Rethinking Ostia : a spatial enquiry into the urban society of Rome's imperial port-town

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Issue Date: 2011-12-07

4 – Methodology: Data Capture, Processing and Analysis

Following advances made in Pompeian studies and elsewhere,[1] this study examines Ostia as an expression of Roman urbanism and explores the ancient city within its own social and spatial context. More specifically, it investigates the mutual relationship between Ostia's built environment and its urban society within the theoretical and methodological framework of Space Syntax.[2] For this reason this study relies on a strong basis in architectural data. This chapter therefore concentrates on the specific methods and techniques that have been applied to collect suitable data sets from Ostia's built and non-built environment for subsequent detailed archaeological and spatial analyses. The second part of the chapter will focus on the methods and techniques which have been selected for the analysis of the spatial data, and will introduce and explain the specific Space Syntax tools used for spatial analysis.

From Ostia's vast archaeological record, particular areas have been selected for closer investigation: Insula IV ii, consisting of 14 buildings, selected guild seats (*scholae)* and Ostia's street network. This selection represents deliberate choices, made to address the ancient city at different scales: the micro-scale of individual buildings (*scholae*), the macro-scale of the entire street system, and the medium scale of the 'local neighbourhood', represented by Insula IV ii. However, the core of this research is a data-based, detailed structural assessment of Insula IV ii and its subsequent spatial analysis. Above all, the Insula serves as a case study to reconstruct urban development during the 2nd and beginning of the 3rd centuries AD, and to examine aspects of the city's spatial organisation, applying selected Space Syntax tools.

1. See Chapter Two of this study reviewing the works of Kaiser (2000), Raper (1977), Laurence (1994 and 2007), Grahame (2000), Wallace-Hadrill (1994) and Zanker (1998).
2. See Chapter Three on the theoretical background of Space Syntax (Hillier 2007; Hillier and Hanson 1984; Hanson 1998).

With this in mind, this research pursues a twofold approach, combining complementary components: an archaeological study, focused on a detailed assessment of sections of Ostia's built and non-built environment, and a syntactical spatial analysis, applied to the archaeological data sets. The two parts are well matched: the Space Syntax analysis demands reliable archaeological data so as not to compromise the results of the analysis through the use of incorrect or deficient data sets. Likewise, the thorough archaeological assessment benefits from the additional analytical component. The combination of both however, moves the study beyond the level of descriptions and cataloguing, and offers new insights into the spatial organisation of Ostia.

Ostia is one of the few Roman sites where the immense archaeological record allows us to explore aspects of Roman urban life. Still, despite the abundance of the archaeological material and vastness of the architectural remains, Ostia's archaeological record is not at all easy to access. The site is beset with many problems; the difficulties resulting from the largely unrecorded excavation campaigns of the 1940s,[3] as well as the undocumented restoration activities, are well known and have often been criticised.[4] Every research project carried out in Ostia is affected by these problems in one way or other. This study is no exception. However, next to problems caused by poor initial documentation and later neglect, the major difficulties encountered concern Ostia's existing site plan and its shortcomings. These 'mapping' issues are crucial since this study includes a systematic GIS-based approach, which ultimately depends on reliable geo-referenced maps to be able to link data to digitized maps.

3. For an outline of Ostia's history of excavation see Lauro (1995: 41-52).
4. Meiggs (1973: 5-7) and Pavolini (2006: 40-41).

4.1 OSTIA'S SITE-PLAN AND THE CO-ORDINATE SYSTEM

One of the drawbacks often encountered when working at archaeological sites with a long history of excavation is inaccurate site-plans. Ostia's general plan was published in 1953.[5] The site-plan developed over a long period of time in a piecemeal fashion,[6] progressing along with the excavations. In the core of the city, within relative proximity to Ostia's established local point of reference,[7] the plan is fairly accurate with minimal divergences between plans and the actual location of the architectural structures. However, the plan reveals substantial margins of inaccuracy in the peripheral areas of Ostia's excavated terrain. These discrepancies were only discovered once advanced methods of recording had been applied. A recent Japanese project, introducing 3D Laser scanning, has studied the plans at the centre of the city and produced interesting insights into the causes of some of these minor divergences, through a comparative study of the 1953 site plans and the results from the laser scanning survey (Fig. 4.1).[8] Interestingly enough, the inaccuracy of the site-plan did not pose noticeable problems for traditional research, concentrating on individual buildings or smaller areas.

However, the site-plans became an issue of concern when recent projects began to examine larger areas, or when studies extended into the periphery of the excavated areas and beyond.

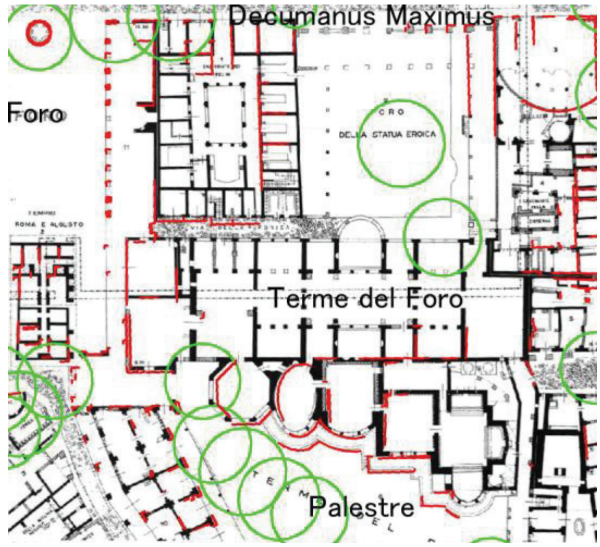


Fig. 4.1 – Divergence between Calza's map and the results obtained from laser scanning (in red) shown on the Terme del Foro; present vegetation (tree coverage) is indicated by green circles (from Hanghai and Hori (2009: 2, fig. 3)

Not only the site-plan's inaccuracies, but also the growing demand for geo-referenced digital maps brought Ostia's 1953 general plan more and more under pressure. At first only a small number of projects, such as the large-scale DAI research, as well as the University of Texas' survey of Ostia's synagogue, employed GIS-based methods of digital recording and data protocols.[9] With a growing interest in intra-site comparative studies and large-scale surveys, the need for computer-based methods of systematic, geo-referenced recording and data-processing has also increased. Hence, in response to research demands as well as current site management requirements, Ostia's Soprintendenza took on the challenge and launched into the production of a new geo-referenced digital site-plan. At the same time the Soprintendenza faced a dilemma, since replacing the 1953 general site plan would mean that an enormous

5. The general site plan was produced by I. Gismondi in 1949, drawn by E. Visca, then published in 1953 in Scavi di Ostia I, Topografia generale (Calza 1953); the general plan has been updated in 1961, see Verduchi (1995: 20, fig. 8).
6. Valieri's plan of 1914 seems to have provided the basis for Gismondi's plan of 1953. Valieri's plan was derived from a 1911 aerial photograph, the so-called 'relievo dal pallone'; for a detailed discussion on the influences of the 'relievo' on subsequent cartographic representations see Shepherd (2006: 15-35).
7. Ostia's local datum of reference was set up by I. Gismondi. The reference point is found in front of the Museo Ostiense, marked on the northern doorstep of the stairs leading into the Museum.
8. Hanghai and Hori *et al*. (2009) revealed minor inconsistencies between the 1953 site plan and the actual positions of buildings; while substantial divergences between site plan and actual location of structures at the peripheral areas were encountered, presumably accumulative error with distance from the established point of reference (personal communication from M. Heinzelmann, DAI project and M. White Texas University project).

9. White (2001); for preliminary reports on the DAI survey see Bauer *et al*. (2000).

amount of embedded information would be lost.[10] The 1953 general plan incorporates a wealth of archaeological and architectural information, reproduced as attribute data, detailing earlier and later building phases and architectural conventions such as wall apertures, discontinued structures, as well as detailed archaeological features. In their efforts to find a workable compromise, the Soprintendenza has been exploring various solutions.

With the production of Mannucci's *Atlante di Ostia antica*, published in 1995, a beginning was made to confront these growing challenges. The *Atlante* offers a new site plan, covering Ostia's extended excavated areas. The new plan is based on aerial photogrammetry,[11] and it is tied to Italy's national co-ordinate system Gauss-Boaga.[12] The *Atlante* aimed at bringing Ostia up to date with modern methods of topographic recording and data management, by offering an updated and updatable site-plan in printed and digital form. The new plan was intended to form the basis for a system of recording and site management that could be adapted to the changing requirements of archaeological research as well as heritage management.[13]

The *Atlante* presents a fairly faithful mapping of Ostia's past built environment, reproduced at a scale of 1:500, and divided into 67 segments of 25 x 25 cm. A double page has been dedicated for every segment, displaying the plans on the left page, matched by a glossy full-colour aerial photograph of the same section on the right side. This dissected way of representation allows full attention to detail, while the coherence of Ostia's site plan is largely neglected. The significance of the complete site plan seems not at all to be acknowledged by the *Atlante*. A representation of Ostia's general plan is found on the inside of the cover, at a scale of 1:5000. This is also where one finds rather casual references to the Gauss-Boaga national co-ordinates,[14] while the detailed plan sections remain without a reference to co-ordinates. Moreover, the new plans are far from containing the amount of information found in the 1953 plans, and also did not follow the established official numerical designations in keeping with the traditional system by Region, Insula, Building, and Room. Altogether these shortcomings compromise the usefulness of the *Atlante*. In fact, the *Atlante* did not succeed in replacing the 1953 site-plans, and on the whole has not found much application.

In a further attempt to remedy the problems posed by the 1953 site-plan and the lack of geo-referenced points, the Soprintendenza introduced a local reference system in 2004/5.[15] This topographic project established 58 local reference points (caposaldi), distributed over the extent of the excavated area. These 'caposaldi' have been cross-referenced to each other and tied to a fixed local benchmark, positioned at the intersection of the *decumanus maximus* and the Via del Pomerio.[16] This local system was intended to enable researchers to reference their own maps to the established points closest to their area of research (Fig. 4.2). Unfortunately, this system proved to be inadequate for a number of reasons: firstly it only offers a local reference system and has as yet not been tied in with the Italian national co-ordinate system (Roma40 Gauss Boaga).[17] Secondly, the concrete blocks which mark the reference points did not prove to be sturdy enough to survive the daily strains of the site. Already after a relatively short time, a number of the concrete blocks used as markers have been destroyed

10. Personal communication from E.J. Shepherd, (formerly Soprintendenza of Ostia).
11. See Ferri and Barreca (1995: 54); see Ferretti (1995: 55) on the technical details of the aerial photogrammetric survey of Ostia.
12. Geo-referenced to IGM reference points (Torre San Michele IV and Ostia antica III).
13. Ferri and Barreca (1995: 53).
14. See Mannucci (1995: 61) "Controllato ai Sensi della legge n. 68 del. 02.02.1960. Nulla Ostia Dell ÍGMI alla Diffusione n. 139 del. 12.04.1994".
15. The topographic survey was jointly carried out by the Università della Tuscia, Viterbo and the École française de Rome.
16. The 0-benchmark is reference point 36 of Ostia local reference system (Ostia antica - maglia caposaldi topografici 2004, unpublished database).
17. The Soprintendenza of Ostia has been involved in long-standing negotiations with the IGM (Istituto Geographico Militare, Firenze) und hopefully will be receiving an official reference datum (punto fiduciale) in the near future.

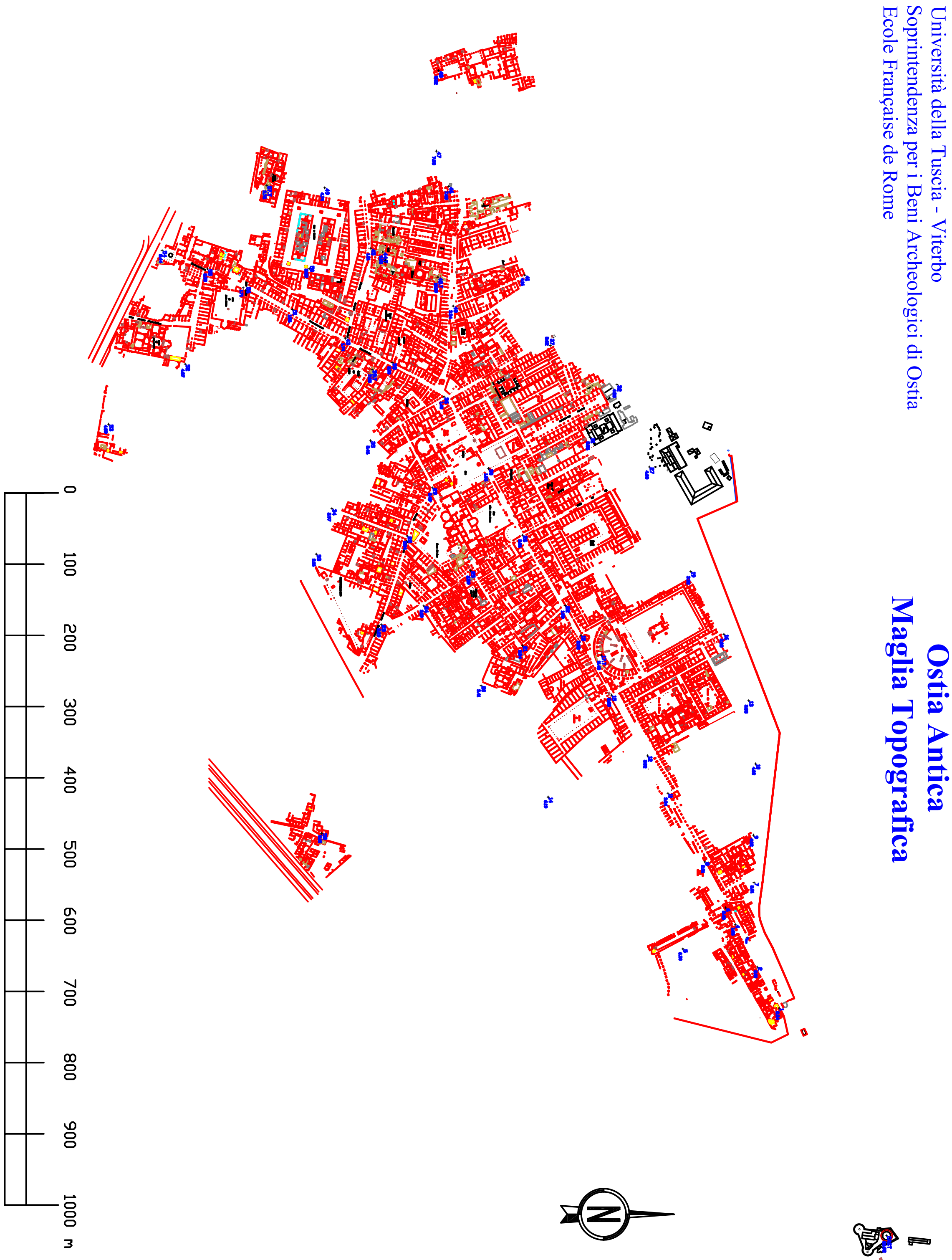


Fig. 4.2 – The local reference system comprises 58 local reference points (marked by consecutive numbers in blue)

or disappeared altogether (Fig. 4.3).[18] Furthermore, a number of reference points seem to have inbuilt error margins: placed at locations chosen for least impact on the archaeological record, and guided by inter-visibility between the reference points, the points themselves have been set up by triangulation using tape measures. In most cases two measurements were taken from corners of architectural structures, while the third point, the reference point itself, marks the spot where the tapes intersect. Naturally, such methods are prone to compound problems of inaccuracy due to human error. At the same time modern surveying equipment, like Differential GPS, almost render a 'local reference system' redundant since readings can be taken on the spot, without the intervention of local reference points. This study was able to employ a Differential GPS (DGPS) and hence the challenges posed by the incorrect site-plan and the lack of co-ordinates could be faced without too many difficulties.

Fig. 4.3 – Local reference points hidden under soil cover, intended for protection from vandalism and amateur excavators

18. In 2006, two years after the local system was set up, H. Kamermans and the author re-measured all 58 reference points with palm-top GPS. This was done to test the equipment and its suitability within an urban context, when difficulties such as high standing walls and vegetation cover (umbrella pines) affect the readings.

4.2 REMAPPING AND GEO-REFERENCING INSULA IV II

In July 2008, in connection and in support of this study, a team from the University of Leiden conducted a limited DGPS survey in Ostia,[19] comprising 229 DGPS readings. The readings were taken at specified topographic points within the excavated area of Ostia. These topographic points were chosen according to the research interests pursued by this study. Hence the DGPS survey concentrated on Insula IV ii and its surrounding area. Significant and clearly identifiably locations have been chosen for these points (e.g. corners of buildings, entrances to buildings). Furthermore, the DGPS survey included control readings taken at a number of Ostia's local reference points, and also at several survey points which had previously been set up by the University of Texas and the DAI.[20]

The high-tech DGPS equipment used by the Leiden team offers geo-referenced positioning with the highest levels of survey accuracy.[21] At the same time the equipment is user friendly and allows positioning surveys to be performed efficiently within a short period of time. DGPS applies 'real-time kinematic technology' (RTK), operating with two receivers, one base station and one rover, which simultaneously record and correct satellite data and atmospheric observations. The two stations communicate via radio, allowing for a flexible and mobile system. The highest levels of accuracy are achieved since the readings are constantly recalibrated and corrected. The method and the technical specification are explained in more detail in the following sections.

19. The Ostia DGPS survey was supervised by H. Kamermans; the DGPS readings were taken by H. Kamermans, E. Mol and D. van de Zande, and the author, and with kind support of G. Offenberg who guarded our base station.
20. See White (2001: 31) for a list of survey points, including DAI survey points.
21. The DGPS survey conducted by the team from Leiden used the TOPCON Positioning System HiPer® Pro; see Hiper Pro Operator's manual for technical specifications.

4.2.1 DGPS Survey – general technical background

Differential Global Positioning Systems use relative positioning techniques, which combine and process the satellite readings received from two or more receivers to calculate the receivers' coordinates with high accuracy. To establish this position, the receiver measures the distance between it and at least 4 satellites. The accuracy of a position depends primarily upon the satellite geometry (Geometric Dilution of Precision, GDOP). The more satellites in view, the stronger the signal, the lower the DOP number, the higher positioning accuracy. When using a single satellite system (GPS or GLONASS), the minimum number of satellites is four, while in a mixed satellite scenario (GPS and GLONASS) the receiver must lock into five satellites to account for the different time scales used by these systems.

With DGPS surveys in the current standard approach, one receiver is placed at a known surveyed location (official position with known co-ordinates) and is referred to as the base station. Another receiver is placed at an unknown location, referred to as the remote receiver or rover. As the base station collects satellite data, it measures the carrier and code-phases to accurately compute and verify its location. Then, the base station receiver transmits this information via radio link to the rover or remote receiver. The rover applies the transmitted measurement information to its observed measurement of the same satellites. Since the position of the base station is known, the rover compares the data it receives from the base station to the data it logs from satellites, and applies correction algorithms to accurately measure a new point. RTK (Real-Time Kinematic) allows a real time communication between base station and the rover via radio signals, whilst any detected signal anomalies or atmospheric disturbances can be directly mitigated against and corrected for to achieve highest positioning accuracy. Furthermore, the data can be recorded and stored for post-processing at a later state.[22]

22. Since DGPS readings not only provide x and y coordinates but also very reliable readings of height (z), 3D terrain models can be calculated and later constructed in GIS programmes.

4.2.2 The Ostia DGPS survey – establishing a base point

The first requirement for a successful DGPS survey is a reliable, well-positioned, known point of reference to 'ground' the receiver base station. As stated before, there is no official IGM point within Ostia's area of excavation. The closest official IGM point is located on top of the Castello Giulio II, in the medieval town of Ostia Antica, outside the excavation area. A number of additional survey points have been set up along the metal fence which encloses the site bordering the access road Via Romagnoli.[23] The additional survey points along the fence have been established by surveyors, but not the IGM; these referential points are triangulated and set up along visual axes. Hence these points are positioned at the edges of fence poles, corners of walls or perched against other physical objects suitable for visual positioning. Since the DGPS base station needs to be exactly placed on top of such a known point of reference, these 'edge positions' make an accurate placing difficult. Therefore the best option for the Leiden DGPS survey seemed the IGM point on top of the Castello Giulio II. However, this reference point proved unreliable since its position had been altered in the course of repair works carried out on the rooftop of the tower, and has as yet not been officially re-positioned by the IGM.[24]

In absence of a 'known' topographic point, the DGPS offers 'auto-positioning', whereby the base station can be located at a chosen point. All the same, the Leiden survey decided to set up the base station on the top of the Castello, since this location ensured a secure placing and allowed excellent satellite communication, and at the same time afforded radio communication over the major part of the survey area. The actual process of auto-positioning requires

23. Information on Italian survey points can be obtained from the website fiduciali.it.
24. Personal communication with Dott.ssa S. Pannuzi, the curator of the Castello Giulio II; the reference point has been re-positioned without IGM readings taken to confirm the exact location. In fact, the Leiden DGPS survey could not confirm the co-ordinates stated for this IGM point (N 4626601,69 and E 2295642,11), and hence decided to auto-position the base point.

some time for the system to establish its own location, based on the received satellite information. These readings are processed and simultaneously calculated, and converted into the pre-selected co-ordinate system, which in the case of Ostia is Roma40 Gauss Boaga, Fuso Est (zone east, oriented on Mt. Mario, Rome).[25]

Once the base point had been established on top of the Castello (Figs. 4.4 and 4.5), the next step was to take a number of control readings within the site using the 'rover'. Then a new base point close to Insula IV ii was set up and the base station was transferred to the new base point at the local reference point 34, located southwest of Insula IV ii. From there the DGPS survey was carried out within and around the Insula. Additional control readings were taken at several local reference points, and specifically at those local points surrounding Insula IV ii.[26]

Fig. 4.4 – Setting up the base point on top of the Castello Giulio II

Furthermore, in order to ensure consistency between the first base point on top of the Castello, and the second base point southwest of the Insula, cross-referenced control readings were taken from both base points; these resulted in divergences smaller than 1 cm, thus more than acceptable for our purposes.

Fig. 4.5 – Castello Giulio II , Ostia Antica

4.2.3 Geo-referencing Insula IV ii

After the on-site DGPS survey of Ostia had been completed, the recorded data were processed back in Leiden. At this point a sufficient amount of topographic data had been collected: a digital site plan of Ostia based on the *Atlante*, the local reference system consisting of 58 cross-referenced points (caposaldi),[27] and above all the DGPS survey (Fig. 4.6), providing 229 geo-referenced positionings converted into the Roma40 Gauss Boaga co-ordinate system. The next step was to geo-reference Insula IV ii. To achieve this, Ostia's digital map has been scaled and rectified in relation to known reference points, using AutoCAD.[28] Next, the stored DGPS readings have been exported in Excel file format and processed in MapInfo. After that, the DGPS readings were projected onto a geo-referenced map, and subsequently aligned to the corresponding known points on the aerial photograph of

25. See Mugnier (2005: 890) on Italian geodesy.
26. Reference point 34 is located southwest of Insula IV ii, reference point 33 southeast, while 28 is at the intersection of the *cardo maximus* and the Via della Caupona, and 23 opposite the entrance to the Campo della Magna Mater.
27. Courtesy of the Soprintendenza of Ostia.
28. Local reference points 28 (intersection *cardo maximus* and Via della Caupona) was used to geo-reference Insula IVii.

Fig. 4.6 – Taking DGPS readings within Insula IV ii

Fig. 4.7 – Aerial photograph of Insula IV ii aligned to the digital map of Ostia

Insula IV ii (Fig. 4.7). In the following stage the aerial photograph was aligned to Ostia's *Atlante* map (digital version), and from the overlay, divergences between the *Atlante* plan and the actual position of the structures could be identified. These problems were resolved in the next step, involving the 're-mapped' plans produced by the author.[29] The new plans have been subsequently digitized and processed using ArcGIS. The procedure will be explained in section 4.4, but first we need to return to fieldwork carried out in the Insula.

4.3 STRUCTURAL ASSESSMENT OF INSULA IV II – FROM WALL TO WALL

To be able to study Insula IV ii in a systematic way, a geo-referenced data-base was set up to form the foundation for the structural analysis of its built environment.[30] During several seasons of fieldwork conducted over five years, the Insula's standing structures have been thoroughly examined and recorded, divided into buildings, and further subdivided into rooms, and finally dissected into individual walls and single units like travertine thresholds or floor pavements. This formal approach has been chosen to meticulously record all structures and to identify consecutive structural changes that occurred during the second century AD and the beginning of the third century AD. The new plans produced by this study are the outcome of several field work seasons and subsequent data processing back in Leiden. It was found necessary to re-map the buildings, as the published plans contain inaccuracies (some features have disappeared since their initial recording in the 1953 plan, while others, especially wall apertures, could at times not be clearly identified as doors or windows). During the process of re-mapping every excavated wall was structurally assessed. This consisted of recording

29. During several fieldwork periods between 2005-2010 all standing structures within Insula IV ii were re-mapped by the author; the new plans have been produced at scales 1:100 and 1:50.
30. ArcGIS has been used for data-base management, with limitless technical support from Jolanda Lee of GeoStar, Leiden.

the dimensions, establishing the building techniques and materials used, as well as recording the surface treatment of walls and floors. In addition, other unpublished information about specific buildings and rooms has been recorded (e.g. interventions due to restoration activities or recent damage). In this way it can be assured that the data sets have a strong basis in the archaeological and architectural data. However, equally important is the fact that the process of re-mapping, since it requires the closest physical relationship between the architectural structure and the archaeologist, was found the best method to reach an understanding of the built environment in the first place.[31]

This systematic study would not have been feasible without well-structured, computer-based data-management. Hence, all architectural and archaeological data have been collected in a methodical way, using data-capture sheets for recording.[32] Subsequently, all field data have been entered into an Access database (Fig. 4.8).[33] Comprising c. 600 individual records, the database forms a coherent body of information. At the same time it is structured in such a way that every individual record can stand alone; this ensures that additional entries can be included at a later point without compromising the coherence of the system. While the data-base allows for data processing and queries, it reaches it full potential only once the archaeological data are linked to geo-referenced digital maps.

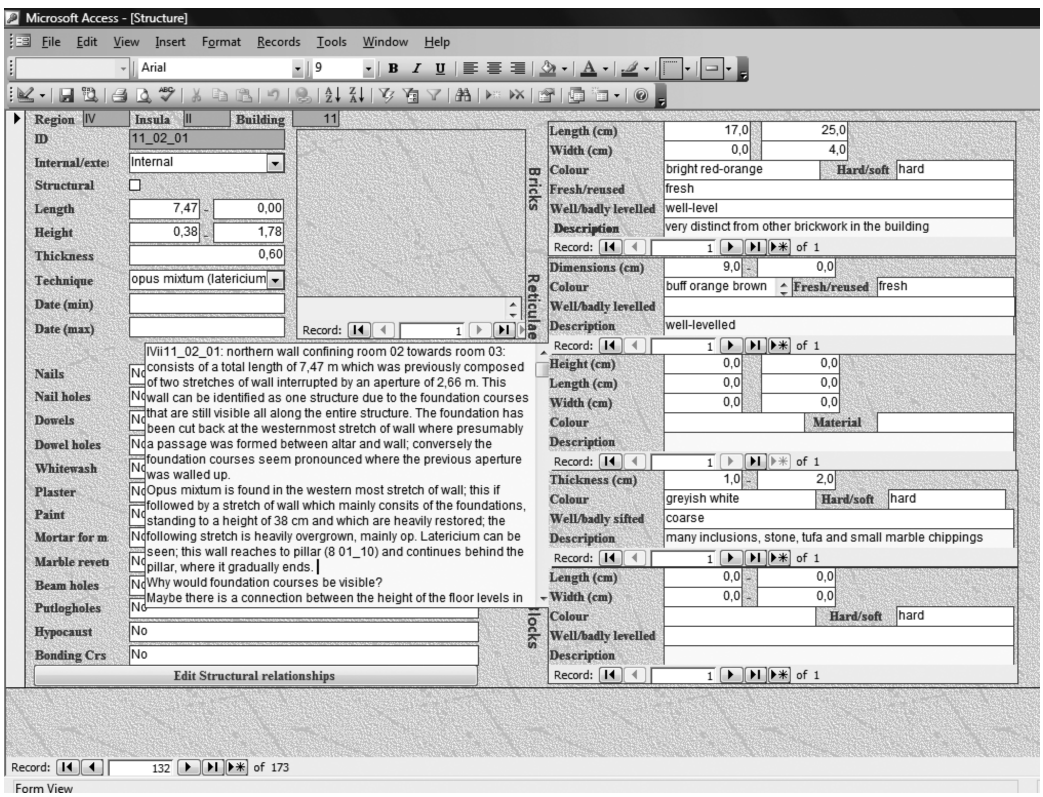
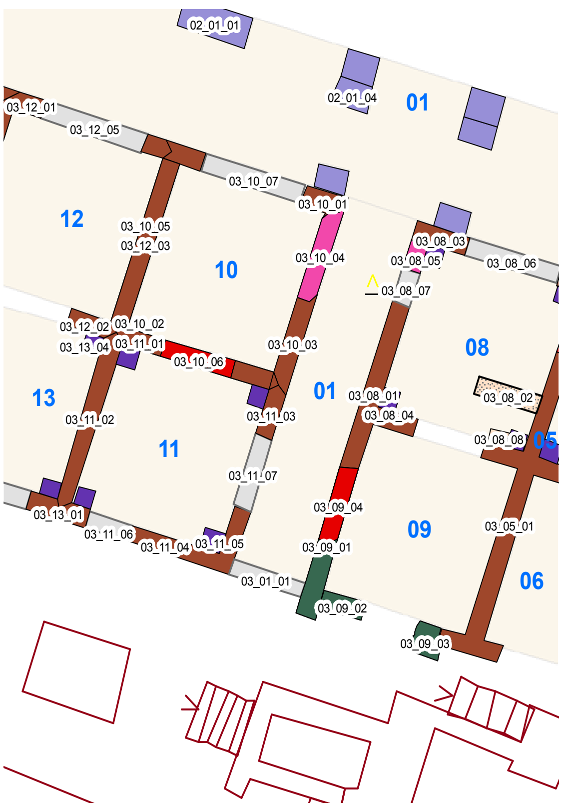


Fig. 4.8 – Access Data-base structure

31. See DeLaine (2008a: 322) for a critical evaluation of different ways of collecting archaeological data. DeLaine reminds us that the resultant record, measured drawing or digital recording, remains essentially an approximation within technically defined limits, not just an objective record.

32. The data capture sheets have been fashioned on P. Rose's Ostia survey, used for a similar structural assessment of Ostia's Regio III and V (Rose 2005).

33. 'Civis' the Access database used by this study has been built with the help of E. Dullaart, IT, Faculty of Archaeology, University of Leiden.



Caseggiato dell' Ercole

DATABASES

ArcGIS shapefile | Civic Access Database

ID	Material	Function	ID*	Technique	Date_min	Date_max
03_08_03		wall	03_08_03	mosaic	200	225
03_08_04		pillar	03_08_04	opus lateric	200	225
03_08_05		wall	03_08_05	opus lateric	175	225
03_08_06	travertine	threshold	03_08_06	travertine	<Null>	<Null>
03_08_07	travertine	threshold	03_08_07	Travertine	150	175
03_08_08		shelf	03_08_08	marble	200	225
03_09_01		wall	03_09_01	opus lateric	175	200
03_09_02		wall	03_09_02	opus lateric	175	200
03_09_03		wall	03_09_03	opus lateric	175	200
03_09_04		door	<Null>	<Null>	<Null>	<Null>
03_10_01		wall	03_10_01	opus lateric	150	175
03_10_02		wall	03_10_02	opus lateric	150	175
03_10_03		wall	03_10_03	opus lateric	150	175
03_10_04		wall	03_10_04	opus lateric	175	200
03_10_05		wall	03_10_05	opus lateric	150	175
03_10_06		door	03_10_06	opus lateric	200	225
03_10_07	travertine	threshold	03_10_07	travertine	150	175
03_11_01		wall	03_11_01	opus lateric	150	175
03_11_02		wall	03_11_02	opus lateric	150	175
03_11_03		wall	03_11_03	opus lateric	150	175
03_11_04		wall	03_11_04	opus lateric	150	175
03_11_05		pillar	03_11_05	<Null>	200	225
03_11_06	travertine	threshold	03_11_06	travertine	150	175
03_11_07	travertine	threshold	03_11_07	travertine	150	175
03_12_01		wall	03_12_01	opus lateric	150	175
03_12_02		wall	03_12_02	opus lateric	150	175
03_12_03		wall	03_12_03	opus lateric	150	175
03_12_04		wall	03_12_04	opus lateric	150	175
03_12_05	travertine	threshold	03_12_05	travertine	150	175
03_13_01		wall	03_13_01	opus lateric	150	175
03_13_02		wall	03_13_02	opus lateric	150	175
03_13_04		pillar	03_13_04	opus lateric	200	225
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03_14_01		wall	03_14_01	opus lateric	150	175
03_14_02		wall	03_14_02	opus lateric	150	175
03_14_03		wall	03_14_03	opus lateric	150	175

Fig. 4.9 – Linking database codes and plan location (ArcGIS)

4.4 LINKING MAPS TO DATABASE

The particular GIS programme used within this study is ArcGIS; it allows one to link digitized maps to a database. The ArcGIS programme does not simply provide for more efficient representation and organisation of the data, it also allows for queries to be performed on the data. ArcGIS permits importing raster data (e.g. scans of plans). For this study the re-mapped plans were imported into ArcGIS and then aligned to their spatially correct position, established with the help of the DGPS control points of our survey. Next, the various elements of the re-mapped plans were digitised into geometrical elements, in our case polygons in a GIS shape-file. Each individual polygon reflects a specific item on the map and is encoded in accordance to the key (id-number) in the 'Civic' Access database referred to above. Hence the ArcGIS database and the Access Data base can be linked together (Fig. 4.9). This system can be expanded to include excavation and restoration data or any site relevant information. In this way it can offer a perfect tool for heritage management. While this is an important consideration, it is not the concern of this study. Instead, this study is interested in the spatial organisation of Ostia's built environment. Hence we now need to turn our focus towards Space Syntax and, since this chapter is concerned with methodology, the selected analysis tools employed within this study will be discussed in the following section.

4.5 APPLIED SPACE SYNTAX

Having discussed the theoretical framework of Space Syntax in Chapter Three, this section introduces the specific Space Syntax tools which have been applied to Ostia's built and non-built spaces by this study. Insula IV ii is one of the data-sets chosen for closer spatial assessment; in addition, a group of individual houses, identified as guild buildings, as well as the street network have been selected for closer spatial examination. As explained in the introduction to this chapter, these particular categories of urban space represent the city at different scales, from individual buildings to the entire street system. While these selected areas are unique and distinguishable spatial entities, they are also members of the city's whole spatial organisation. It is precisely their dual nature, having both local and global spatial properties, which is at the heart of Space Syntax analysis.

From a larger variety of Space Syntax techniques a number of tools have been selected. Their strength and ability to reveal Ostia's underlying spatial signature depend on several factors such as the quality of the data sets, as well as the suitability of the tools chosen. This section will explain the analytical procedures and will explicate how the spatial values are being calculated. However, since theory and techniques are inseparably interwoven, these explanations cannot stand alone without the larger theoretical framework which has been set out in Chapter Three. For the same reason we will find several 'excursions' reverting back to Space Syntax's theory in those chapters which are dealing with the actual spatial analysis of Ostia's built environment, i.e. Chapters Six, Seven and Eight. This was found necessary since theory and method are constantly reinforcing each other, and, although the theoretical framework and the tools have been explained in separate chapters, nevertheless at times the analyses or their subsequent interpretation need to be fully embedded within Space Syntax's theoretical or methodological considerations to reach their explanatory potential.

4.5.1 Space Syntax tools for spatial analysis

The core tools of Space Syntax include access/convex, axial, segment, and isovist analysis, with Depthmap software (UCL) strengthening the analytical toolbox through Visual Graph Analysis (VGA). The latter enriches the results of the Space Syntax analysis through visual analysis. The types of analysis employed by this study will be explained in the following sections. The analyses and calculations have been made with the help of Depthmap software (UCL),[34] and Jass (KHT Stockholm) for Access Analysis.

Convex or Access Analysis

Access Analysis represents the most commonly used type of Space Syntax analysis.[35] It is most suitable for the syntactical analysis of buildings to identify how spaces within a structure are arranged and related to each other. From a building's spatial organisation inferences can be made about its potential to mediate the relationship between its occupants and visitors, but also the movements of permanent occupants. The analytical procedure requires a two step process: first, the building's floor plan is translated into a graph. The second step involves the calculation of spatial values inherent in the graph structure.[36]

The access graph begins with the subdivision of the floor plan into convex spaces (rooms and open spaces). Next, all convex rooms are marked by a node (circle), with access between rooms represented as lines linking them together. The resulting graph is a purely topological representation of the building, bearing no reference to the building's dimensions or type of decoration. The access graph is often justified with respect to the outside space; alternatively any room within the building can be selected to form the root of the graph. When selecting the outside space as the graph's root, all spaces which are directly

34. The Depthmap software is available free of charge for research purposes from the UCL which grants an annual license.
35. In earlier literature it is also referred to as gamma-analysis; see Hillier and Hanson (1984: 143).
36. See DeLaine for a succinct explanation of Access Analysis (2004: 158).

linked to the outside space are placed at one level above the root. This process is continued until all spaces within the configuration are placed on the levels of depth calculated in step-depths from the outside space. While the graph in itself is a powerful visual tool for a first-hand qualitative appreciation of a spatial structure, a number of spatial values can be calculated on the basis of the graph structure. In the following section only those spatial values will be explained which are relevant for the types of analyses used by this study: control values (CV) and integration (RRA).

Control values (CV) measure the degree of control a space brings to bears over its immediate neighbours and hence refers to local spatial properties. The more neighbouring rooms a room has, the more control it will exert. The calculation is as following:[37] each space in the building is assigned a score of 1. The score of 1 is then divided by the number of the neighbouring spaces (1/n) to which it is connected. For example if a room is surrounded by five neighbouring rooms, each will be given a score of 0.2 (1/5). The scores received by each space from its surrounding spaces are totalled. If a space ends up with a CV in excess of 1, it can be considered a controlling space; if control values move towards 0, it will be a controlled space. The higher the CV, the more controlling the space is. Control values are effective measures to identify locations of high local movement mediation within a building.

Integration/Real Relative Asymmetry (RRA) is a ratio calculated for each space to all other spaces measuring accessibility within a building, hence it is a global measure.[38] Accessibility is defined by the number of boundaries that have to be crossed on average, to reach a space from any starting point in the system. If few boundaries need to be crossed a space will be accessible, if many boundaries need to be crossed, it will be more inaccessible. The measure that Hillier and Hansen have developed to quantify accessibility depends on the principles of symmetry and asymmetry, hence the index devised by Hillier and Hanson is Relative Asymmetry (RA). RA is computed by calculating the average depth of each node from all other nodes in the graph.

The calculation involves several steps: first, the graph's mean depth (MD) needs to be calculated (see Fig. 4.10). This is the total depth of all spaces divided by all the spaces present minus one:
MD= Σdk / k-1, where Σdk is the sum of the depth values d for each of the k spaces.
Once the mean depth of a space has been calculated, its Relative Asymmetry may be calculated using the following formula: **RA= 2(MD-1) / k – 2.**

One difficulty with RA values is that if the configuration becomes larger, RA becomes disproportionably smaller. This is quite understandable from the formula, as the number of spaces (k) increases, so the denominator becomes larger and this has a disproportional effect on the resulting RA values. Hillier and Hanson recognise the problem and offer a method for adjusting RA values by introducing the diamond-shaped justified graph.[39] The latter is characterised by an almost 'normal' distribution of nodes across its levels forming a diamond shape, and so has been found to represent a more realistic benchmark for comparing spatial settings of different sizes. To facilitate the calculation, Hillier and Hanson supply a table with standardised D-values for diamond shaped complexes with between 5 and 300 spaces.[40] To standardise RA values one simply needs to look up the D-value for buildings of the same number of spaces and divide the RA by the relevant D-value. The standardized RA is then called RRA, which refers to Real Relative Asymmetry. RRA values range from zero to infinity. The higher the RRA value, the more inaccessible a space will be. The mean of all RRA values is the MRRA value. Current Space Syntax studies typically report integration values, which are the inverse of RRA values (1/RRA). Higher integration values of nodes, therefore, indicate that the node is less deep on the average from all other nodes, or that it is more integrated into the spatial system.[41]

37. Hillier and Hanson (1984: 109), see also Grahame for a detailed explanation (2000: 33-34).
38. Hillier and Hanson (1984: 108-109), Bafna (2003: 25); see Grahame for more detailes (2000: 34-35).
39. See Grahame (2000: 35) and Bafna (2003: 25).
40. Hillier and Hanson (1984: 112, table 3).
41. Bafna (2003: 25).

Calculating axial integration
Mean depth for each axis [MD]:
MD = sum depth/k-1
k = number of axes in a system
sum depth = the topological depth from each axis to all other axes
Dk= diamond value

Calculating the back street axis:
[MD] = sum depth/k - 1 = 50/16 - 1 = 3,33333

Real asymmetry [RA] = 2 [MD-1]k-2 = 2(3,33333-1)/16 - 2 = 0,33333

Real relative asymmetry [RRA] =
RA/DK = 0,33333/0,086 = 3,875968

Integration value of the street 1:
1/RRA = 1/3,8759689922=0,258

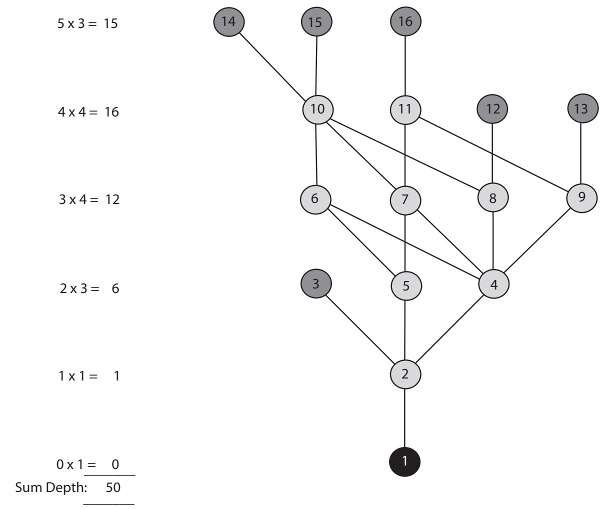

Fig. 4.10 – Steps involved in the calculation for axial integration (after Van Nes' unpublished handbook)

A correlation between Control Values and RRA/ integration offers more nuanced insights into the syntactical structure of a building. Using CV and RRA in tandem allows us to assess which spaces were more likely to have been the spaces for interaction, and which ones most likely offered privacy. This requires that the numerical values are being converted into qualitative indications of local and global interaction potential.[42] The combination of local and global indicators for a particular space gives a reading of its 'presence-availability' in relation to those who used the spaces, inhabitants and visitors. [43]

The Difference Factor offers a further level of analysis, gauging a building's interior-exterior relationship.[44] It is an entropy-based spatial index which quantifies the spread or degree of differentiation among a building's integration values.[45] It can be applied to the whole structure in terms of its interior/exterior relationship, but can be also be used to assess the building's key functional spaces. The calculation is based on each building's RRA measures, using the highest, the lowest and the mean RRA measures. Difference factors closer to 0 indicate differentiated and structured spaces, while values closer to 1 indicate homogenised spaces. The Difference factor is calculated as follows:

H = [a/t In (a/t)] + [b/t In (b/t)] +
[c/t In c/t)]
H* = H – In2 / In3-In2

Axial Line and Segment Analysis

Next to Access Analysis which has been extensively used in this study to investigate the buildings of Insula IV ii and the guild seats, axis analysis has been applied to the city's linear spaces, the principle movement spaces, e.g. the street network and public squares. Axis analysis is best suited to detect potential movement patterns within a system. It is based on the longest straight line that passes through a convex space; this process is repeated until all convex spaces within a spatial setting are crossed by lines, linking all adjacent spaces to each other through intersecting lines. The resulting network of intersecting straight lines represents the axial map. The axial map can be examined for a number of spatial properties, most importantly global and local integration. These measures refer to how each street is interrelated to all

42. The numerical values for local and global interaction potentials are converted into qualitative indications of interaction potential, defining them as low, moderate or high.
43. DeLaine (2004: 158).
44. The difference factor has been included into the spatial assessment of Ostia's guild buildings; see Stoger 2009.
45. Hanson (1998, 30-32); see Hanson (1998: 31) for the formula and calculation.

other streets within the system (global integration), conversely, they indicate how a street is related to its immediate neighbouring streets (local integration). Within Space Syntax the degree of integration does not depend on metrical but on topological distance. This means that the ease of access for a certain street is calculated by the number of directional changes one has to make to arrive at destination. Integration is equivalent to Real Relative Asymmetry (RRA) and hence is calculated in the same way (see above). In terms of visualisation there are several ways to reproduce an axial line graph. The most user-friendly version is the axial graph produced by Depthmap which represents a street network as a colour coded hierarchy, whereby the degree of integration is visually expressed along a spectrum from red to blue, with the most integrated streets in red, and the most segregated streets in blue.[46]

Segment Analysis

This type of analysis adds another analytical perspective, focussed on the line structure of the street network.[47] The units of analysis are the street segments and the distance relation between them is the amount of angular changes from one segment to the other.[48] Segment analysis identifies the paths with the least angular changes, and hence corresponds closely to observed actual movement patterns.[49] The analysis employs two spatial values: integration and choice. These values respond to the principle components of human movement: selecting a destination (integration) and selecting a route (choice). Within this study segment analysis has been applied to Ostia's extended street network. The procedure and the results of the analyses are discussed in Chapter Seven.

The most significant findings about street networks which came out of Space Syntax research have been formulated into theories about the city. The relevant ones for this study are 'Cities as Movement Economies' and 'Centrality as a Process'.[50] These concepts will be discussed in connection with Ostia's street network and the related distribution of land-uses, as well as the vitality of an urban neighbourhood (Insula IV ii).

4.5.2 Space Syntax tools for the analysis of spatial perception

Isovists and Visibility Graph Analysis (VGA)

Isovists and VGA are techniques for the representation and analysis of bounded spatial systems, which may also be applied to landscapes. These techniques add yet another perspective to the available Space Syntax tool kit by offering a way of addressing the relationship between the viewers and their immediate spatial environment. An Isovist, or viewshed,[51] refers to the area in a spatial environment directly visible from a location within the space. This makes Isovists an intuitively attractive way of thinking about a spatial environment; Isovists provide a description of the space ´from inside, from the point of view of individuals, as they perceive it, interact with it, and move through it.[52]

Visibility Graph Analysis (VGA) takes Isovist analysis further by integrating a set of Isovist polygons into a single visibility graph. In order to form a visibility graph a grid of many (thousands) points are taken across a space. Each node represents a point location within the open space of the configuration, and these nodes are linked according to one of two rules: the first rule creates a link in the graph between two nodes if they are mutually visible. The second rule requires that a link is only created if the Isovist polygons from each node

46. Depthmap provides all relevant spatial values in table format; these can be exported into excel tables to facilitate a comparative assessment.
47. Instructions on how to use segment analysis are available from The Bartlett School of Graduate Studies; they come in the form of a simple guide produced and circulated by B. Hillier; see Hillier (2008b).
48. A straight connection between two segments is a 0-degree connection, while a series of 0-degree connections will be a straight line.
49. Hillier and Iida (2005).

50. Hillier and Penn *et al*.(1993), Hillier (2007: 112-137).
51. The concept of isovists has a long history in both architecture and geography; the same idea, but called 'viewshed', has been developed in the field of GIS; on the development of isovists see Turner *et al*. (2001: 103).
52. Turner *et al*. (2001).

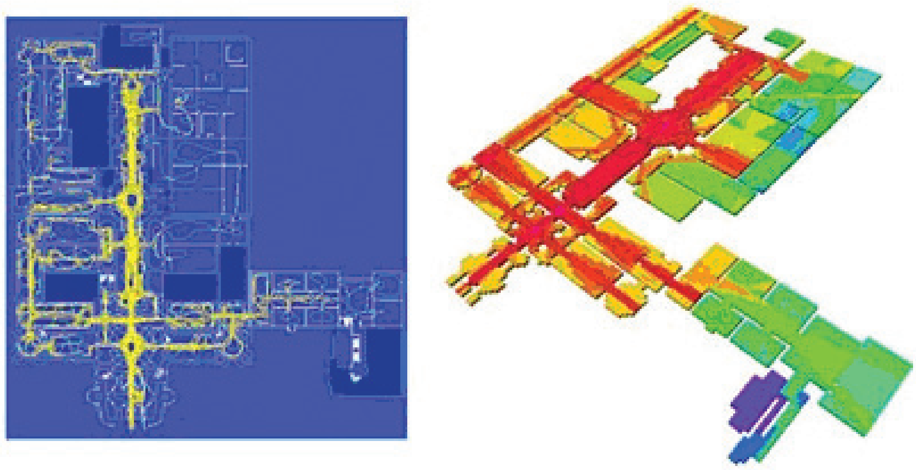

Fig. 4.11 Ten-minute movement traces (left) compared with visibility graph analysis integration of the Tate Gallery (right). Note how most movement occurs in the most visually integrated areas, identified by the analysis (source VGA website, The Bartlett School of Architecture, UCL)

location intersect.[53] Once the visibility graph has been constructed, measures of various features of the graph can be taken. Inspired by Hillier and Hanson's (1984) work, VGA has been concentrating on the integration of a point in the graph. The integration is a normalised (inverse) measure of the mean shortest path from the point to all other points in the system. The study of London´s Tate Gallery was the first application of VGA conducted by The Bartlett School. The study compared the first ten-minute movement trace of people entering the Tate with the pattern of VGA integration for the gallery space. The results were surprising: visual inspection showed that the highest integration values corresponded well with where movement occurred (Fig. 4.11).

Agent-based analysis

Finally, the last analysis which was used in this study is agent-based analysis. Space Syntax incorporated agent-based modelling into the already existing Space Syntax theory about the significance of the spatial configuration in guiding movement and interaction.[54] Space Syntax's starting point was: if configuration is important, how exactly does it affect the way people move around the world? This question was answered with an agent simulationin which the only movement strategy possible was dependent on the configuration of a space. The impetus for the method of analysis is Gibson's theory of natural vision. In natural vision, the subject is drawn through a configuration not by planned decisions, but by the available affordances of objects within it.[55] Space Syntax research has shown that it is possible to simulate human movement by encoding Gibson's principle of affordance in the context of natural movement.

53. Turner and Penn (1999: 3).

54. Turner and Penn (2002: 473-490).
55. Gibson (1979).

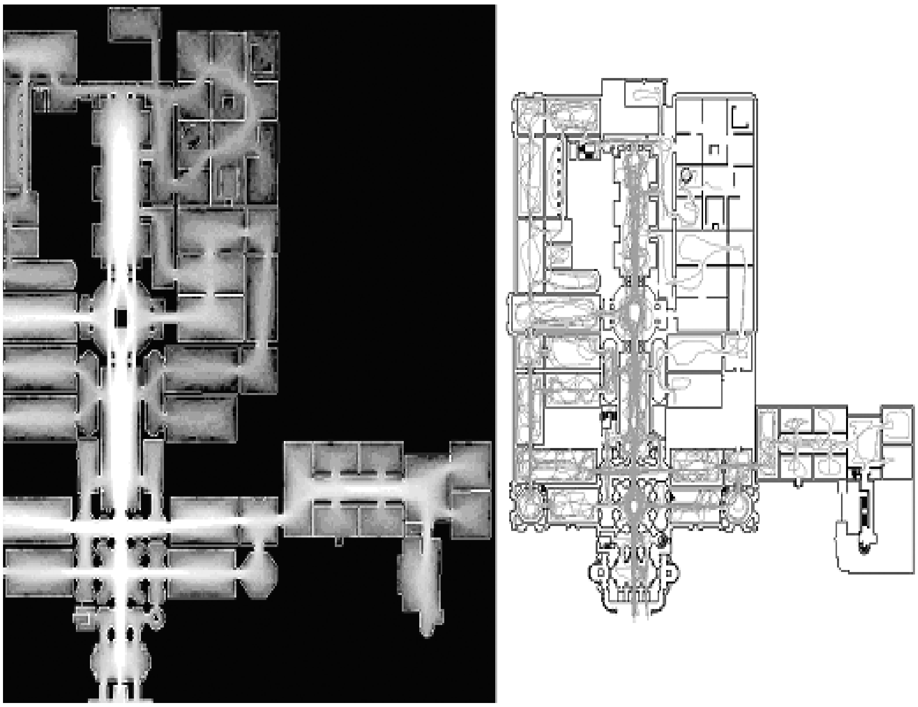

Fig. 4.12 – Tate Gallery London: positive correlation between observed movement and the trails left by computer agents walking through the Tate Gallery (black areas have low counts and light areas have high counts) (source Turner and Penn 2002: 408, fig. 6)

London's Tate Gallery served once more as a case study, and it was found that the actual level of movement observed within the Tate Gallery can be reproduced by agent-based analysis with a correlation coefficient of R2 = 0,76, if only elementary guidance rules were applied. These rules were that destinations may only be chosen from a 170 º visual field from the current heading, and that the destination is reassessed every three steps. Agent-based analysis can make interesting contributions to archaeology since it comes very close to actual patterns of observed movement, and therefore allows insights into the relationship between the built environment and spatial behaviour.

4.5 CONCLUSION

The methods and techniques discussed in this chapter range from re-mapping an archaeological site to a fully embedded spatial analysis. The complexity of Ostia's archaeological record requires a combination of methods. Despite their diversity these methods can be summarised as non-destructive or non-invasive methods of archaeological research. Such approaches have been successful in gaining new insights into sites which have been excavated some time ago. These methods are achieving more and more importance since excavations have become too demanding on both human and financial resources. There is a large potential for integrating old excavation data with standing architecture at sites with a long history of excavations. The added analytical component, employing Space Syntax methods for spatial analysis, however moves the approach followed by this study beyond the conventional recording and data processing and towards a more holistic study of past urban space.