windows as if they were doors. This project will shortly produce a VGA for the house in Unity at "eye-level" (57" = 1.448 m), revealing the impact of the windows on the VGA. This Unity-generated VGA was produced by filling the volume of the house, which had been modeled in 3D, with cubes (voxels), calculating the relative visibility of the voxels given the architecture, and then constraining the visualized output to a given height, in this case floor level. It is obviously not possible to model every house in Pompeii in 3D, so future iterations will depend on the export of house shapefiles from ArcGIS into AutoCAD, editing to include eye-level windows, and export into Unity using the PiXYZ plugin, which converts AutoCAD files into a format Unity can read.

3. PLAYER TESTING: DESIGN AND RESULTS

3.1 Experiment Design

We performed our initial round of testing between May 1-11, 2018, with 45 human subjects, all of whom were students at the University of Arkansas. The testing was done on an Alienware laptop with a 17" screen, which hosted the experiment scenarios. These consisted of desktop application builds of the House of the Ara Maxima, the House of the Prince of Naples, the House of Paquius Proculus, and the House of Octavius Quartio, as well as an introductory environment designed to train the subjects on movement in 3D using the PlayStation 4 handheld controller. As the controller involves using only the two joysticks, one to control gaze and the other movement, it is more intuitive than player input through the mouse plus WASD or direction arrow keys. This testing round included the use of an Emotiv Epoc EEG headset, with 9 wet sensors and a wireless Bluetooth connection to an iMac running the Emotiv software. With this setup, the Alienware would run the 3D applications and capture player movement data as they navigated each house while the iMac would record their EEG data. We used the Epoc headset to determine if there were consistent patterns in EEG responses to different spaces in each house, and also consistent patterns in EEG responses to the presence/absence of decoration. While our initial uses of the Epoc headset were promising, in sustained testing with human subjects it proved too sensitive and cumbersome. The sensors needed to be very wet (using a saline solution), and their positioning had to be just right, or a poor connection and loss of data would result; subject hairstyles and head movement during testing sessions were persistent issues. We consequently decided to set aside the EEG data and focus on the player

Experimental design flowchart showing the sequence of tasks and scenarios for 45 subjects. The process starts with a Pre-Test Survey (4 minutes), followed by Training for 3D Environment + PS4 Controller (6 minutes). The main experiment consists of four scenarios (Ara Massima, Prince of Naples, Paquius Proculus) with Free Exploration and Object Discovery tasks, each lasting 5 minutes. The scenarios are divided into two groups: Free Exploration (Decorations OFF/ON) and Object Discovery (Decorations OFF/ON). The final task is Octavius Quartio, fully decorated (8 minutes), followed by a Post-Test Survey (10 minutes). The total duration is 45-50 minutes.

Task/Scenario	Duration	Parameters
Pre-Test Survey	4 minutes	
Training for 3D Environment + PS4 Controller	6 minutes	
Free Exploration, Decoration OFF	5 minutes	Ara Massima, Prince of Naples, Paquius Proculus
Free Exploration, Decoration ON	5 minutes	Ara Massima, Prince of Naples, Paquius Proculus
Object Discovery, Decoration OFF	5 minutes	Ara Massima, Prince of Naples, Paquius Proculus
Object Discovery, Decoration ON	5 minutes	Ara Massima, Prince of Naples, Paquius Proculus
Octavius Quartio, fully decorated	8 minutes	
Post-Test Survey	10 minutes	

45 Subjects

Four Scenarios with Task and Decoration (-/+) as Variables

45-50 minutes

The experiment sequence unfolded in seven steps for each subject, moving left to right. Of these, four steps were presented in the same way to all the subjects, the pre-test survey, training environment, House of Octavius Quartio, and post-test survey. At the core of the experiment, however, the path of each subject diverged into one of the following four paths: 1) Free Exploration of the House of the Ara Maxima, the House of the Prince of Naples, and the House of Paquius Proculus with decoration off, 2) free exploration of these three houses with decoration on, 3) object discovery in these three houses with decoration off, or 4) object discovery in these three houses with decoration on. In both free exploration and object discovery scenarios, the subjects were placed just inside the door of the main front entryway (*fauces*). In free exploration, subjects were given a fixed amount of time to explore the structure, while in object discovery, they were given the task of finding a vase hidden in a room of the house. "Free" exploration, of course, is not free, in that the unspoken object of investigation and discovery becomes the plan itself and understanding how it fits together. In object discovery, comprehending the plan is a means toward finding the vase: the plan may not be as thoroughly explored since the subject's interest in it is subordinate to their explicit goal. The houses were intentionally arranged in order of size and number of features and rooms, from the House of the Ara Maxima (10 rooms, no garden, 200 m²), to the House of the Prince of Naples (13 rooms, small garden, 270 m²), to the House of Paquius Proculus (18 rooms, large garden, 832.5 m²). This arrangement was intended to increase the challenge of exploring and understanding the plan (again, in free exploration this "goal" was never made explicit) and, in the object discovery scenarios, finding the vase.

Although they vary significantly in plan and size, in all three houses the vase was positioned in a similar location (see Fig 7). This, of course, raises the question of how "similarity" is defined across houses in Pompeii, and highlights the spatial imprecision of the traditional nomenclature for rooms. Simply placing the vase in the tablinum in each house (whose location is open to dispute in all three instances), or a cubiculum or a triclinium would not have presented the subjects with a pattern of clues that were consistent and associated with features that were spatially and cognitively relevant. Consequently, we chose to place the vases in rooms with similar SSA profiles: relatively distant from the main entrance in network and physical terms, low betweenness (or hub) scores, moderate to high authority (or eigenvector) scores, moderate to low visual integration, and a high level of decoration. The rooms chosen were thus similar in terms that are meaningful (if not always conscious or explicit) for human subjects finding their way through the houses.

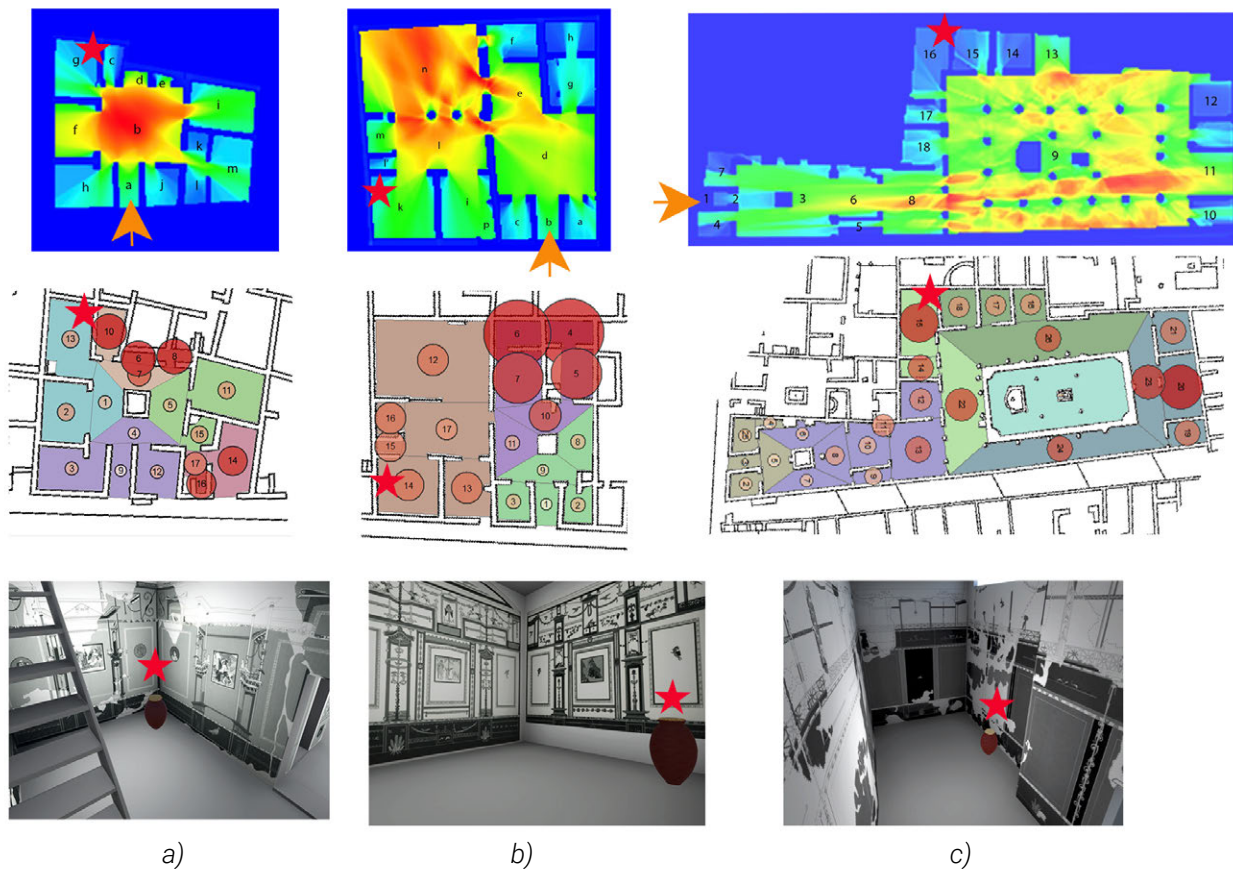


Figure 7. Column a) House of the Ara Maxima: visual integration (top), eigenvector scores (middle), location of vase in room g (bottom); Column b) House of the Prince of Naples: visual integration (top), eigenvector scores (middle), location of vase in room k (bottom); Column c) House of Paquius Proculus: visual integration (top), eigenvector scores (middle), location of vase in room x (bottom). Main entrances marked with orange arrow, location of vase with red star.

The arrangement of variables within the experiment was designed to test several questions: 1) the impact of object discovery, as a task, on the subjects' ability to learn (implicitly) the spatial grammar of the houses and predict, after houses one and two, where the object would likely be in the third house, 2) the impact of decoration on that process, and 3) the ability of subjects to recall the plan of each house, depending on task (free exploration vs. object discovery) and the presence/absence of decoration. Along the object discovery path toward the vase, we also included the unexpected drop of a virtual coin that the player would need to stop and pick up. Our goal here was to test the impact of decoration on the player's ability to recall where the coin drop happened. Behind these queries lay the fundamental questions for our project: would the players go where our updated version of SSA predicted they would go? How would decoration impact this movement?

It is a painstaking task to reconstruct, as fully and accurately as possible, the interior of a Pompeian house with its mosaics, wall paintings, garden features, and furniture. For the sake of consistency and time in this first round of testing, we only include the decorations in black and white for all three houses, based on the diagrams found in the German series *Häuser in Pompeji* (HIP). As the project has moved forward, we have included color decoration and garden features (2020), and we plan to include furniture in 2021, recognizing that it adds a significant new level of complexity to the network topology. The 3D models of each house were similarly based on their respective HIP volumes, with additional documentation provided by the entries in PPM, together with reference photographs provided by the online website Pompeii in Pictures and the photographic and video record of each house developed by our team through several research trips to Pompeii (Fig 8).

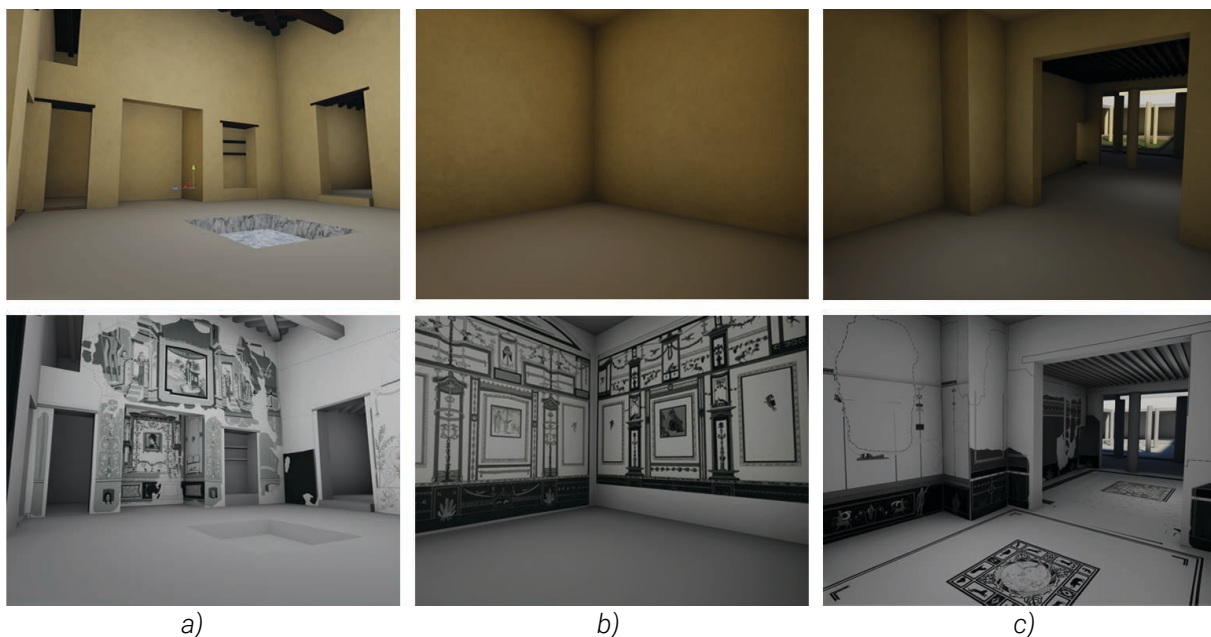


Figure 8. House of the Ara Maxima: a), room d; House of the Prince of Naples; b), room k; Paquius Proculus; c) view from room 6 through 8 and into the garden (see Fig 17, b for room numbers), decorations off above, on below.

We also decided to mark garden spaces for this pass with a simple patch of green "grass," because the development of our plant library remained in progress, and the workflow for lighting plants with adequate performance also remained in development.

The House of Octavius Quartio (II.2.2) was much closer to a fully finished state, with color frescoes, fountains, and its upper and lower garden stocked with digital shrubs and trees. Our intent in the experiment was to assess player movement data against SSA in this much richer environment, but in practice we concluded that our frame rate dipped too low at times, producing a choppy response to player input. We felt, moreover, that our SSA work, especially in the lower garden, required careful rethinking. The lower garden is massive, and it raises the question of how nodes are defined—the equivalent of "rooms" – by foliage and garden furniture, with a VGA that would vary with the seasons and replanting (see Fig 9). Recognizing that our SSA approach needed further iteration, and the model itself would need further optimization to produce a smooth framerate, we set the data from this portion of the experiment aside in order to focus on the "heart" of the experiment, the exploration of the three houses with different tasks and the decoration on versus off.



Figure 9. House of Octavius Quartio (II.2.2), view from *triclinium* h out along the length of the lower *euripus* and garden, with fountains active.

3.2 Experiment Results

3.2.1 House of the Ara Maxima (VI.16.15-17)

As mentioned above, as the subjects navigated the virtual houses, their position and rotation in the XYZ coordinates of the game space were recorded at sub-second intervals. This data was then aggregated to produce a heatmap of where the players collectively went most often, in each of the scenarios (Fig 10).

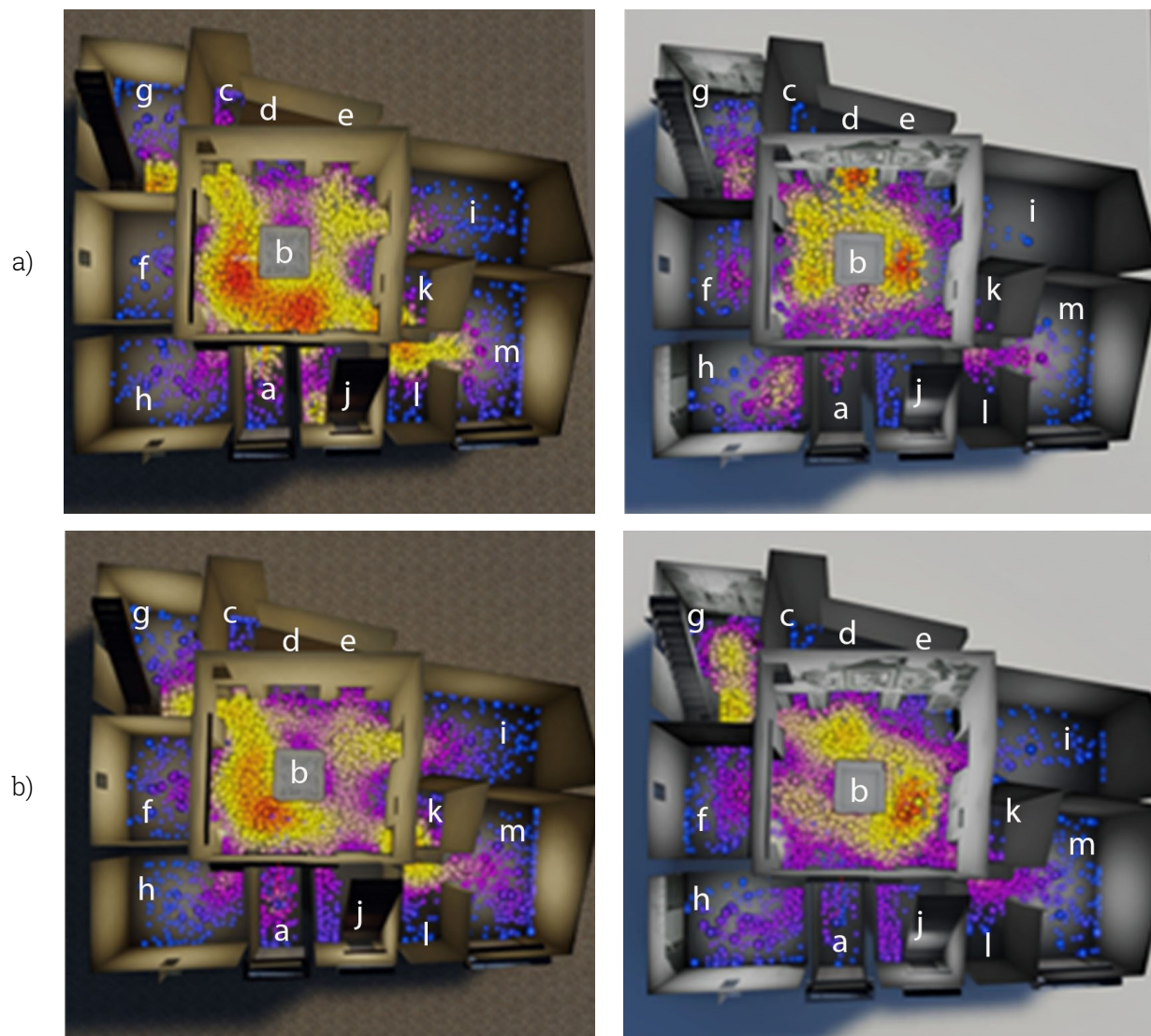


Figure 10. Player Data for the four scenarios, the House of the Ara Maxima: a) Free Exploration; b) Object Discovery.

With decoration off, in both free exploration and object discovery scenarios, player movement reflects the network topology hub score and visibility graph predictions quite closely, particularly in the four sections of the atrium (Fig 11).

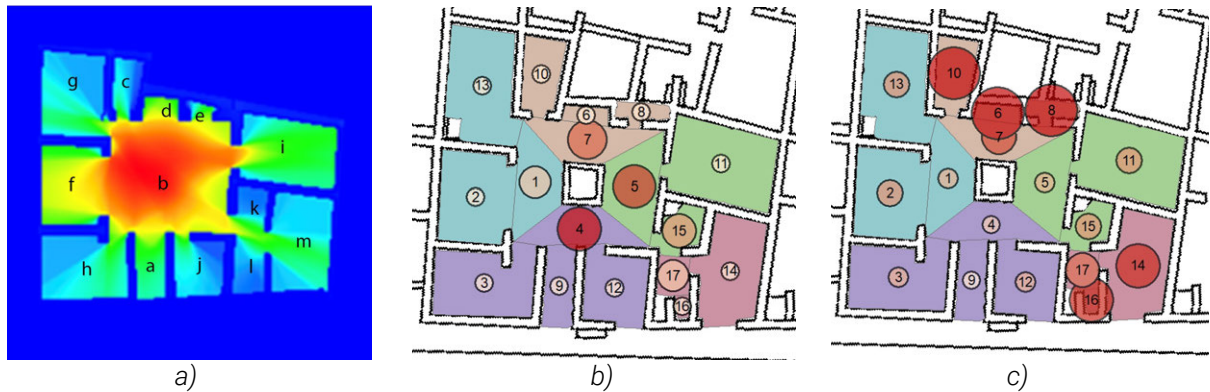


Figure 11. House of the Ara Maxima: a) Visibility Graph; b) Network Topology Betweenness Score; c) Network Topology Eigenvectors Score.

Table 2. Network Topology Hub Scores for House of the Ara Maxima.

ID	Betweenness Centrality	Eigenvector Score
1	8	0.087211
2	0	0.254958
3	0	0.087211
4	15	0.015057
5	14	0.087211
6	0	1.000000
7	12	0.509915
8	0	1.000000
9	0	0.000000
10	0	1.000000
11	0	0.254958
12	0	0.087211
13	0	0.254958
14	0	0.784904
15	9	0.254958
16	0	0.784904
17	8	0.507528

As can be seen in Fig 11, (b) and (c), and Table 2 the betweenness scores are weighted toward the right side of the atrium, while eigenvector scores are balanced laterally but somewhat weighted toward the far side of the atrium. If the atrium were reduced to one node, this would be highly unusual, but with the atria and peristyles split into four nodes, it is not uncommon for the "far-side" node (in a directed graph) to have high eigenvector or authority scores.

In this instance, the node is directly in front of the elaborately frescoed niche with the central painting of Narcissus, and immediately below the dramatic stage scene painted on the upper zone of this (west) wall of the atrium; even though it is in the atrium, the high eigenvector score here does correspond to a high degree of complexity (information) in the decoration (Fig 11, c). Meanwhile, the Visibility Graph, with its bulge toward the left (south) side and hollow in the right (north) side of the atrium, suggests (contrary to the betweenness scores) that movement will tend toward the left side of the *impluvium*, and indeed this is the pattern we see with decoration off. However, when the decoration is on, traffic shifts decidedly to the right-hand side of the atrium, and (to a lesser extent) the far side of the atrium beyond the *impluvium*. Of rooms outside the atrium, room g is consistently the biggest draw with decoration off or on, but when it is on players tended to circle around the atrium to the right of the *impluvium*, rather than taking the more direct route to the left. This reflects the influence of the *lararium* painting and niche on the right side of the atrium, and then the intricate painting in the *tablinum*-like nook (room d) on the far side of the atrium, with a central painting of Narcissus (Fig 12).



Figure 12. House of the Ara Maxima, room d, central painting of Narcissus.

It is interesting that room f, the middle room off the left (south) side of the atrium does not attract much traffic, despite being equivalent in hub score to the other rooms off the atrium, and having a decided advantage in visual integration due to its wide doorway. The decoration in room f is of high quality, but even with the decoration on its traffic increases only slightly, and remains significantly less visited than room g, in the top left corner of the plan. While it is true that humans do tend to gravitate toward areas of high visual integration, where they can see the most, it is important to remember why: to quickly learn as much as they can about the structure. Room f, while having a high visual integration score, is not very informative in terms of wayfinding. With its wide door opening, the room can be taken in at a glance, and no further insights about the plan will be gained from venturing inside. It is obviously a static space and endpoint.

Room g, which is not nearly as well integrated visually, is a different story. The location of the door on the short side of the room rather than along its length requires that the subject cross the threshold and turn right in order to determine whether the room is an endpoint, as its narrow doorway suggests, or a node with connections that lead to rooms still deeper into the house. However, the door for g is visible as soon as one enters the atrium (b) from the *faucis* (a), but unlike for room f, one cannot tell much more without actually entering the room. One therefore enters room g with a question that is not there for room f. Indeed, none of the other rooms off the atrium pose this question in quite the same way. Rooms h and n lie on the front side of the house, on the near side of the atrium toward the street, which suggests they are endpoints (a hypothesis that can be quickly confirmed, but does require the visitor to move beyond the room threshold for h), while room i, at the top right, might lead deeper, but this, too, can be checked at the threshold because the doorway opens a view down its length. The sequence of rooms k-l-m in the lower right requires deeper exploration in order to confirm where the plan ends, and so the traffic into these spaces (with decoration off) is nearly equal to that into room g at upper left. However, with decoration on, this pattern changes somewhat, as room g is highly decorated while rooms k-l-m are not. The high traffic result for room g also reflects what we now recognize as a flaw in our experiment design. Room g includes a ladder up through the ceiling to what was the second story. The evidence for this is clear in the plans and photographs, and so we included it in our 3D model. Looking at the results for all three houses, ladders clearly translate as potential affordances, and are powerful attractors, as the subjects would bump up against them several times in the attempt to determine if they could climb them. For a version of the project focused on assessing the relative contribution of space and decoration to movement patterns on the ground floor of these houses, the ladders are a third experiment variable that distorted the outcomes together with the inclusion of the EEG headset and the House of Octavius Quartio, and we removed them for the second iteration of the experiment (summer 2020).

Finally, the heatmaps for object discovery match those of free exploration in a general way, but there are some meaningful differences. In the free exploration scenario with decoration on, traffic to room h, in the bottom left, increased significantly, while it did not in object discovery. This pattern is likely due to the fact that the vase was placed in room g, and subjects in the object discovery scenario were focused on that task, passing into room g first to find the vase, before ever visiting room h. This may in turn be connected with the fact that room g's tantalizing doorway is visible to the viewer as they exit the *faucis*, which is slightly off-axis toward the left side of the atrium – which means the entrance to room h is behind them. Although they were allowed two additional minutes for

exploration after their task was completed, they generally did not double back to explore room h. For subjects in free exploration, however, the decoration in room h proved attractive. Meanwhile, subjects in object discovery tended to move deeper in and linger in room g (again, this may be partly due to the ladder), giving it a very high traffic rate in the object discovery-decoration on scenario.

For the House of the Ara Maxima, the impact of these decorative elements on movement is clear, but it is also clear that the network topology and visibility graph were a fairly reliable starting point for predicting movement. To sum up: with decoration off, they circled left around the atrium (in agreement with network topology and visibility graph), but with decoration on they circled right, in agreement with the visual interest of the decoration itself. A more subtle and nuanced effect of the decoration is a reduction in player movement into the less well connected and visually integrated rooms, especially on the right side of the plan. As we will see, this can be generalized across the three houses: decoration has the effect of confining players to what we might call the beaten path.

3.2.2 House of the Prince of Naples (VI.15.7,8)

The network topology and visibility graphs are a good if blunt predictor of movement patterns in the House of the Prince of Naples (Fig 13). However, in this house there are some disagreements between the two measures that produce nuance, reflected in the movement data collected from the subjects (Fig 14).

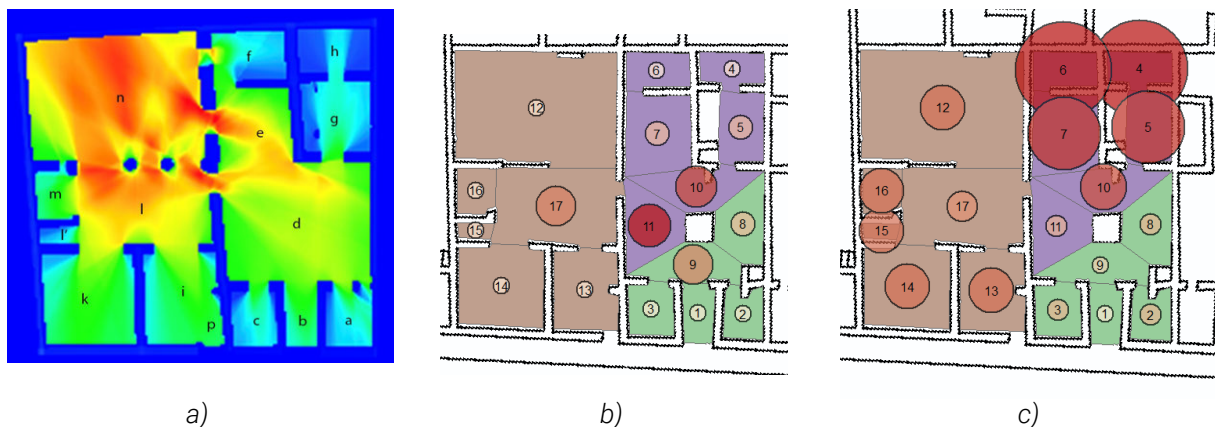


Figure 13. House of the Prince of Naples: a) Visibility Graph; b) Network Topology Betweenness Score; c) Network Topology Eigenvectors Score.

For the House of the Prince of Naples, the betweenness scores strongly suggest that the left-hand node of the atrium will be the "on" side, with more traffic, and the right-hand node will be the "off" side, with less traffic (see also Table 3). However, the visibility graph contains two streaks of greater visual integration that leave a dead space in the bottom left corner of the atrium and terminate on its right side. In the experiment, in all four scenarios subjects tend to favor the right side of the atrium, with its somewhat higher visual integration and deeper views into the house, over the left, despite its straight visual and physical shot into room e (*tablinum*). The inclusion of ladders in the rear kitchen-bathroom complex (rooms g and h) on the upper right is again a problem, though the attraction is expressed most strongly in the free exploration, decoration off scenario.

Table 3. Directed Network Topology Hub Scores for House of the Prince of Naples.

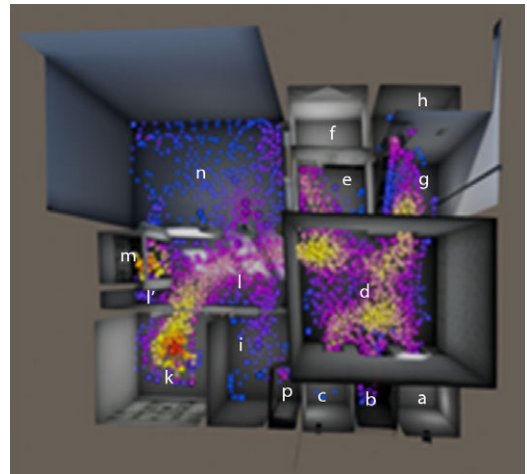
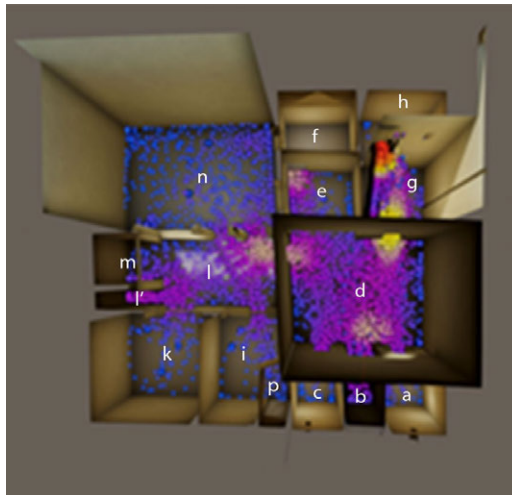
ID	Betweenness Centrality	Eigenvector Score
1	0	0.000000
2	0	0.066901
3	0	0.066901
4	0	1.000000
5	5	0.703287
6	0	1.000000
7	5	0.703287
8	5	0.066901
9	15	0.012083
10	16	0.374394
11	17	0.066901
12	0	0.357685
13	0	0.357685
14	0	0.357685
15	0	0.357685
16	0	0.357685
17	15	0.187197

There was an additional error that complicates reading the movement data results for this house: the collider for the *impluvium* was inadvertently left off. While most subjects still avoided crossing directly over it, some clearly did, especially in free exploration with the decoration off.

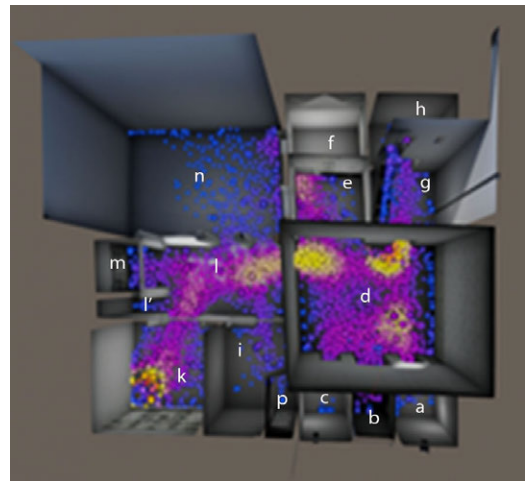
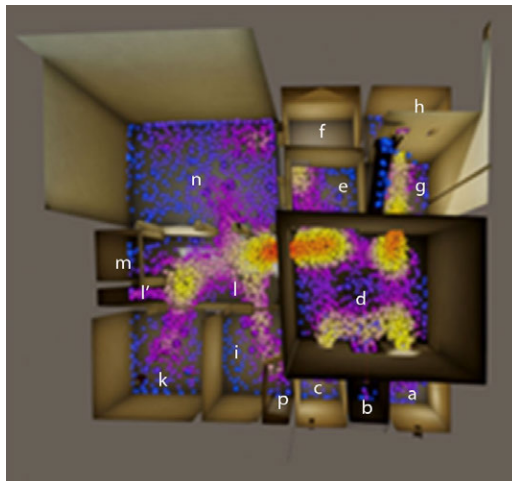
In the object discovery scenario, with the decoration off, movement data reveals the subjects venturing at least several steps into most rooms, and passing back and forth between the atrium (d) and the portico (l) as they attempt to locate the vase. The result is that the room containing the vase (room k, lower left, usually identified as a *triclinium*) shows very little boost in traffic compared to the other rooms beyond the atrium, and significantly less than the room sequence g-h in the upper right where again the ladders seem to have had an impact.

Notably, with the decoration on, subjects discover the vase more directly, with less attention given to other non-atrium rooms, and far less traffic back and forth between rooms d and l. Meanwhile, the presence of decoration significantly reorients movement in free exploration, drawing more subjects into rooms k and m, the most highly decorated rooms in the house (see Fig. 15), and far less to rooms g-h, despite the ladders. At the same time, as in the House of the Ara Maxima, when the decoration comes on, traffic to peripheral areas (especially rooms g-h) tends to go down. In all four scenarios, there is a hot spot in the bottom right corner of the atrium, reflecting the relative impact of the visibility graph over the network topology.

Free
Exploration



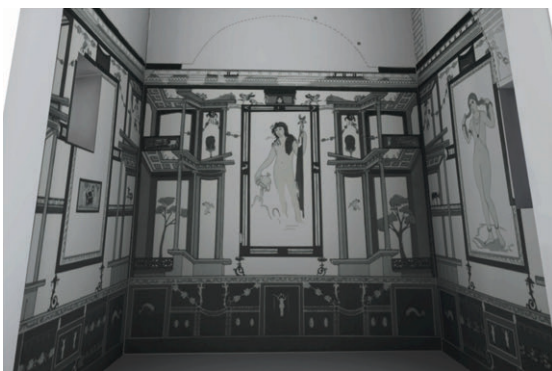
Object
Discovery



Decoration Off

Decoration On

Figure 14: Player Data for the four scenarios, the House of the Prince of Naples.



a)



b)

Figure 15: House of the Prince of Naples: a) room m; b) room k.

3.2.3 House of Paquius Proculus (I.7.1)

The House of Paquius Proculus is the largest of the three and features a fully elaborated garden space. Nonetheless, the experiment results confirm and extend those found the House of the Ara Maxima and the House of the Prince of Naples.

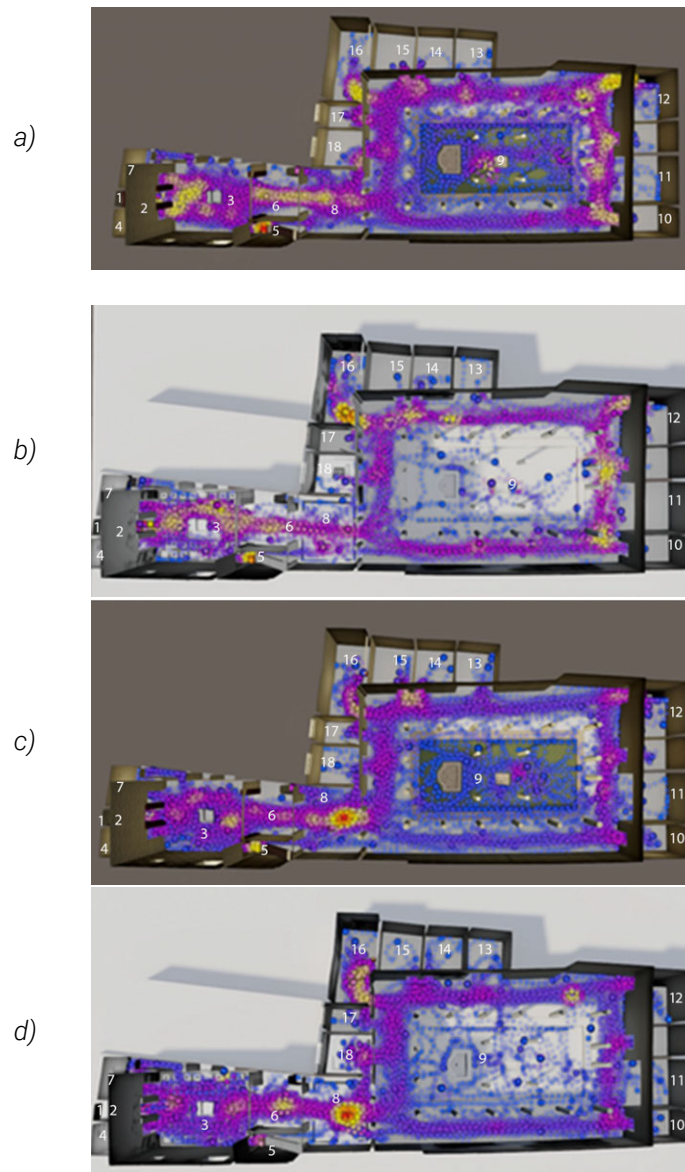


Figure 16. House of the Paquius Proculus: a) free exploration - decoration off; b) free exploration - decoration on; c) object discovery - decoration off; d) object discovery - decoration on.

For free exploration (see Fig 16), the presence of decoration again sharply reduced the subject's willingness to range off the beaten path, leaving the garden with very low traffic, despite its prominence in the network topology and visibility graphs. The presence of decoration also seemed to make the path to the vase (placed in room j, off the upper left corner of the peristyle) more efficient in the object discovery scenario, with a modest reduction of time spent in the atrium, and in the deeper part of the house at the right end of the peristyle. Meanwhile, the network topology and visual integration graphs proved somewhat less accurate as predictors of movement, especially in the object discovery scenarios (see Fig 17).

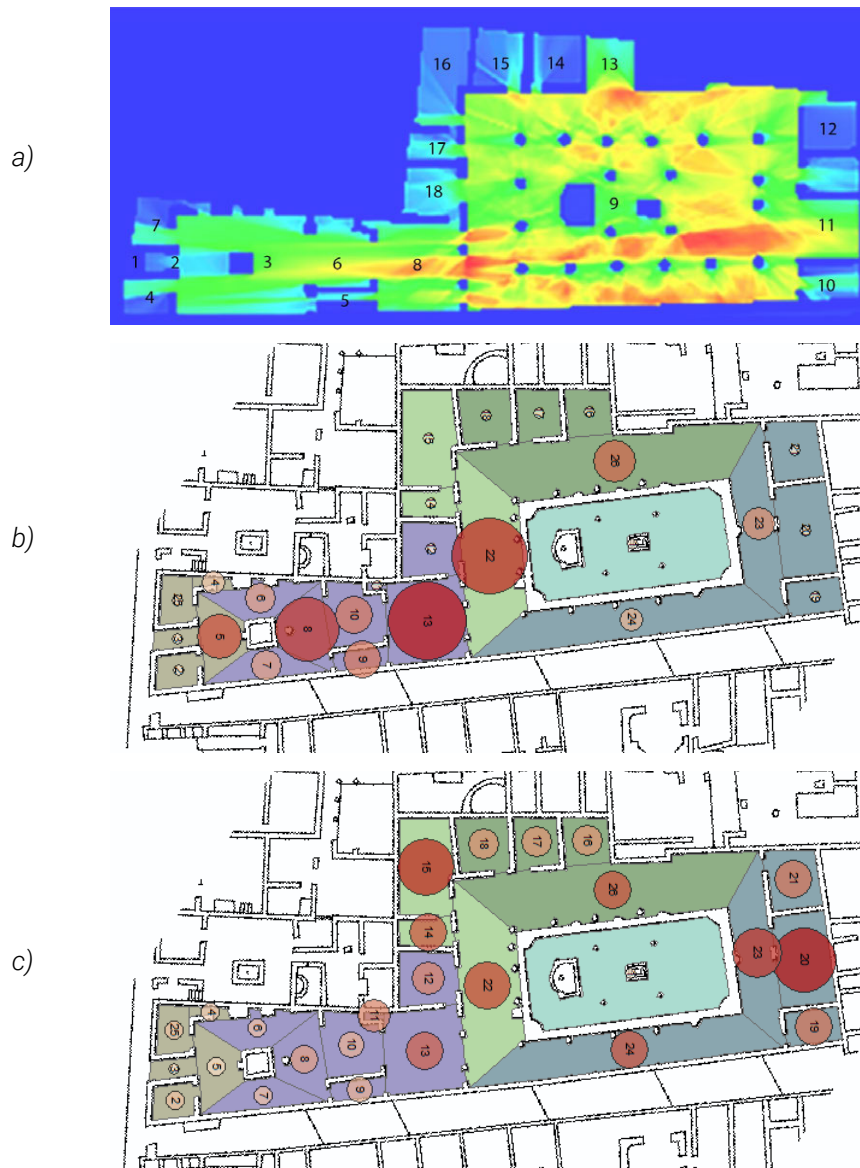


Figure 17: House of the Paquius Proculus: a) Visual Integration; b) Betweenness scores; c) Eigenvector scores.

With decoration off or on, in the object discovery scenarios, once the vase was found in room j, subjects generally did not venture more deeply toward the rooms at the far-right end of the garden. It is interesting to note, however, that when the decoration was on, subjects were even less willing to extend their exploration to the far end of the garden.

It is clear that the presence of the peristyle, with nine rooms ranged around it, has impacted the betweenness scores of the atrium, which now distributes to only three rooms (besides the *fauces* and room 5, a narrow passageway that links the atrium to the portico). The betweenness scores also reveal that the left side of the *impluvium* (looking in from the entrance) seems to be the "on" side (see also Table 4).

Table 4. Directed Network Topology Values for House of Paquius Proculus.

ID	Betweenness Centrality	Eigenvector Score
1	0	0.000000
2	0	0.162134
3	0	0.000000
4	22	0.161546
5	66	0.160210
6	36	0.162134
7	36	0.162134
8	102	0.323091
9	52.5	0.300244
10	52.5	0.300244
11	0	0.402911
12	0	0.402911
13	126	0.510992
14	0	0.516541
15	0	0.880826
16	0	0.364284
17	0	0.364284
18	0	0.364284
19	0	0.500000
20	0	1.000000
21	0	0.500000
22	121	0.704273
23	42	0.728569
24	24	0.516541
25	2	0.162134
26	60	0.516541

However, the visual integration graph shows a "tail" that reaches into the right side of the atrium (looking in from the entrance), and this suggests that subjects will generally move to go around the right side of the *impluvium*, as this would yield a deeper view into the bright center of the garden (see Fig 18).



Figure 18: House of the Paquius Proculus, view from the entrance across the atrium toward the garden.

Despite that fact that moving right also brings one closer to the ladder, subjects fairly consistently chose to bear left around the *impluvium* in three of the four scenarios, in keeping with the betweenness scores, with no preference shown in the fourth (object discovery, decoration on). As this is the third house in the sequence, by this point subjects have likely learned that the ladders are not interactable. A bright patch of sun on the left side of the atrium, beyond the *impluvium*, may also impact this pattern, but more testing is required to confirm this variable. Further, the dominant element in the floor mosaic, the large peacock in the left foreground of Fig 18, is not located directly at center, in front of the *impluvium*, but offset left to bisect one of the long vertical lines drawing the eye toward room 6 (identified as the *tablinum*) and the garden. If this were a factor, however, in drawing subjects to the left side of the *impluvium*, one would expect to find this equally expressed in both scenarios with decoration on. It is pertinent here to state the obvious: network topology and visual integration graphs do not take into account the impact of light or decoration. This is part of a fundamental limitation in the ability of this method to predict movement: it measures visual

integration as a quality of space, but not visual interest as a quality of surface compositions, and light. This is actually part of what makes this updated form of SSA useful. If the subjects do not go where SSA predicts, this forces our attention on other aspects of the environment for their contribution to wayfinding and movement choices.

The results from the House of Paquius Proculus clearly confirm the impact of the decoration in constraining subjects to the "beaten path:" for instance, when the decoration is on, subjects restrict their movement to the porticoes surrounding the garden rather than traveling directly across it. This is especially noticeable in free exploration, as there is a substantial clump of traffic around the central *triclinium* space in the garden with decoration off, reflecting both the eigenvector score of this node and its high visual integration. However, with decoration on, this clump of traffic disappears entirely. This house also reveals the ability of spatial composition and decoration to draw attention. Room 16 was chosen as the location for the vase because of its combination of relatively high depth in the house, relatively low visual integration, relatively high eigenvector score, and high-quality decoration. It was surprising to find, however, that this room, like room g in the House of the Ara Maxima, drew quite high traffic in all four scenarios. In one respect, room 16 here is similar to room g in the House of the Ara Maxima in that it offers a door at a corner that seems to lead beyond the known boundary of the plan: it does not front on either wall of the peristyle, and thus it raises a spatial question. At the same time, it forms part of a sequence of rooms with relatively wide doors that open onto the northern side of the peristyle and smaller side doors connecting to the next room, and thus offers two ways to access the same place. This provides subjects with a spatial pattern to explore and confirm – but they discover a surprise, in that the "side" door here actually looks down the length of the room while the "front" door looks down its short wall, and the space itself is liminal in that it leads the subject beyond the expected envelope of the structure.

4. CONCLUSION: DIVERSE PROXY PHENOMENOLOGY

A founding assumption of this project is that these digital houses, created in a game engine and navigable through conventional input devices for games (in the 2018 iteration, a PS4 controller), can serve as a valuable virtual laboratory for testing interpretive approaches and hypotheses for spatial cognition and movement patterns in the ancient houses of Roman Pompeii. A second assumption involves the recognition that space syntax (with Visibility Graphs included) can provide a valuable first set of hypotheses about movement, based on the statistical profiles of the spaces. To generate these hypotheses, we have produced an updated form of SSA that is consistent with contemporary network analysis approaches and measures, and understandable across disciplines. We are also working on a software solution for generating visibility graphs in Unity itself, as this game engine now has wide use within archaeology. Beyond its update to SSA, this project also involves a significant expansion of the use of phenomenology in archaeology to include virtual (but nonetheless embodied) experiences with 3D models of an archaeological site, rather than physical experiences by a small group of archaeologists (or even just one) in a landscape setting. This recasts the now quite long debate about the methodologies and value of phenomenology and its ability to tell us useful new things about archaeological sites.

The houses act upon the subjects. The subjects' movement choices and spatial behavior are shaped by the houses and their decoration, and while the subjects may not be Roman, the houses are, even if they are not the physical houses themselves. That is, of course, these digital reconstructions are not literally the houses, but the question might be: are they close enough for useful testing? The issue here is point of view, and the nature of the experience provided by "playing" virtual environments. In the end, these digital houses are, in themselves, encoded digital data, and thus nothing "like" the Houses of the Ara Maxima or Paquius Proculus. As a comparison case, the same can be said of a 3D model produced in Autodesk Revit that is used by an architectural firm and engineers as a basis for the construction of a new hospital. The Revit file is literally nothing like the hospital as it will be built, but the digital model will be opened, navigated, and used to drive design decisions, construction plans, cost estimates, and materials ordering. As a Building Information Model (BIM), it will include precise types and dimensions for the myriad pieces and fixtures that will go into the hospital. Therefore, this 3D model must somehow be very much "like" the hospital, and this goes beyond its function as blueprint to the 3D experience it can provide. Through use, the digital model takes on an experiential position or status in the mind of the user that compares in key respects with the hospital itself. Not least of these is the ability of the model to provide an accurate sense of the flow of movement and action in the operating rooms (for instance), or the speed and safety of evacuation plans for the upper stories. This "accurate sense" exists in the minds of users in a digital walk-through or fly-through, and it is not reducible to quantifiable data alone. For instance, the hospital recovery, physical therapy, and admission spaces are all critical to the overall success of treatment, and for architects and interior designers, what is being assessed when they engage with the model is often its psychological and emotional impact. Increasingly, 3D architectural or engineering models are being imported into game engines (Unity3d or Unreal) in order to provide this qualitative engagement with the space in real time, as well as capture quantitative player data. The ability to navigate this virtual model in first-person mode, rather than a predetermined render or fly-through, allows architects and engineers to ask where people went, where they looked, and what they did in the model. Which is to say, if there were an unbridgeable distance between digital model and physical space, neither Autodesk software nor game engines would be used for this purpose. The 3D model of the hospital is being ported to a game engine and "play tested" there because the phenomenology of this play test is assumed to have a substantial and meaningful relationship to the phenomenology of the real space, when built – substantial in the sense of controlling building costs and improving healthcare outcomes.

For this project, the evidence for the Pompeian houses contained across a range of sources, primarily the HiP publications, PPM, the website Pompeii in Pictures, and our own onsite experience and photographs, was used to construct digital 3D models of the houses in Autodesk Maya. The 3D models are accurate dimensionally and faithful in decoration, where "faithful" in the 2018 phase of the project means carefully based on the wall drawings found in the HIP volumes, where the majority of photographs are black and white. For the current phase of the project, with testing in summer 2020-spring 2021, the decorations have been updated to color, and the House of the Fontana Piccola (VI.8.23,24) has been added to the set. Textures for floors have also been updated using color photographs for mosaics, and repeating textures based on photographs for cocciopesto, lavapesta, and beaten earth (Fig 19). The models are then imported in Unity, and much like the fictional example of the hospital above, play tested for quantitative and qualitative outcomes. Behind this is a similar

premise: the phenomenology of this play test is assumed to have a substantial and meaningful relationship to the phenomenology of the real structures.

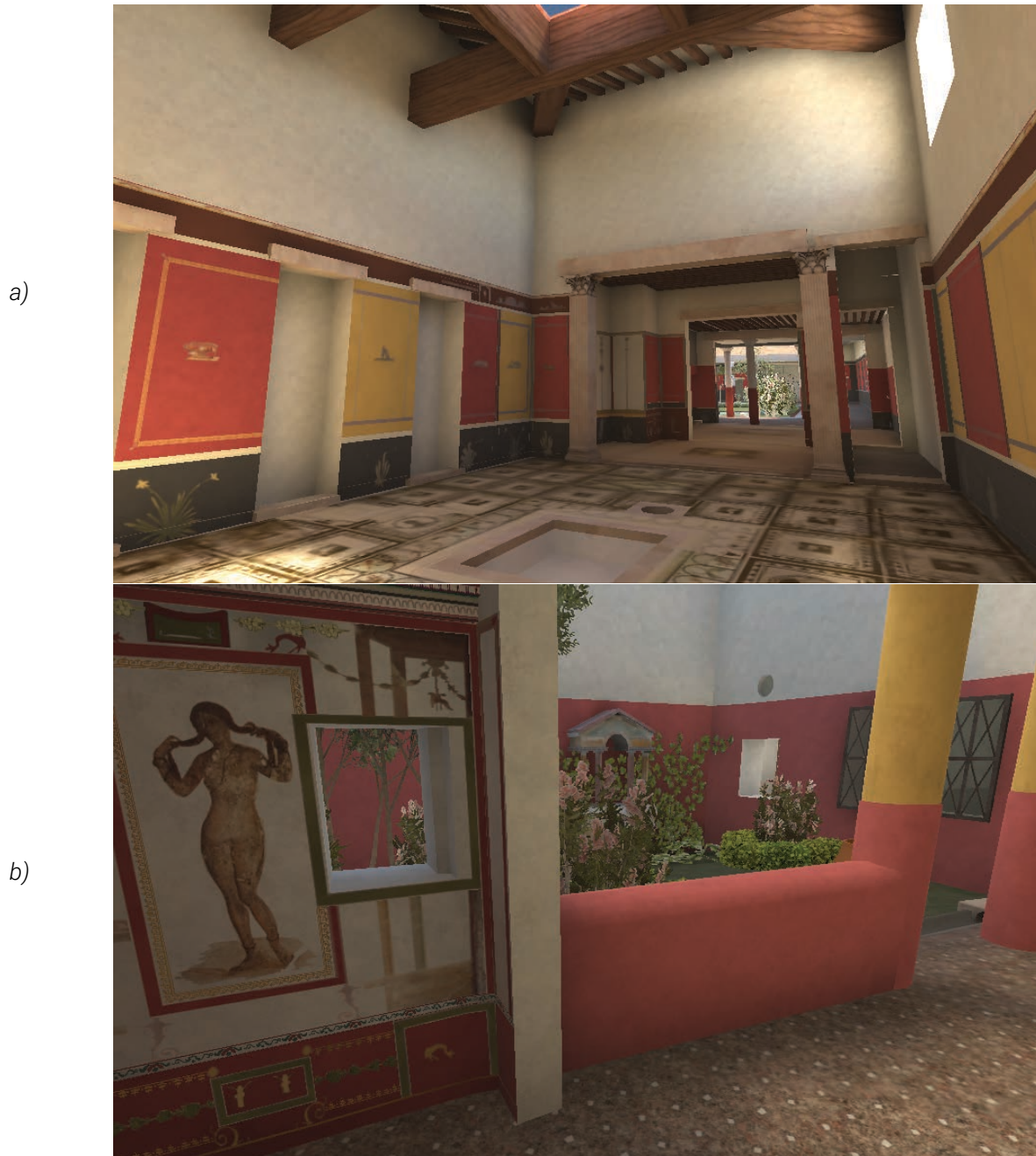


Figure 19. House of the Paquius Proculus and House of the Prince of Naples, with color decoration and gardens: a) View from the atrium across the *tablinum* into the garden; b) View from the *biclinium* (m) across portico I into the garden.

This leads us directly into the debates about the methods and value of phenomenology in archaeology that have unfolded since the early 1990s, but now with a twist. In its earliest and most well-known applications, phenomenology in archaeology was an approach to prehistoric landscapes, especially in Britain, and the phenomenologist-archaeologist was solo researcher, intent on capturing their embodied experience of the landscape: not just what one could see from where, but its sound, smell, inclines, declines, and weather [e.g., Tilley 1994; see also Brück 2005]. These early practitioners of archaeological phenomenology were well aware that they were not prehistoric Britons, but they were nonetheless convinced that the body, senses, and situated condition of the interpreter mattered. In short, their bodies were not so absolutely divorced from those prehistoric bodies. Such a movement in landscape archaeology reflects a renewed emphasis on the experiential side of archaeology: what was it like to be those people in the past, rather than what it is like to gather and analyze data as an objective means toward proving hypotheses about the past. As Matthew Johnson [2012a] has observed, phenomenology was part of a larger move in postprocessual archaeology toward interpretation as an embodied rather than strictly objective practice. This shift in focus is connected in turn with a rejection of both the Cartesian framing of the landscape and the poststructuralist emphasis on language rather than the materiality of things – which do not signify in the same way as words – and the body [see also Hamilton et al. 2006]. The emphasis on embodied practice, however, leaves phenomenology open to the critique that it is more a collection of highly personal and subjective observations and reactions rather than a repeatable scientific method.

While briefly presented here, the background and critique of phenomenological approaches in archaeology is relevant to our project because this disciplinary history has produced a split between phenomenology as an embodied practice of landscape engagement on the one hand, and computer visualization primarily grounded in GIS on the other. As Stuart Eve [2012:582-583] puts it, as an approach to understanding the perceptions and social behavior of past cultures, the visual emphasis and laboratory setting of GIS is "anathema and totally at variance with their [the phenomenologists'] objectives," and vice-versa. As long as the use of computer analysis to understand past perceptions and social behavior is equated with GIS, or with 3D models bound to hyperfidelity, which tend to produce prerendered stills and flythroughs of archaeological sites, this disparity was understandable. With the emergence of game engines and their ability to present 3D models as navigable in real time, the antithesis between computer models and phenomenology, as ways to research past perception and social behavior, begins to erode. This is literally enacted in our project through our refusal to accept SSA as somehow an objective record of movement rather than a predictive methodology that required testing through embodied experience in the space. On its own, SSA neither objectively describes nor records human movement patterns in a structure. It is rather a tentative prediction of what these movements might be. The process of testing the predictions of SSA through player navigation of these houses is an experiment in embodiment, not of the physical body itself in the structures, but the player's body, which is neither entirely virtual nor entirely physical, a hybrid and a proxy.

The recognition of embodiment as a critical aspect of video game play has led to an emergent critical discourse on the phenomenology of video games [e.g., Gee 2008; Farrow and Iacovides 2013; Keogh 2018]. This work points out that while the gamer's body projected in the 3D digital space is not equivalent to the player's physical body, it is enclitic on that physical body, hybrid with it, and

extends it into the virtual space of game play. The gamer's body is what allows the architects and engineers of the fictional hospital to trust that the phenomenological experiences of their play testers have a meaningful relationship to the phenomenological experiences and spatial behavior of real people in the actual structure. This project shares that faith in the gamer's body, which in fact underpins the expanding use of game engines to provide real-time 3D experiences in architecture, engineering, product design (especially automobiles), and other industries. In our instance, the play testing is not directed toward the future of a more responsive Audi, a more engaging Walgreens, or a more mindful hospital: it is not intended to aid in the reconstruction of real (improved?) Pompeian houses. It is aimed toward the past. As noted in the introduction, this aligns our project with the 'sensory turn' in archaeology [e.g., Betts 2017, Day 2013, Hamilakis 2014, Howes 2005], a movement which has its roots in phenomenology.

The recognition of embodiment – of the turn toward phenomenology – in our project's approach has elicited repeated, pointed objections in conference presentations that our experiment subjects are not Romans, and therefore this approach cannot tell us much, if anything, about Roman perceptions and behaviors in these houses. This objection has not been lodged against traditional SSA, widely applied in archaeology, because its methodology appears sufficiently numbers based. SSA also skips over the need for testing through embodied experience with the claim that (all?) humans will navigate structures the way it predicts. SSA manages to look objective and scientific through a highly suspect claim ("space is the machine") that resonates well with the gendered subordination of interior design and decoration to architecture. No need to test, and for most archaeological sites, testing is challenging if not impossible. In responding to the challenge that our approach would require living Romans in order to be useful, it is important to separate out two aspects of the objections to phenomenology more broadly. The first is that phenomenological methods and conclusions in landscape archaeology are grounded in the subjective experience of a single observer in a setting that is highly variable. Hence the approach is not repeatable and scientifically not testable [e.g., Fleming 2006:269; see also Fleming 2008]. In response, we would point out that ours is not a phenomenology of one, but of many. While our first iteration of testing was done with 45 subjects through a desktop application in 2018, our goal has always been to publish the houses in the browser-based format of WebGL, which will allow global, crowd-sourced testing. Our next step toward this unfolded in summer 2020 using 3D models published in WebGL and remote subjects who are students in classical studies classes at the University of Arkansas (31 subjects). The test was extended to a broader university audience in fall 2020 (57 subjects), and we plan to move to global testing in spring/summer 2021 (initially for several hundred subjects). Through the Virtual Roman Retail project, we intend to move this approach out into the (virtual) streets of Pompeii to research movement patterns and behavior of the streets and shops, eventually bringing the houses and streets together to form a holistic approach to environmental modeling in Pompeii. Such a holistic approach does not rely only on the material and structural data, but is always embodied through game play, yielding its own set of both quantitative and qualitative data.

As we have shown, the variables in the models and experimental scenarios can be precisely controlled. In the 2018 iteration presented here, there were two variables: free exploration versus object discovery in scenario, and decoration off versus decoration on in environment. Our current iteration includes planted gardens, so these are toggled off and on together with the wall paintings

and floor materials. Additional environmental elements to be tested include sound, light (time of day, season), water features, and furniture placement. This points to the scaffolding of experiment scenarios: more elaborate navigation challenges that begin to include non-player characters (NPCs) and interaction systems that explore hypotheses about social behavior through game play.

In the end, however, Chris Tilley is guilty as charged. He is not a prehistoric, woad-painted engineer of megalithic stone circles, and this has always been, in the most literal way, an *ad hominem* objection. Likewise, our subjects can never be ancient Romans. Unlike most instances of the phenomenology of ancient landscapes, however, our subjects can be multiple. None of us in ancient Mediterranean archaeology or classics is Roman. Thus, no matter our training or institution, we are always proxies in our engagement with material or textual evidence. A Ph.D. does not make us more qualified to "be Roman" when let loose in a 3D model of a house in Pompeii; in fact, our habitus is likely to be an impediment. What we are, to this day unfortunately, is a very narrow demographic slice that is overwhelmingly white, American, European, or Australian, highly educated, and middle to upper-class. Johnson points out [2012b] that the objectives and methods of phenomenology in landscape archaeology are shaped by class, gender, and nationalism; our methods and observations are not rendered objective by virtue of our expertise in the field. The proxy relationship cannot be directly overcome, but it can be substantially deepened by extending access to these playable 3D Roman spaces to a global audience that is ethnically, racially, culturally, and economically diverse. We have chosen to call this approach Diverse Proxy Phenomenology. In technology, it depends on the ability to host accurate 3D models of Pompeian houses in WebGL in order to reach a global audience, and to capture player data as subjects navigate, or "play," the models. Conceptually, it depends on the assumption that this broad, global set of player data will illuminate our understanding of space and behavior in ancient Roman culture, which was neither white nor homogeneous, in ways that strictly white, Euro-American, upper-class interpretations cannot. As Johnson notes [2012a: 523], "Such developments are not in opposition to science: rather they expand and deepen scientific enquiry. They render it more critical and more rigorous by exploding the narrow circle of trust."

While the discussion above has concentrated on the quantitative data, it seems fitting to close with an example of the qualitative data collected in the 2018 iteration. In the post-navigation survey, subjects were asked to pick out the correct plan of each house from a set of four 2D plans. The three additional plans represented real houses in Pompeii selected based on their similarity in size and layout to the correct plan. The results (see Table 5) show that the subjects were generally able to identify the correct plan. However, the data also tells us that they were significantly worse at this with the decoration on, in free explore and object discovery scenarios (the one exception is the House of the Ara Maxima in object discovery). Having observed this, it is also important to note that this effect was substantially more pronounced in free exploration than object discovery. For instance, in the free exploration scenario, correct identification of the plan fell 44.1% in the House of the Ara Maxima; 38.9 % in the House of the Prince of Naples; and 40% in the House of Paquius Proculus. For object discovery, correct identification rose 12.2% in the House of the Ara Maxima, but fell 28.3% in the House of the Prince of Naples (from 72.7% decoration off to 44.4% decoration on) and 17.1% in the House of Paquius Proculus (72.7% decoration off to 55.6% decoration on).

Table 5: Subject responses to the task of picking out the correct house plan after navigation, for all three houses and all four experiment scenarios.

	Free Exploration			Object Discovery		
	Decoration off (11 subjects)	Decoration on (7 subjects)		Decoration off (11 subjects)	Decoration on (9 subjects)	
House of the Ara Maxima	72.7%*	28.6%	-44.1%	54.5%	66.7%	+12.2%
House of the Prince of Naples	81.8%	42.9%	-38.9%	72.7%	44.4%	-28.3%
House of Paquius Proculus	54.3%	14.3%	-40%	72.7%	55.6%	-17.1%

*percentage of subjects who correctly identified the house plan in the post-navigation survey

This outcome was quite surprising to us, and it opens a whole series of questions about the relative impact of different decorative styles on subjects' ability to develop a cognitive sense of the house plans as they navigate and remember this well enough to select the correct plan in the post-navigation survey. These houses are all decorated in the 4th Style, but it would be possible to vary them to the earlier styles and assess which has the greatest impact on the ability to grasp and later identify the plan. Even by proxy, this outcome also raises the question of intent: if the decoration makes the plan of the house harder to understand and harder to remember – if it works against knowing where you are – is this part of how decoration constructs power in these houses? We cannot assume that the decoration exists to make the house spatially more legible or transparent, rather than less.

It is clear, even from this brief look at the quantitative and qualitative data from 2018, that the embodiment of subjects through game play in 3D real-time past environments allows a host of questions to be posed and explored that would never occur through traditional SSA or GIS-based approaches. This generates new data about ancient Pompeii, and while the proxy relationship can never be eliminated, the wider the set of proxies, the deeper and more varied the light it can cast on perception and social behavior in the Roman past. This is partly because diverse proxy phenomenology recognizes, as an explicit part of its methodology, that these houses neither felt the same way nor meant the same things to their ancient inhabitants.

5. ACKNOWLEDGEMENTS

The authors gratefully acknowledge students and Tesseract staff, past and present, who have contributed their talents to the Virtual Pompeii Project. We offer special thanks to Virtual Pompeii's project manager, William Loder, to Chloe Costello Hiley, who took a lead role in modeling and lighting the house models, and to the members of the Network Topology team, Nina Andersen, Claire Campbell, and Rachel Murray, for generating the network topology plans and values tables used in our analysis and included in this publication. We would also like to express gratitude to the special issue editor, Dr. Matthew Notarian, and to the reviewers for their thoughtful and constructive feedback on an earlier version of this manuscript.

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Received September 2020; revised December 2020; accepted December 2020.