Abstract: Ostia, the ancient port of Rome, had a rich religious landscape. How processional rituals further contributed to this landscape, however, has seen little consideration. This is largely due to a lack of evidence that attests to the routes taken by processional rituals. The present study aims to address existing problems in studying processions by questioning what factors motivated processional movement routes. A novel computational approach that integrates GIS, urban network analysis, and agent-based modelling is introduced. This multi-layered approach is used to question how spectators served as attractors in the creation of a processional landscape using Ostia’s Campo della Magna Mater as a case study. The analysis of these results is subsequently used to gain new insight into how a greater processional landscape was created surrounding the sanctuary of the Magna Mater.

Keywords: Roman Processions, GIS, Urban Network Analysis, Agent-Based Modelling

1 Introduction: Processional Movement and its Problems Within Archaeology

One of the primary difficulties in studying ancient processional routes is that they were preserved in the memories of those that saw, heard, or read about the act rather than being overtly visible within the archaeological record (Connelly, 2011, p. 314). While the repeated occurrence of a procession might survive within the archaeological record in the form of commemorative architecture, such examples only attest to the occurrence of a procession, not its actual composition or spatial route. Therefore, studies of processional routes predominately rely on literary accounts which are problematic. This is because ancient authors provide only minimal details of a procession, its ritual components, and its movement pathways through a city (e.g. Cicero Epistulae ad Atticum 13.44.1; Dio 47.40.8).

The lacunose nature of the existing evidence relating to processions has shaped current scholarly approaches. The majority of studies concentrate upon well-documented examples from the city of Rome, such as triumphal or circus processions (e.g. Coarelli, 1968; Favro, 2008; Arena, 2009). In these instances,
scholars have adopted a connect-the-dot approach where various literary accounts of a procession are merged and considered in light of Rome’s ancient topography. Different monuments mentioned within literary accounts, and which are identifiable within Rome’s built environment, are subsequently linked together to form a hypothetical processional route through the city (see Rogers, 1991 for a similar approach applied to the processions of Artemis at Ephesos). However, due to the fragmentary nature of processional accounts, such an approach does not accurately reflect how a procession might have navigated the city between these mentioned topographic nodes. As Graf (1996, p. 64) highlights, a procession consists of more than just travelling between points A and B: the entire ritual context needs to be considered. This includes contemplating what urban and social factors shaped movement between two specific nodes within the urban landscape.

Processional studies in cities outside of Rome have adopted various approaches due to the limited nature of surviving evidence which rarely include literary accounts. One method assumes that a city’s primary street, the *decumanus*, served as the principal processional way (see, e.g. Ball, 2016, pp. 304–305). Further questions of why a procession might have travelled along this street or any other routes it may have taken through the city are rarely considered. An alternative approach adopts a connect-the-dot method similar to that discussed above, but without the integration of literary evidence, where the spatial position of temples within a city are linked together to form a hypothetical processional way (e.g. DeLaine, 2008; Keay, 2010). This infers that passing different religious spaces was the primary driving factor of all processions within the city. The commonality between these two approaches is a clear attempt to determine how urban processional movement would have manifested within an ancient city. These assumptions, however, remain too generalised. While a procession would have undoubtedly travelled along a city’s primary street, for at least a portion of the ritual, it is unlikely that the ritual would have been solely confined to this street. Likewise, other areas that might be important for a procession to pass apart from religious spaces need to be considered and questioned.

The present study aims to address existing issues in studying processional routes by focusing on alternative ways in which processional movement can be examined. A new approach is proposed that focuses on the agency of spectators in serving as attractors for a passing procession. As a moving ritual, an especially critical component was a procession’s engagement with people as it passed through a city. Without some degree of visibility, such rituals were effectively meaningless. Recognising this joint relationship, we can question how different spectator groups (e.g. groups engaged in commercial activity) shaped the route of a procession. To test this approach, the Campo della Magna Mater at Ostia, the ancient port of Rome, is used as a case study. Through the application of a novel computational approach, potential processional movement routes are visualised within the city based upon passing different spectator groups. The results provide new insight into how a processional landscape developed surrounding the sanctuary.

2 Case Study: Ritual Processions of Ostia’s Campo della Magna Mater

The Campo della Magna Mater, located within the southern-most excavated area of Ostia, was the city’s largest sanctuary during the late 2nd century CE (fig. 1). The triangular shaped sacred area, which measures 4,500 m², consists of separate temples to the deities Cybele, Attis, and Belonna, a *schola* of the *hastiferi* (headquarters of the spear-bearers association) and other various cult rooms (Meiggs, 1973, pp. 356–362; Rieger, 2004, pp. 96–104; 113–117). The sanctuary’s sizable central open area would have served as an important venue enabling variations on the cult’s standard ritual practices that traditionally include the self-castration of the *galli* (priests of Cybele) and a *taurobolium* (bull sacrificial ritual) (Lambrechts, 1952; Sanders, 1972; for an argument refuting the practice of the *taurobolium* at Ostia, see Rieger, 2004, pp. 111–112). The importance of maintaining a dedicated ritual area is seen through the preservation of the sanctuary’s size and ground level throughout its existence. Other sacred spaces in contrast, such as the Republican Sacred Area (Boos, 2012), were increasingly encroached upon by the city’s growing infrastructure (Pensabene, 2005, p. 528).
Processional rituals constituted an important component of the cult’s ritual activity which was renowned for its annual flamboyant festivals that travelled along a city’s streets (Alvar, 2008, pp. 240–292). For a city that was already culturally and ethnically diverse, processions functioned both as an expression of the cult’s identity as well as helped to shape a particular understanding of the cult. As a mystery religion, the majority of the Magna Mater’s rituals would have occurred within the confines of the sanctuary, with their observation limited to cultic followers (Cooley, 2015, p. 245). The act of a procession, therefore, provided a venue for disseminating a particular image and interpretation of the cult to the wider Ostian public that differed from the private rituals enacted within the sanctuary during the rest of the year.

The occurrence of Metroac processional rituals (processions of the Magna Mater), which are embedded within the cult’s various festivals, are well documented by ancient authors (e.g. Herodian 1.10.5–6; Ovid Fasti 4.179–90, 337–72). One particular festival occurred 15–28 March, and commemorated the death of Cybele’s consort, Attis (Scullard, 1981). 15 March marked the festival’s start with a procession of the cannophori (reed-bearers). The next procession occurred on 22 March, which was led by the dendrophori (tree-bearers) who carried a pine tree symbolising Attis’ death through the city before it was placed in front of the temple of the Magna Mater. The Sanguem, which occurred 24 March, began with a procession that included the galli and hastiferi (spear-bearers) enacting a religious frenzy of dancing and self-flagellation as they processed through the city’s streets. A final procession took place 27 March as part of the lavatio (ritual washing) (Salzman, 1990). Comparative evidence from Rome and the wider Mediterranean in addition to the numerous Ostian dedicatory objects and inscriptions of the cannophori...
(e.g. *CIL XIV* 33, 45, 53) and *dendrophori* (e.g. *CIL XIV* 34–37, 40, 117) enable us to build a strong case for this festival’s presence within the city (Turcan, 1996, p. 55). In light of existing evidence, it is highly probable that at least some of these processions transpired annually at Ostia.

The route that these Metroac processions would have taken at Ostia, however, remains unknown. While Metroac processional routes have been reconstructed at Rome (Pensabene, 2008), an identical approach cannot be undertaken at Ostia due to the lack of written accounts detailing the festival. Taking the same approach would also assume that the form of the procession at Rome was identically replicated at Ostia, which is infeasible due to the differences in urban topography. Despite the various uncertainties that exist concerning these processional rituals, our understanding of the occurrence of certain processions illustrates their importance for the ritual life of the cult. Reassessing how these processional rituals can be studied, therefore, presents a novel approach towards considering how processional activity contributed to the Ostian sanctuary’s larger religious landscape.

### 3 Methods

#### 3.1 Reframing Processional Movement Study

To address the complications in studying processional rituals due to a fragmented archaeological and literary record, the present methodology applies a movement focused approach that questions what factors underlie a procession’s movement patterns. Study of movement within Roman cities has seen a marked increase in recent years; however, the majority of studies address vehicular movement and how it can be identified within the archaeological record (e.g. Tsujimura, 1991; Poehler, 2017). Only a limited number of studies, in contrast, have considered the topic of pedestrian movement dynamics. Early research focused upon questioning what factors within an ancient urban landscape guided pedestrian activity (MacDonald, 1986; Ling, 1990). At Pompeii, research has identified and shown how specific urban features such as street-side benches and *tabernae* (shops) structured movement along the city’s streets (Ellis, 2004; Hartnett, 2008). These examples build upon spatial theories that recognise the relationship that exists between the built environment and social behaviour (Lawrence & Low, 1990; Lefebvre, 1991).

An alternative approach attempted to apply GIS network analysis to reconstruct potential pedestrian routes through Pompeii by studying the probability of passing different shop-fronts (Poehler, 2016). The similarity between the aforementioned studies is that they all question what features within the urban environment dictated pedestrian movement, an idea which can be applied to questioning what factors influenced processional movement.

Archaeological and anthropological studies have identified that a clear relationship existed between moving rituals, the urban environment, and the participants involved with the ritual (Scheid, 1998; Demarest, 2006; Morton, Peuramaki-Brown, Dawson, & Seibert, 2014; Huet, 2015). Processions were highly interactive events, engaging with specific temples, cultic participants, and spectators in order to create a temporary shared ritual experience (Favro & Johanson, 2010; Popkin, 2016). A particularly significant factor of a procession, therefore, would have been its engagement with urban spectators. As a communicative event, where a procession travelled within a city and the spectators it intersected with both provided crucial meaning to the ritual (Rüpke, 2012). While the importance of specific spectator groups for an individual procession remains unknown, we can question how different spectator groups acted as a natural draw for a procession, and therefore influenced its route through the city. For instance, if passing people engaged in commercial shopping activities was important due to the economic visibility it would afford a particular cult, what routes would the ritual have taken through Ostia’s streets? Reversely, how might certain urban activities and the people involved serve as a detractor to a procession and therefore be avoided?

Although spectators and where they congregated within a city are not preserved within the archaeological record, different building classification categories can be used as a proxy for areas that attracted different spectator groups as well as accounting for a group of people engaged in a similar
urban activity. This allows us to evaluate where different groups of spectators were likely located within the cityscape, and how they may have subsequently served as an attractor to processional movement. The present study follows this line of enquiry and questions the extent to which these different proxy building classifications affect possible processional routes. In other words, is it more important to pass one building classification category (e.g. commercial space) compared to another? While spectatorship would not have been the only factor influencing a procession’s movement through the city, focusing on this one factor provides a formalised way of questioning how processional movement can be studied and visualised at Ostia. Other elements such as street width or city gates might impact mobility patterns through the city, but studying movement routes by focusing on these elements alone discounts other more critical urban and social influences that effected movement patterns.

3.2 Moving Beyond Space Syntax Methodologies

The application of computational approaches has particular potential in enabling us to methodologically question how spectator groups shaped processional movement patterns. Previous methodological approaches of applying space syntax principals are first examined to demonstrate their unsuitability for the present enquiry. A new multi-computational methodology is then introduced that combines GIS, urban network analysis, and agent-based modelling to visualise potential areas of processional movement.

The theory and methods of space syntax were developed by Hillier and Hanson (1984) as a new paradigm for studying the relationships that existed between space and human interaction. Over the past several decades, their methodologies have been applied to archaeological contexts with varying degrees of success (e.g. Thaler, 2005; Clark, 2007; Fisher, 2009). For studies of movement within ancient cities, space syntax has developed as one of the predominate approaches applied by scholars, enabling new insight to be gained into how people interacted with and moved within ancient built environments (Grahame, 2000; Kaiser, 2000; Stöger, 2011).

Movement dynamics along ancient city street networks are primarily visualised through the aid of axial analysis. This specific analysis creates a map that consists of the fewest and straightest lines within a city’s street system, which subsequently enables various metrics to be calculated relating to how movement is structured. While axial analysis has been previously applied to general movement studies within Ostia, it has not been used to question processional movement (e.g. Kaiser, 2011; Stöger, 2011). Three different axial analyses (integration, choice, and step depth), calculated using depthmapX 0.50 software, will be briefly considered as they relate to the spatial position of the Campo della Magna Mater. Calculations take place using Ostia’s street network, which combines both archaeological and preliminary geophysical survey data (see 3.3.1). The results will show that while space syntax provides general insight into how the city’s street network shapes movement, it is unable to account for other movement motivating factors, which includes how spectatorship influences movement patterns, necessitating the development of an alternative methodology.

The first axial measurement is integration, which computes the relative accessibility of every axial street segment to every other street segment within the entire axial network (Hillier, Penn, Hanson, Grajewski, & Xu, 1993). The results, when considered in terms of the spatial location of the Campo della Magna Mater, provide a broad understanding of the sanctuary’s accessibility. Figure 2 shows the results of local integration, which is calculated by measuring the connection of each axial street length within a radius of 2 other streets, which is repeated for every axial street within the street network. The results provide a visible measure on a colour scale indicating the general accessibility of all streets within a street network, with the most accessible streets displayed in red and the least shown in blue. The results are interpreted as correlating to a street’s degree of use. In figure 2, the eastern and western decumanus, illustrated in red, are shown to have seen the greatest degree of use when compared to all other streets within the system. In relation to the spatial location of the sanctuary, the results indicate that it is moderately well located due to its position along the southern cardo, where it exists by the city wall.
The calculation of choice (e.g. movement potential) along Ostia's street network shows a different perspective of the sanctuary's spatial position (fig. 3). Choice is calculated by identifying the shortest path from all origins and destinations along the street network, and is used to predict how movement flowed through the city (Hillier, Burdett, Peponis, & Penn, 1987; Turner, 2007). The results, illustrated on a scale of red to blue, provide an indication into which streets saw the greatest degree of movement passage, which in this instance correlates to the eastern *decumanus* displayed in red. In terms of the Campo della Magna Mater, the results indicate that the sanctuary is positioned at a location that would have seen little to no pedestrian interaction. When assessed in relation to the archaeological record, however, this interpretation remains inaccurate. The sanctuary is positioned directly next to one of the city’s primary entrance gates, the Porta Laurentina, which alludes to it having seen a fair amount of pedestrian passage.

More localised movement can be visualised surrounding the sanctuary through the measurement of axial step depth. Step depth measures how many streets have to be passed in order to reach a specific location within a city (Hillier & Hanson, 1984, p. 104). Figure 4 shows how the various streets of Ostia are connected to the sanctuary. Streets displayed in red represent those with the greatest connection, requiring only three or fewer turns to reach the sanctuary. In terms of the present query, it can be interpreted as illustrating what may be hypothesised as a surrounding processional area, the total space through which a procession travels. However, this supposition is based upon the assumption that the processional area is structured by a street’s general accessibility to the Campo della Magna Mater. Other influences that shaped this sanctuary’s ritual movement patterns, and therefore the wider processional area, are omitted.

The previous three axial analyses all provide useful insight into how Ostia’s street network generated movement patterns, however, they remain unable to account for how the built environment or people influenced and shaped processional movement, or address movement originating at a specific location within the city (see Leach, 1978 and Netto, 2015 for more general critiques of space syntax). Although the results can be interpreted in light of the spatial location of the Campo della Magna Mater, as demonstrated above, they are not specific to movement patterns structured by the sanctuary as an initial and terminal node in a procession. This is especially problematic since urban research has shown that the interactions of an urban population and the utility of different buildings serve as a significant factor in the generation
of pedestrian movement rather than solely the shape of a city’s street network (Batty, 2003). Consequently, while space syntax can be used to address general movement patterns along Ostia’s street network, it cannot be applied to a specific form of pedestrian movement, including processions.

**Figure 3.** The Campo della Magna Mater on an axial graph, which shows the calculation of choice (radius n, 385 street segments). Streets shown in red have the highest choice, or movement potential. Streets shown in blue have the lowest choice value.

**Figure 4.** The Campo della Magna Mater on an axial graph, which shows the calculation of step depth 4 from the sanctuary. Streets shown in red are connected to the sanctuary by 4 or fewer street turns. Streets shown in blue have the highest depth, located the greatest number of street turn away from the sanctuary.
3.3 A Multi-Layered Computational Approach

Due to the limitations in existing data concerning Roman processional movement routes, current movement focused methodologies like space syntax are not sufficient in determining potential routes. In order to account for both the dynamic nature of processional rituals as well as the more general uncertainty concerning their form at Ostia, a multi-layered computational approach was developed to visualise potential processional movement routes within the city based upon their influence by spectator groups. This is accomplished through the integration of geographic information systems (GIS), urban network analysis (UNA), and computer simulation. GIS is used to create a plan of Ostia’s urban landscape, including the different building classification categories, which are used as a proxy for spectator activity. UNA addresses some of the issues implicit within space syntax methodologies to show how movement routes at Ostia are structured by building classification proxies. The final step consists of agent-based modelling (ABM), a form of simulation that looks at the behaviours that emerge from decisions made by agents within a built environment.

3.3.1 GIS Model of Ostia’s Urban Landscape

The data underlying the present study was first developed within a GIS. This was accomplished through the identification of Ostia’s built environment and street network during the late 2nd century CE, which constitutes the temporal focus of this study. The built environment was subsequently classified following five broadly defined building classification categories: commercial, production, residential, public, and religious (fig. 5). These classifications are representative of different forms of social activity that are identifiable from Ostia’s archaeological record and therefore representative of the types of spectators that

![Figure 5. Plan of 2nd century CE Ostia showing building classification categories and the extended street network.](image)
could engage in watching a passing procession. The street network incorporates both the streets known within the excavated city as well as the extended street network based upon preliminary geophysical survey efforts (Heinzelmann, 1998; Martin & Heinzelmann, 2000; Stöger, 2011). Inclusion of the extended street network is necessary to reduce the occurrence of an edge effect, or creation of an artificial boundary, by accounting for the possibility of movement occurring beyond the extent of the presently excavated city.

Some degree of uncertainty exists in terms of both the classification of individual buildings as well as in dating portions of the extended street network. In the first instance, a primary concern is the multifunctionality of urban space. The present classifications attempt to mitigate this issue by being representative of urban spaces that have direct access to the street. While upper storey spaces with street facing windows access might constitute an additional draw, consideration of upper storey space is beyond the scope of the present study. The second issue concerns the date of the extended street network. Sections of this network probably date to the beginning of the 3rd century CE, thereby postdating the present study. However, until the geophysical survey results detailing these streets are fully published, it is not possible to accurately determine which street segments belong to which date. The full street network is included, therefore, as a way to limit edge effects within the different analyses.

3.3.2 Urban Network Analysis

In order to question the extent to which different building proxies act as a draw for passing movement, betweenness centrality is computed within ArcGIS using a new form of network analysis termed urban network analysis (UNA). Unlike most network analyses that occur on the scale of a city’s street network, computed using nodes (intersections) and edges (street segments) (Porta, Crucitti, & Latora, 2006), UNA adds a third metric, buildings. Within this tripartite network design buildings become the main focus of examination for the calculation of betweenness centrality, which calculates how likely it is that a certain node within a network will be passed when the shortest distance between two nodes is traversed (Freeman, 1977; Brughmans, 2010). The results subsequently provide an indication into which streets saw the greatest proportion of passing movement. This new focus addresses some of the issues found within space syntax methodologies by accounting for what influences passing movement.

To implement this framework at Ostia, the urban network analysis (UNA) toolbox that was developed for use within ArcGIS 10.0–10.3 was applied (Sevtsuk & Mekonnen, 2012; Sevtsuk, Mekonnen, & Kalvo, 2016). The UNA toolbox requires four primary inputs: buildings, a street network, radius type, and a specified search radius (for further details see Crawford, 2019). Since the present study concerns how different spectator groups shaped movement patterns throughout the city, all five of the proxy building classification categories were appropriately weighted within an ArcGIS attribute table. Second, a network was created for the city’s extended street network. This was accomplished using the ArcGIS network analyst extension. The radius type specifies whether calculations occur using a network or Euclidian radius. The use of a network radius restricts the calculation of movement to the street network, thereby eliminating the possibility of movement through buildings. Search radius concerns the metric distance (e.g. 200 meters) that is used to calculate betweenness centrality from one building to all other buildings accessible within this distance along a network radius. This was calculated for each individual building within the dataset using a specified search radius value.

To ensure that the betweenness centrality results reflect movement surrounding the Campo della Magna Mater, rather than within the entire cityscape, only the buildings located within a 200 meter radius of the sanctuary were weighted since the sanctuary exists as the main node of the procession. The buildings located outside of this area were accounted for within the calculation of betweenness centrality, but they were not provided with weighted values. The betweenness results provide a visualisation of which buildings, and by extension which streets, would have seen the greatest likelihood of passage regardless of a specific start or end location.

Figure 6 shows the calculation of betweenness centrality where all buildings within a 200 meter radius of the sanctuary are weighted with a value of 1, while buildings located within the rest of the cityscape are
weighted with a value of 0. The results are computed using a 200 meter network radius, thereby focusing movement analysis within the area surrounding the sanctuary. The visualisation output produces a visual gradient of the betweenness centrality results. The buildings shown in black have the highest betweenness centrality values, while those shown in light grey have the least. The streets corresponding to buildings with the top 20% of the highest betweenness values, representing buildings with the greatest potential of seeing passing movement, are indicated in red. The streets with the next highest potential of movement are indicated in orange.

![Betweenness Centrality (r200)](image)

**Figure 6.** Map showing the calculation of betweenness centrality weighted by buildings within a 200 meter radius of the sanctuary. The streets following the two highest betweenness centrality metrics are designated in red and orange.

Each proxy category is separately considered (figs. 8–12) and assessed in light of how it differs from the unweighted betweenness graph (fig. 6). While this analysis begins to provide a more nuanced understanding of how different building proxies structure movement surrounding the sanctuary, it only provides partial insight into the formation of a processional landscape. To address this issue, a secondary computational method is applied that both questions the validity of the betweenness centrality results while providing a more detailed visualisation of potential movement routes within Ostia’s urban landscape.

### 3.3.3 Simulation

Agent-based modelling is used to further question how building proxies shape specific movement routes that begin and end at the Campo della Magna Mater by focusing upon the interactions that occur between a processional leader and its route selection. This method, therefore, provides an alternative approach to studying movement dynamics within the city as well as serving as a way to verify the probability of the betweenness centrality results.
The model was developed using the software platform NetLogo (Wilensky, 1999), which enables the integration of the GIS plan previously created for Ostia, including the different building classification categories. A detailed description of the model is provided in Crawford (2018) while the source code is available on https://github.com/K-A-Crawford/ABM-Processional-Leader. The main agent, the processional leader, is coded to leave the Campo della Magna Mater following a movement route composed of travelling past buildings that are weighted with the highest influence values. This serves to simulate passing hypothetical groups of spectators that could be found in the vicinity of different buildings, therefore serving as a draw for the processional leader in determining its route. This is repeated for a predetermined amount of time, at which point the leader then returns to the sanctuary, completing a hypothetical circular procession. The leader is confined to moving along the street network, thereby limiting the possibility of travelling within buildings or open spaces. Other agents occupy the street space, which requires the processional leader to additionally choose movement routes that do not run into other agents. Furthermore, the agent is not allowed to travel over areas previously traversed, ensuring that it does not travel in circles. The basic movement procedure taken by the processional leader during each timestep of the simulation is detailed by the following pseudocode.

**Pseudocode of Processional Leader**

For each timestep:

- **Move-leader:**
  - If distance to target <= 0:
    - **Define-target:**
      - Calculate as the closest & highest influence building
  - If distance to target > 1:
    - **Travel to target:**
      - Calculate the best way to reach this target
      - Move to the target
      - Record route

Each time a simulation is run with a specific set of variables, different results will arise. Variability in results is accounted for by running the simulation ten separate times for each variable (e.g. weighted building value). While the number of simulation runs could equate to 100, within the present model the same variation of movement along different streets occurs within 10 simulation runs. Therefore, each simulation with a different weighted building value is run only 10 times, with the results subsequently collated to show the variation in street movement patterns. Figure 7 shows the routes taken by the processional leader, beginning and ending at the sanctuary, during 10 different unweighted simulation runs. These results indicate movement routes that are purely structured by the shape of the urban landscape rather than any desire to pass specific buildings or areas within the cityscape. The likelihood of the processional leader using a street is represented on a colour gradient of red to green, with red representing streets that are used 90–100% of the time across all simulation runs. Dark green, in contrast, shows streets that are traversed during only one or two of the simulation runs.

Different simulations are run weighting each of the five proxy building classification categories (figs. 8–12). Each simulation is visually presented and analysed in terms of how it differs from the unweighted simulation (fig. 7). This provides an indication into the extent to which the building proxies shape movement patterns through Ostia’s urban landscape.
Figure 7. Map showing the similarity of street usage by un-weighted processional runs on a gradient of red to dark green. Streets shown in red are consistently used by the processional leader during almost all of the simulation runs. Streets shown in dark green are only used during 10–20% of the simulations.

4 Visualising Processional Movement Around the Campo della Magna Mater

A series of five different experiments were run to question if and how different spectator groups may have dictated the directionality of processional routes. In each experiment, one of the building classifications categories is tested as a proxy attractor for processional movement, with the routes subsequently analysed in relation to the unweighted models. These results (figs. 8–12) demonstrate that while certain streets are consistently used across all of the various analyses, there are distinct variations in movement areas, thereby indicating that different spectator groups can act as a draw for dictating processional route creation.

4.1 Commercial Weighted Processional Routes

Commercial space dominates Ostia’s urban landscape, ranging from tabernae (small shops) to large horrea (warehouses). Over half of the ground floor buildings within Ostia would have had some form of a commercial function (Rickman, 1971; DeLaine, 2005). Despite the urban landscape consisting of predominantly commercial spaces, both the UNA and ABM models (fig. 8) indicate that these spaces have a clear effect on processional movement, which differs from the unweighted models (figs. 6–7). Unsurprising considering the breadth of commercial spaces, the possible movement routes in both models encompass a large proportion of Ostia’s street network. When compared to the unweighted models, the movement patterns from both analyses are focused within the area north-east of the sanctuary, moving towards the direction of the Theatre. In particular, both methods of analysis indicate that the Semita dei Cippi and the Via della Fortuna Annonaria would have seen a significant degree of passing movement. Both of these
streets host a large quantity of street-front shops. Additionally notable is that movement predominately passes the smaller tabernae, with an only minimal potential of travelling past the city’s large horrea that are concentrated within the northern area of Ostia.

Figure 8. Top: Betweenness centrality graph weighted by commercial buildings. Streets displayed in red and orange follow the highest betweenness centrality metrics which are different from the unweighted graph. Bottom: Similarity of street usage by processional runs weighted by commercial space.

4.2 Production Weighted Processional Routes

Spaces defined as having a production function include areas such as bakeries, fullonicae (fulleries), and workshops (Bakker, 1999; Flohr, 2013). This category of space has the fewest number of buildings identified within the built environment compared to the other classification categories, an aspect that has to be considered when interpreting the models that are weighted by production space (fig. 9). The buildings classified as having a production function are scattered throughout the larger movement area, often located within close proximity to commercial spaces. Unlike the UNA commercial weighted results, movement weighted by production space shows routes confined to moving within the streets located east of the sanctuary, along the Semita dei Cippi, and along a portion of the eastern decumanus. The simulation
results indicate a similar trajectory of movement, with a return route to the sanctuary that travels within the unexcavated area of Ostia. This return pathway is partly due to how the model is coded, which dictates that the processional leader does not return following previously traversed streets. However, it also raises the possibility of movement travelling within unexcavated areas of the city. Both models show that production spaces, despite the limited number identified within the built environment, have a clear draw on movement patterns. Within the simulation model, this could in part be due to many of them being located at street corners, acting as an attractor for the processional leader. Conversely, while it was not modelled, production spaces could also serve as a detractor to movement. These areas of movement could alternatively be interpreted as areas that might be avoided due to their smell or avoidance of people engaged in these forms of activities (Flohr, 2017).

Figure 9. Top: Betweenness centrality graph weighted by production buildings. Streets displayed in red and orange follow the highest betweenness centrality metrics which are different from the unweighted graph. Bottom: Similarity of street usage by processional runs weighted by production space.
4.3 Residential Weighted Processional Routes

Residential spaces are well-identified throughout the city and include *insulae* (apartment buildings), *mediumum* apartments, and upper class *domus* (houses) (Packer, 1971; Hermansen, 1982; DeLaine, 2004). Their limited visibility within the present GIS model (fig. 5) is because the majority of domestic space would have been located within upper storey spaces. The present models, therefore, are indicative of the extent to which ground floor residential spaces serve as an attractor for processional movement. The movement routes are largely confined to the area directly east of the Campo della Magna Mater (fig. 10). These results reflect the spatial position of the ground floor residential spaces that are positioned along the city’s secondary and tertiary streets. Especially notable is the minimal potential of movement occurring along the eastern *decumanus*, a reflection of the few residential spaces that are directly accessible from the city’s primary street. The areas with the highest probability of movement, which are found around *insula* V.ii (delimited by the Semita dei Cippi and the Via della Fortuna Annonaria), are represented by both analyses. These results are unsurprising considering the presence of several upper class houses and apartments.

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**Figure 10.** Top: Betweenness centrality graph weighted by residential buildings. Streets displayed in red and orange follow the highest betweenness centrality metrics which are different from the unweighted graph. Bottom: Similarity of street usage by processional runs weighted by residential space.
that are located within this area. The main difference in the simulated movement directionality results when compared to the betweenness centrality graph is the possibility of movement travelling towards the northern area of Ostia, passing the various *insulae* apartments located along the Via di Diana. One factor that is not considered within these two models, but needs to be acknowledged, is the possible affect that spectatorship from upper storey windows would have had.

### 4.4 Public Weighted Processional Routes

Public spaces include baths, open spaces, gathering points, administrative areas, and areas of entertainment (Meiggs, 1973; Hermansen, 1982). While distinct in terms of the various urban activities that occurred within these spaces, they represent areas of the urban environment that would have seen high levels of social interaction which were not strictly commercial or residential. Public weighted movement routes are predominantly confined to travelling along the *decumanus* and *cardo* (fig. 11). These routes largely correspond to the concentration of public spaces being located within the vicinity of these spaces. The

![Figure 11](image)

*Figure 11.* Top: Betweenness centrality graph weighted by public buildings. Streets displayed in red and orange follow the highest betweenness centrality metrics which are different from the unweighted graph. Bottom: Similarity of street usage by processional runs weighted by public space.
simulation indicates a high probability of movement travelling within the northern area of Ostia. Ostia’s major streets are shown to have existed as a focal point for facilitating movement to many of the public areas that are directly accessible from these two streets. Significant is also the variation in movement that extends off of these major streets. While the *decumanus* and *cardo* might serve as important passageways for movement, these analyses indicate that movement passage was not solely restricted to these streets. Concentration along Ostia’s primary atrial streets is unsurprising considering the large proportion of public spaces located within their vicinity. The spatial location of these spaces enabled the increased attraction of spectators, and processional routes took advantage of these spaces.

### 4.5 Religious Weighted Processional Routes

Religious spaces include temples, sanctuaries, and areas with a predominant religious affiliation (Taylor, 1912; Squarciapino, 1962; Meiggs, 1973). In the present analyses, private religious spaces are not considered since they do not usually manifest in structures that are directly accessible from the street. Both the UNA and ABM results (fig. 12) indicate movement routes that travel from the Campo della Magna Mater towards
the northern area of Ostia along either the southern cardo or the Semita dei Cippi. While not as apparent within the UNA graph, the simulation indicates extremely centralised movement surrounding the forum, as well as a high potential of movement travelling from the southern to the northern area of Ostia. These results additionally show that even when religious spaces are the highest attractor for passing movement, the routes taken are not confined to travelling along the decumanus as has been previously hypothesised for Ostia. Instead, it indicates that even religious structured routes are much more nuanced in their movement patterns and the areas of the city they might traverse.

5 The Creation of a Processional Landscape

Interpretation and analysis of the different movement routes all provide a general understanding of how movement areas changed depending upon what served as an attractor for processional movement. Summative movement areas, shown in figure 13, indicate clear route distinctions within the city. In particular, routes characterised by passing commercial, production, and residential building proxies are primarily concentrated within the south-eastern area of the cityscape. Routes weighted by religious and public building proxies, in contrast, predominately travel within the northern cityscape. In all examples, the decumanus and cardo exist as major thoroughfares, enabling the passage of movement. It is important to note, however, that they do not necessarily exist as the predominant processional way. Instead, they played a crucial role in structuring different routes that went from one area of the city to another.

The integration of urban network analysis and agent-based modelling results show movement areas that are considerably more complex than those originally discerned from the different space syntax axial analyses. Whereas the axial analyses of choice and integration (cf. figs. 2–3) both indicate that movement was concentrated along the decumanus, the weighted UNA and ABM results show a more nuanced picture. The decumanus is used in every iteration, indicating that it was in fact used as a major passageway, but

Figure 13. Map showing a summary of possible movement routes weighted by each classification category. Streets displayed in black represent pathways consistently used by each weighted classification category.
what is more significant is the movement that occurs along additional streets. This indicates that movement was not solely confined to Ostia’s primary street. In comparison to the calculation of step depth (fig. 4), these routes also demonstrate a wider variety of processional passage that extends beyond the immediate streets surrounding the sanctuary. The results show, first, that alternative methodologies can give insight into different pedestrian movement patterns. Secondly, the summary routes (fig. 13) illustrate the extent to which different attractors shape processional movement patterns through the cityscape.

The significance of different processional movement areas is not the individual routes that are visualised, but rather, the insight they provide as to the possible variability in movement. The different results all present movement patterns that are structured by one particular attractor. In reality, however, it is unlikely that only one attractor factored into the determination of specific routes. The value of this analysis, therefore, relates to understanding how these potential processional routes inform our understanding of a larger processional landscape that surrounded the sanctuary of the Magna Mater. Rather than attempting to discern the most probable processional movement route, a feat that is improbable considering our limited understanding of the Magna Mater’s processional rituals, these potential routes can be used to better understand how spectators played a critical role in shaping the overall processional landscape.

The broader implications of the processional movement area concern the portion of the cityscape the Magna Mater’s processional rituals encompassed. Considering the compilation of the most probable movement areas, shown in figure 14, an indication into all of the primary streets that might have seen some degree of processional movement is provided. This ritual movement area indicates that routes are predominantly structured along streets surrounding the forum, although movement does not travel through this space. This is in part a result of the present methodology being focused upon building proxies rather than open spaces within the city. Assessing the potential movement routes in light of the total processional area they constructed addresses both the variability and uncertainty that existed within processional movement routes as they were practised throughout time. Route variation would have occurred depending upon what

![Figure 14. Map showing the total processional area structured around the Campo della Magna Mater following the most likely processional movement routes.](image-url)
was most significant to pass within a given procession, something that would change as the social and urban infrastructure of the city developed over time. Therefore, considering processional movement in this manner further emphasises the fluid nature of processional rituals at Ostia, which occurred within a living urban landscape. Rather than attempting to determine any one particular path, this method allows us to envision a range of different movement possibilities.

Through the territorial engagement of processional rituals (de Polignac, 1984), the Campo della Magna Mater was able to demarcate a processional area that extended beyond the constraints of its sanctuary. Processions served as a way to create a malleable border surrounding the sanctuary. The portions of the cityscape that were traversed and the people and buildings that were passed subsequently became temporary participants within the cult, as they were incorporated within a shared ritual experience. Processions were not only used to demarcate the extent of the processional area, but they also brought attention to different areas of the cityscape that might hold specific significance for the cult. The area detailed above shows the range of Ostia’s cityscape that may have been temporarily engaged with the Magna Mater’s passing processions. Passage past these areas would not only highlight them within the urban landscape but ritually tie them to the cult’s mythic past. At Ostia, this could include travelling past the Theatre where ritual plays may have occurred, or, to the Tiber, referencing Cybele’s initial arrival at the city (Fasti 4.291–328; Pensabene, 2008; Iara, 2015). Just as certain urban spaces might be joined through processional rituals, other areas or urban groups of people may have been intentionally excluded. As the cult developed over time and the city’s urban and social landscape changed, the routes of processional rituals, and by extension, the shape of the ritual area, would have been adjusted in reflection.

A joint relationship existed between how the rituals were expressed and how they would be understood by the Ostian public who were not participants within the cult. Processional rituals created a spatial and experiential framework for understanding the cult of the Magna Mater. Meaning would be developed in light of the intended ritual viewers and their prior relationship to and understanding of the cult. The processional rituals enabled Ostia’s inhabitants to engage with aspects such as seeing some of the sanctuary’s cultic statues as well as the distinctive dances and music that characterised the cult. Ovid emphasises the spectacle aspect of the cult’s processions through his description, which states that “the goddess herself will be borne with howls through the streets” (Ovid, *Fasti* 4.186). Whereas the cult’s daily rituals were secluded within the sanctuary’s precinct and confined to the cult’s followers, processions ensured the city’s temporary attention through both where the procession travelled as well as with the ritual’s multi-sensory components. All of these factors ultimately added different levels of meaning and interpretation to the processional landscape that surrounded the sanctuary.

6 Critiquing the Suitability of Digital Approaches for Studying Ostia’s Processional Landscape

Due to the overall uncertainty of processional movement and the nature of possible routes at Ostia, the application of digital methods provides one of the only ways in which this topic can be addressed. The most commonly applied digital methods for studies of ancient movement, namely space syntax, do not adequately capture the complexity that underlies processional movement. To address this, a multi-layered computational approach was applied to question the extent to which spectatorship associated with various forms of social activity played a part in structuring movement routes.

The results of both the betweenness centrality and agent-based modelling provided complimentary movement results, enabling new insight into how movement patterns might have been structured at Ostia. The application of betweenness centrality provided partial insight into which areas surrounding the Campo della Magna Mater would have likely seen processional passage. The various weighted graphs all reflect differing movement patterns. However, the visualised results only capture segments of streets that would have had a greater potential of passing movement. Considering movement patterns within the city only using this method alone does not sufficiently address potential processional movement patterns, therefore making the application of a comparative method necessary. The simulation results of weighted movement...
patterns provided more nuanced results when compared to the betweenness centrality graphs through their ability to capture full hypothetical processional routes. While they can afford a more detailed picture of how potential movement patterns would be shaped by building proxies, the validity of these results needs to be addressed through a more formalised method. By comparing these results to the betweenness centrality graphs, we can discern substantial similarities in the street sections that would have seen the greatest probability of passage. The strength of applying both computational methods in tandem is their ability to both validate and build upon the results gained from each method.

The application of digital approaches ultimately serves as a heuristic tool to question how a processional landscape might have been constructed at Ostia by questioning what served as an attractor for the movement patterns. The benefit of applying such an approach is that it allows for the study of a topic that remains largely invisible within Ostia’s archaeological record. It needs to be emphasised, however, that the present analyses were conducted using a very specific dataset consisting of building classification categories as a proxy for spectators. As previously addressed, this proxy data is subject to alteration as information or interpretations of the late 2nd century CE city change. The benefit of applying digital methods, however, is that they can adapt to changes in data and interpretation. As our understanding of Ostia’s built environment changes or our understanding of the importance of different spectator groups improves, the model’s underlying data can be changed and the models run to reflect these developments. In this sense, the areas of processional movement detailed above present preliminary insight into how a processional landscape was constructed surrounding the Campo della Magna Mater based upon our current understanding and interpretation of the cityscape.

### 6.1 Improvements to the Present Computational Models

The ability of urban network analysis and agent-based modelling to capture potential ritual movement patterns presents a marked advance for studies of a sanctuary’s processional landscape. Despite the ability of these methodologies to present potential movement routes, there remain several issues in terms of the used archaeological data and our understanding of processional rituals more generally that would benefit from future consideration.

The partially excavated cityscape inherently shapes the nature of the results. While the extended street network is included within the present urban model, buildings that are included within the unexcavated areas of the city remain unaccounted for within the different analyses. As a result, some degree of bias in the movement results is highly probable, especially considering the position of the Campo della Magna Mater at the southern edge of the excavated city. Future studies would, therefore, benefit from developing approaches that explore how the extended built environment might be integrated within the present methodology. Such a study would enable the current methodology to be applied to a larger variety of urban contexts, including those known solely through geophysical survey studies.

Engagement with other urban factors that likely affect ritual movement, such as processional size, street width, and urban barriers, would serve to bring a more nuanced understanding about possible ritual movement routes in light of a procession’s movement dynamics. The integration of different processional sizes, meaning the number of people partaking in the procession, would serve to assess how the size of a procession served as another factor dictating movement along the street network. At present, the agent-based model focuses upon the route chosen by the processional leader following building weights. The addition of processional followers would add further complexity by accounting for a street’s occupancy capacity as well as urban street architecture.

A final topic that would enhance our understanding of the street dynamics involved in shaping processional rituals includes accounting for a city’s daily street traffic. It is equally possible that on days of major processions street traffic was closed. The development of models that account for the more general dynamics of street movement, including both vehicular and pedestrian traffic, would address how processional rituals needed to contend with the city’s daily urban movement flows. This could lead to new questions concerning the extent to which a procession might choose to travel along less congested streets, or not, depending upon the purpose and framework of a single procession. Considering processional
movement patterns within this light would further bring attention to the practice of rituals within a living landscape.

The present computational models, while relatively simplistic, aimed to address how a particular processional landscape can be visualised at Ostia. More significantly, it provides a methodological foundation for undertaking future analyses and asking more complex questions to explore how processional movement actively shaped a sanctuary’s surrounding ritual landscape.

7 Conclusions

This study has aimed to present a new approach for studying how processional movement can be studied within the Roman city of Ostia. The application of a multi-layered computational methodology provided a heuristic approach that enables us to postulate about how processional routes were structured by various spectator groups within the city. The results of these analyses provide a new perspective into the larger processional area constructed surrounding the Campo della Magna Mater. While certain issues remain in the application of digital approaches, not least of which is due to a paucity of surviving information attesting to how such rituals navigated ancient cities, it presents a new way of considering how processional areas were structured within urban contexts. Although the present study is relevant to Ostia, the methods introduced could easily be applied to any ancient city with a sufficiently surviving urban landscape and street network. Ultimately, the hypothetical nature of this approach has particular potential for studying the processional landscapes of cities from different regions and time periods.

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Abbreviations

| Abbreviation | Description                        |
|--------------|-----------------------------------|
| ABM          | Agent-Based Modelling             |
| CIL          | Corpus Inscriptionum Latinarum    |
| GIS          | Geographic information systems    |
| UNA          | Urban Network Analysis            |

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