

# Laser-scanning in Ostia and revising the general map

Yoshiki HORI

Kyushu University

## Summery

Laser scanning provides us with a new dimension in archaeology and architectural history. We introduced that technology in Ostia from 2008 to 2012 and a detailed analysis is made of all the point cloud, which records three-dimensionally its archaeological remains as below.

- 1) Revising General Map and laser-scanning as reverse engineering or diagnostic technique; firstly the new map outside the Roman Gate is a remarkable achievement by Japanese team, made even more by the first map of this area, which will serve us useful references for scholars. And, in revising the general map, there are a few errors which can be detected in the form of differences between them. Additionally, one of the most important conclusion to be drawn from the laser-scanning survey undertaken in two buildings; the House of the Painted Volts and the Termopolium, is an unique fact that this technology can provide the sections and elevations as transparent views.
- 2) Brief topographical survey and Housing against floods; less clear is the evidence for the republican surface, and the roles and purpose of the raising ground, but some basic observation on the raised surface of Decumanus Maximus and the area enclosed by the Via Epagathiana and the Via della Foce can be made from the result of laser scanning. The surface of the Decumanus Maximus was assembled in stages rather than commonly raised as a unit and flood regulations require, we can suggest, that the flood attack be avoided in evacuating onto the first floor and the safety level is represented on the top floor of the Capitorium.
- 3) Alignment of streets and buildings in Ostia; there are arbitrary relationships between the axis of buildings and alignment of the streets. Ostian builders seem to replace the rule of perpendicularity by that of linearity, and in the later 2<sup>nd</sup> century, had also an increasingly wide choice for essential elements of urban planning under the restriction imposed by having to incorporate the element of Republican buildings.

## 和文要約

2008年から2012年までオスティアにおいて実施したレーザースキャニングの成果について以下のように要約する。

- 1) オスティアにおいて一般的に利用されているジズモンディによる全体図（以下ジズモンディ図）について、まず「ローマ門」以北の彼の未描画部分のデータを得ることができた。次に、ジズモンディ図における誤りを指摘した。最後に、「絵画ヴォールトの家」および「テルモポリウム」において、上部構造の実測も行い、点群データを「透かし図」のように上階と地階、正面と内部断面を重ねてみられる図を作成した。
- 2) オスティア全体の地形データを分析することで、共和制時代の地形を復元するとともに、オスティアを定期的に襲った洪水のシミュレーションを行った。とくに、エパガシアーナ通りとフォーチェ通りに囲まれた地区は、共和制期地盤に建つヘラクレス神殿や後3世紀末の「プシケとアモーレの家」が混在しており、共和制期以降のかさ上げの実状を伝えている。また、デクマヌス・マキシムスについても、部分的なかさ上げが確認でき一体的に計画、建設されたものではないことが指摘できる。
- 3) オスティアにおける街区と道路の関係について、街路と道路が必ずしも平行、直角の関係を持たず、一方で離れた場所で平行、直交関係が確認されることから、共和制に敷かれた道路計画は後2世紀ころにはほとんど忘れ去られ、各開発計画において独自に基準線（軸線）が設定あるいは引用され段階的に都市計画が行われた様子が見て取れる。

### **Intorduction: laser scanning in Archaeology and Architectural History**

During three seasons (from 2010 to 2012), the investigation of city fabrics and mosaics has been carried out at Ostia by Japan Research Group (Leader: Koji TOYOTA, Professor in Sophia University) that provided important new evidence for its city fabrics, topographical features, and urban development in the final. Prof. Akira SAKAGUCHI had been succeeded as the leader of Japanese research in 2010 by Prof. K. TOYOTA, who continued the work as below.

From 2008, one of our main purposes in the work of laser-scanning the streets and buildings drawn in Calza's map, which is still general but unreliable in detail, and shown in Manucci's photos, which is incomplete below tall and wide trees covering the

structures, is providing a basic and complete map of the site. And, in Ostia, we applied a short-range laser scanner; Faro Photon 120 and Focus 3D that can launch the laser rays reaching as far as 120 m and but can turn round angle of 360 degrees. Using that machine the distance error occurred under  $\pm 2\text{mm}$  at 25m away and up to 976,000 points can be measured in one second. Our field survey with those high-resolution scanners is producing valuable new data in three dimensions, but still does not cover the whole area of Ostia until 2012. A detailed analysis of those point clouds will doubtless provide much telling information on the methods of measuring.

On the other hand, the laser scanning technology has made spectacular advance over these 5 years in accuracy, speed, mobility, and price. Especially colour mapping is a key technology for next 5 years. The rapid development of CCD (Charge Coupled Device) image sensor will make an important contribution to the colorization of point clouds. We can remember the introduction of total station in 1970s or 80s, which made a technical innovation in archaeology, and the same or more radical innovation may be coming to us. For example, the walls thickly covered with tress, which can be easily erased from the point cloud, are seen in an orthographic view of edited data. Furthermore mosaics can be set into the plans in the orthographic views of point clouds (Fig.1).

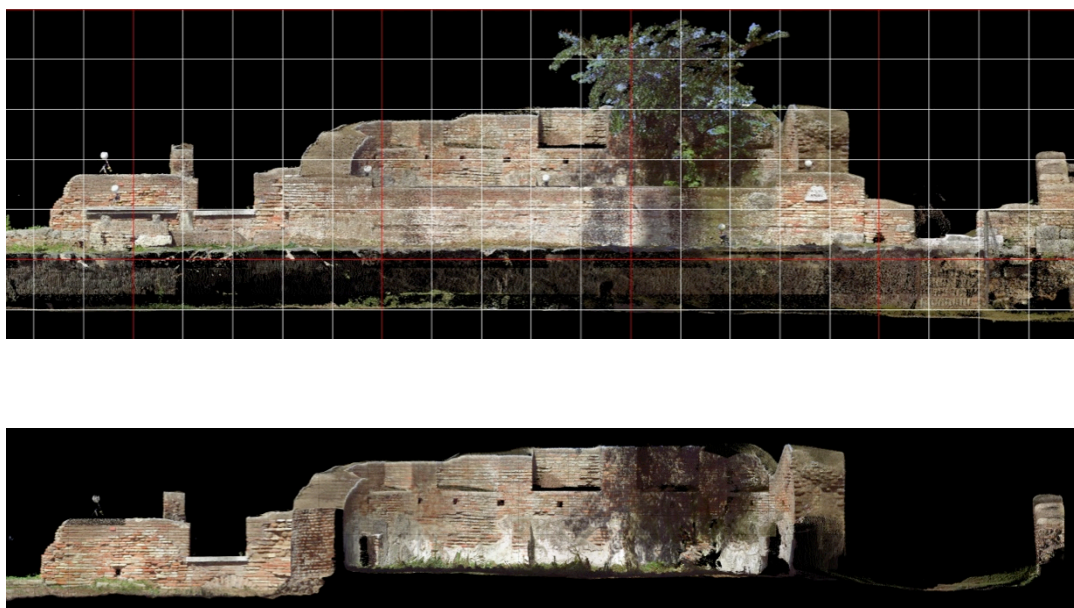


Fig.1a Elevations rendered and in the picture below a tree disrupting the view of the

wall behind has been cut.



Fig.1b Orthographic Views of the Terme dei Sette Sapinetti

Generally speaking, the laser scanner does not improved the accuracy of the measurements but can make 3D models described as point cloud, which seem to be 3D copies of the ruins in the computer. Traditionally we trace roughly from the line in straight connecting the points of measurements provided by a total station. The usual method of drawing proves even less certain than those by laser scanning, since many of measured points by a total station appear to have been indicated by observers. Machine takes an accurate measurement, but much more is involved into observer's choice than simply being located at a particular point relative to others. For example, the west of Forum of the statue of Eroica angles slightly westwards in the result of laser scanning, but on the map by Gismondi completely drawn in straight (fig.2). It is possible to trace roughly from the line of point cloud how the wall ran or the windows open not only from the ground but also from the air.

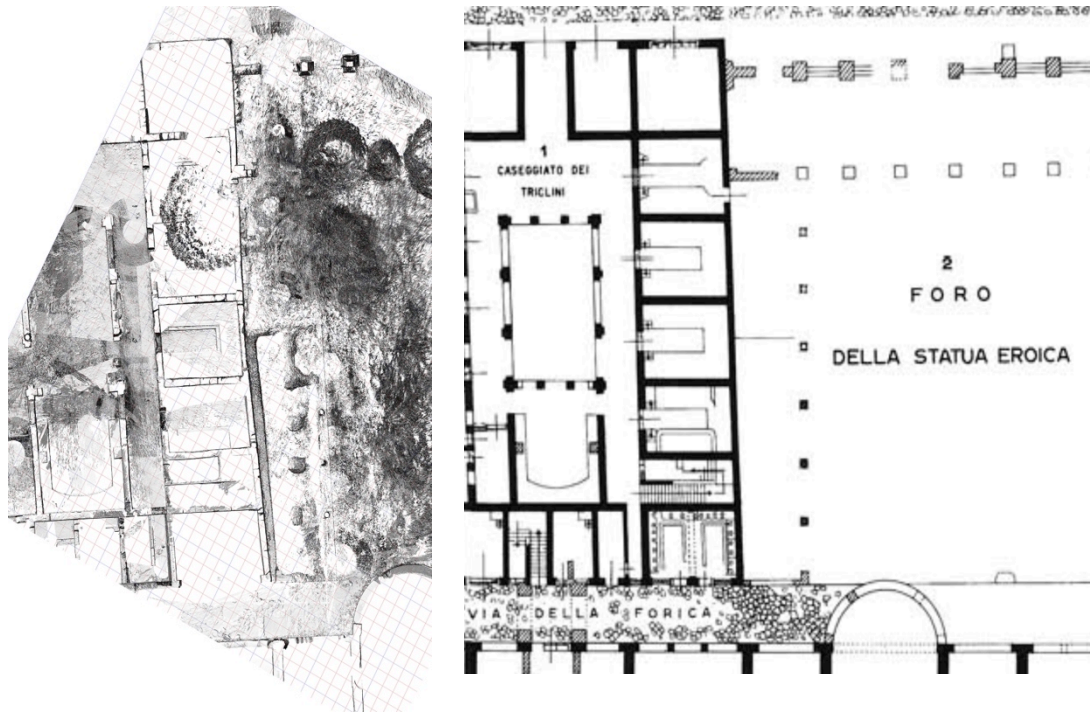


Fig.2 Point Cloud Data and Gismondi's Map of the Foro della Statua Eroica

In Japanese investigation, we provide 3D points clouds data covering the whole area of Ostia and a major part of this presentation is devoted to the summary of laser-scanning applied in past reported discoveries. And some results from the survey and some preliminary consideration on that city will be reported as below.

### 1) Revising General Map and laser-scanning as reverse engineering or diagnostic technique

During the seasons from 2008 to 2012, we used two types of laser scanners with long and medium ranges to collect point cloud data that tied each scan position into a minimum of four control points (Fig.3).

Consequently the whole structures in the visible area were separately measured into more than 6 hundreds of points clouds, of which each consists more than million dots, and then they were aligned and merged into one three-dimensional model on the general coordinates, which can provide a new general map as a by-product of our works. Since there is no adequate evidence for a reliable degree of accuracy in previous general maps created in 1940s and 50s, the laser scanning covering long distances makes a

number of salutary points: there is some evidence to corroborate the contribution to the revision of the general maps where the plans of all the buildings were assembled by a single archaeologist; where slight and unavoidable errors may have been also assembled over long distances in the lay-out of the whole city, which may thus have been different with the result coming from aerial photos and laser scanning.

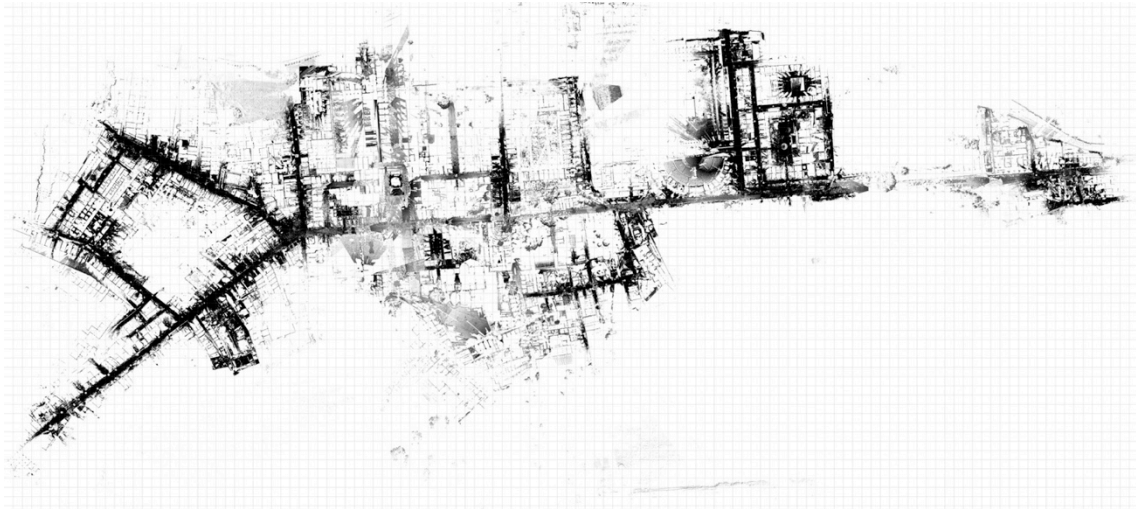


Fig.3 Scanned area from 2008 to 2010

We move to revising of the general map of Ostia. Our works carried out from 2008 in Ostia is not completed yet, and the following result is preliminary to 3D map of Ostia, which we are planning to create rather than simple revise of the two-dimensional map. The map outside the Roman Gate is a remarkable achievement by Japanese team, made even more by the first map of this area, which will serve us useful references for scholars (Fig.4). However low-resolution map has been created from point cloud data collected by a long-range scanner, we need further scanning by a middle range machine, that can obtain high-resolution pictures in the next season.



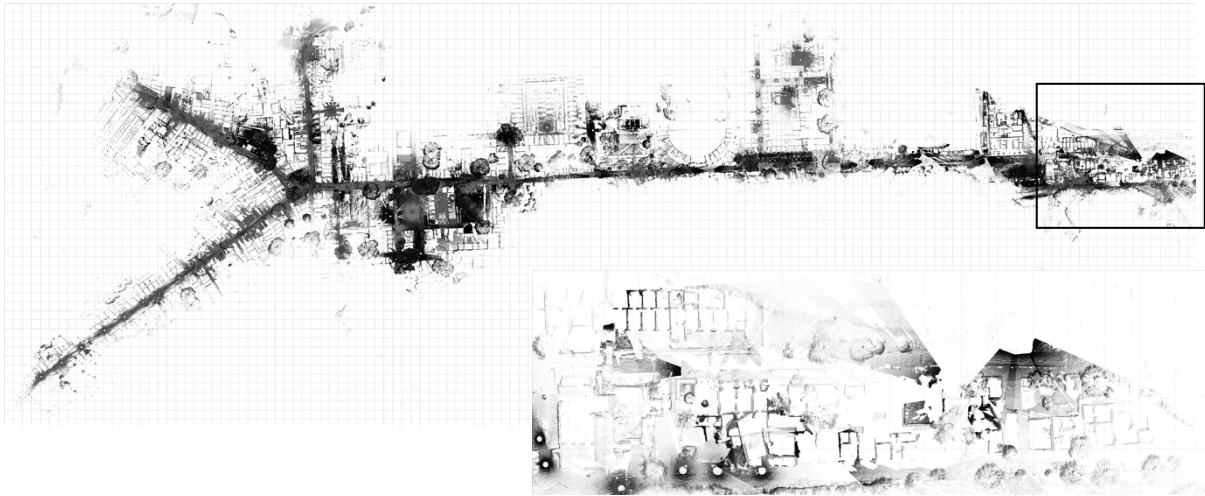


Fig.4 The map outside the Roman Gate

In the north-western part of Ostia, we create the map from the point cloud data, and attempted a comparison between that and the Gismondi's map. It is not conclusively proven that the general map by Gismondi attained the considerable accuracy, or, if it did, that it was ever the same as our point cloud data except for a few places as below; so whether we can really say that this is still general map we can justifiably call the plan of Ostia, and but, at least, it should do in an account so concerned at not being revised to improve its accuracy of his measurement by new techniques.

In fact there are a few errors which can be detected in the form of differences between Gismondi's and our scan maps as below.

Whilst, in the city block containing the Neptune Bath, the front Portico and the insula between the Via delle Corporazioni and Via della Fontana are congruent with the points clouds in accuracy of 10-15 cm (fig.5), it can, however, be calculated with a considerable degree of accuracy both from the over-all measurements and from the main building of the Neptune Bath on slightly different alignment. The interest of those walls of main building, of which floors are of the same height as the republican mosaic floor below the surface of Via dei Vigili, is that it shows that there were already substantial buildings on the site before the Palestra was extended, following exactly the same orientation as that of the insulae delle Soffito Dipinto and Ercole Banbino.

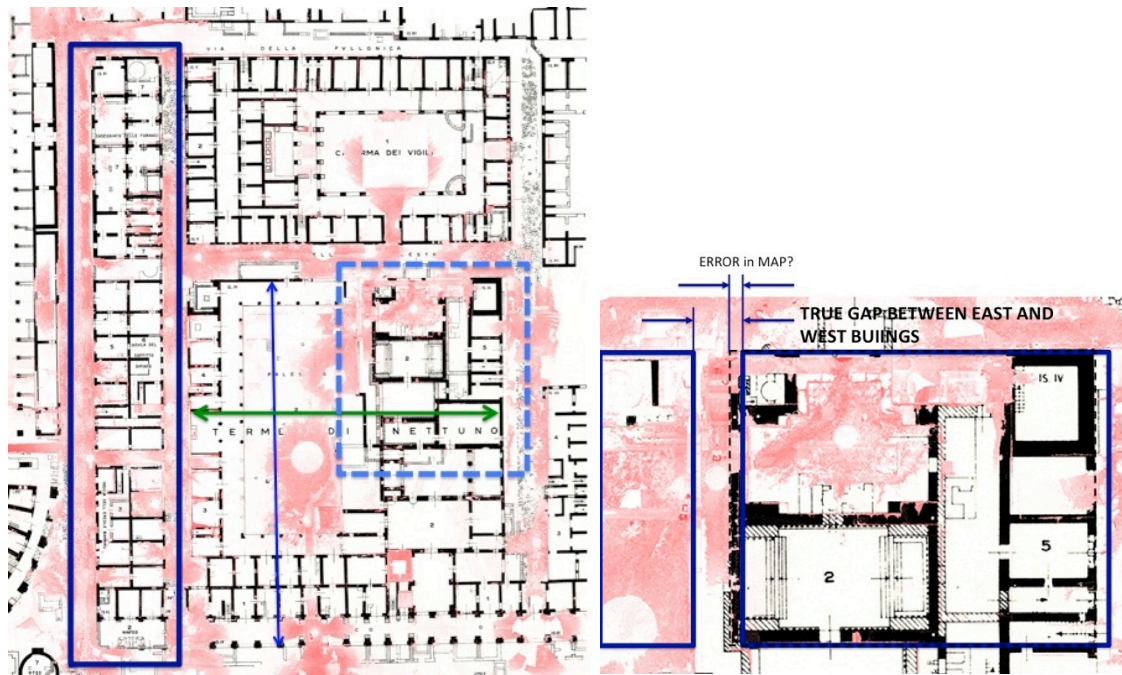


Fig.5 The map of the Terme di Nettuno (Point Cloud; red in colour and Gismondi's; black)

In the Forum Bath of Ostia including the high-rising buildings, data from laser scanning coincides very closely with the Calza-Gismondi's map and those point clouds closely overlapped on the west and east wings surrounding the Forum Bath. In 2009, we indicated the slight but sharp divergence that appears in the portico and colonade on the east side of the Forum Bath building. The length of the east-west length of the city block measured by Calza-Gismondi falls short of the figure coming from the clouds by approx. 45 cm. And the high walls surviving in the Forum Bath has been moved about 20cm to the north-west against the true location indicated by the point clouds (Fig.6). Whilst the details of the south building are completely overlapped on the result from laser scanning (Fig.7); such as non-parallel walls running east-west and different thickness between the walls. Furthermore Gismondi has recorded the added pilasters on the front portico in hatched areas, the figure of the point cloud is of interest, not so much because of its resemblance to the Gismondi's map, as because it illustrates a characteristics which these pilasters depicted by point cloud individually unpretentious but cumulatively powerful picture had in common with the hatched pilasters in his map and which found eloquent expression in that figures.





Fig. 6a The Terme del Forum

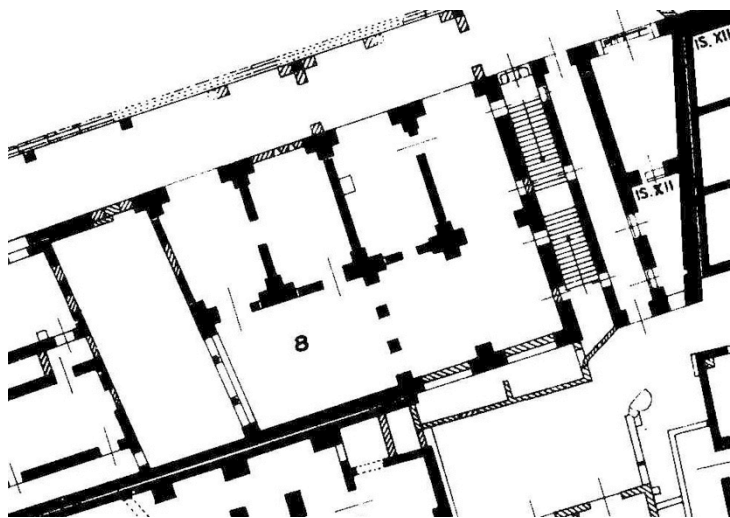
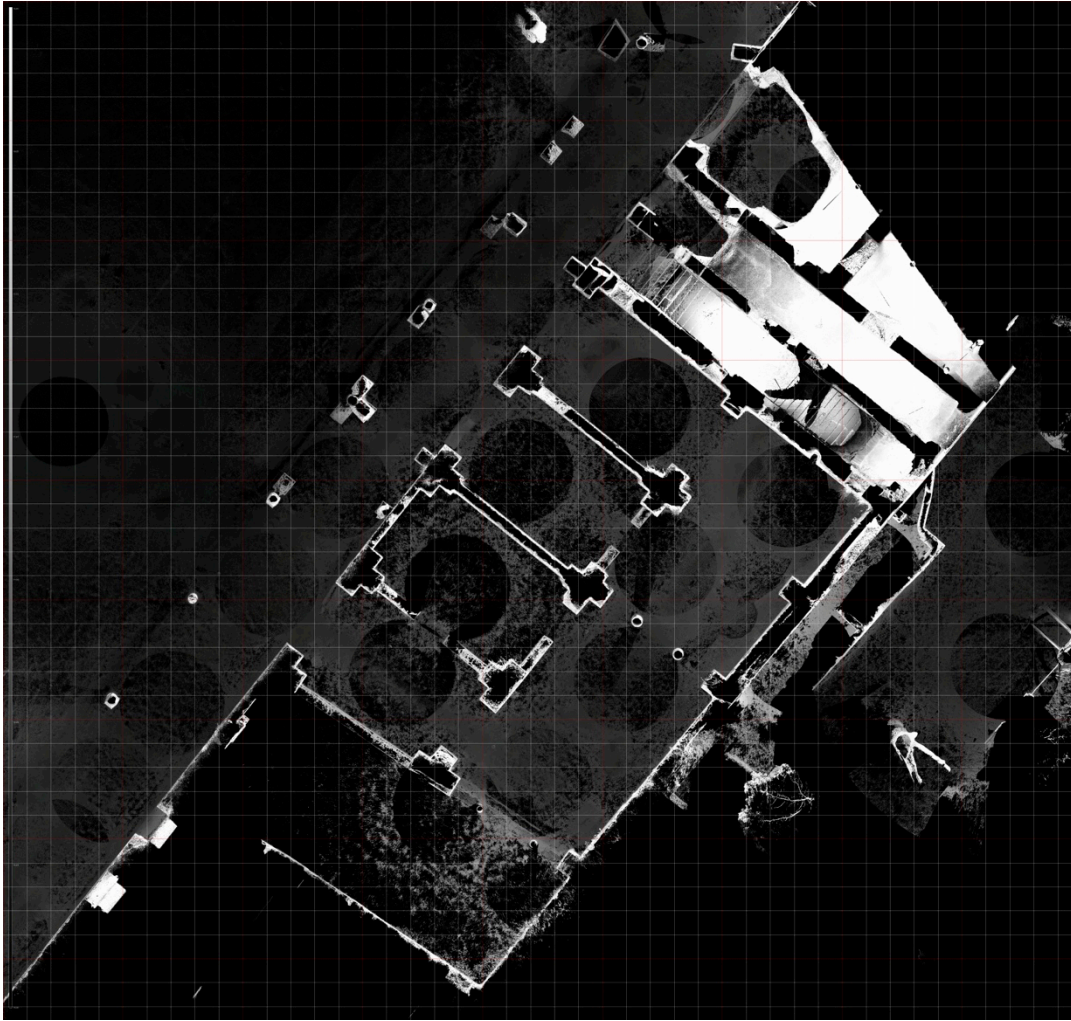


Fig.7 The Main Building of the Terme del Forum (above:Point Cloud, below: Gismondi's)

On the other hand, the Mithraeum is composed of walls either curves irregularly, with slight inward and outwards undulations, or of more or less straight stretch, which systematically linked the Mithraeum Bath to the courtyard with a niche (Fig.8). When that building has been extended, a much larger area was enclosed by those walls that did not precisely conform with the convex outline of ledges but proceeded by straight or gently bent stretches. And the gateway was made to open laterally crossing over the parallel houses so that the entrance to Mithraeum has been hidden beyond the courtyard.

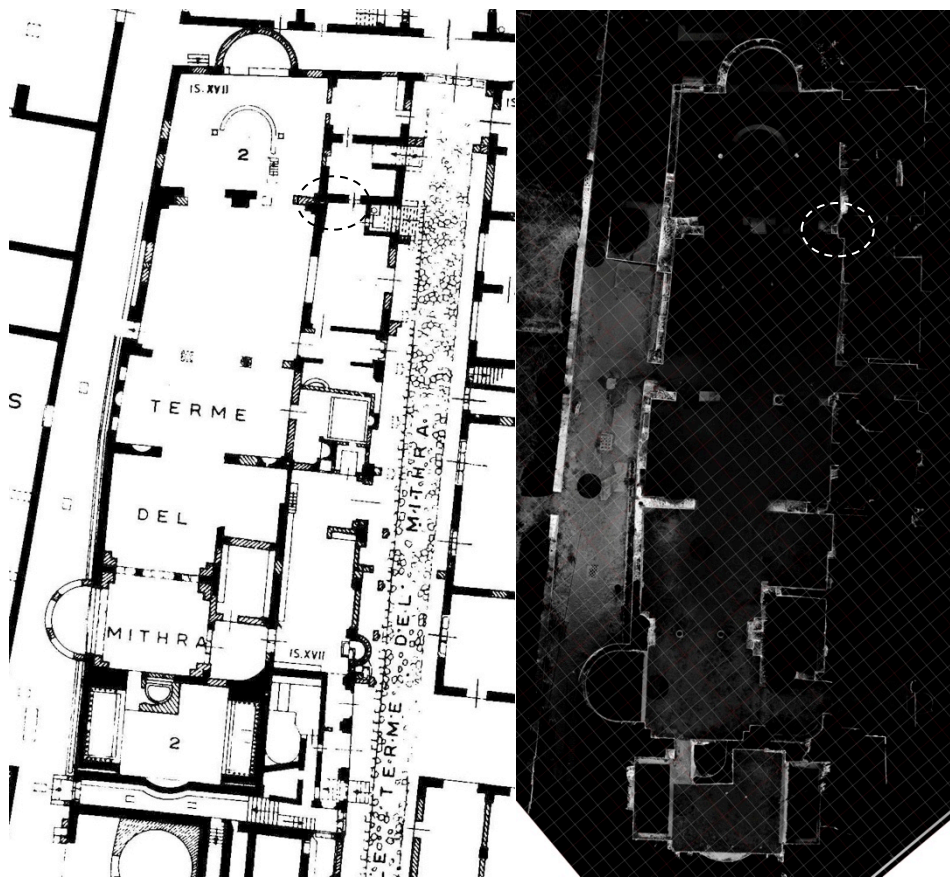


Fig. 8 Mitraeum (slight error can be detective in a circle)

We can find some errors in Gismondi's map (Fig.8 in a circle), but the most obvious are those, which mostly offer needlessly complicated structures when the simpler forms already in use would serve most purposes.

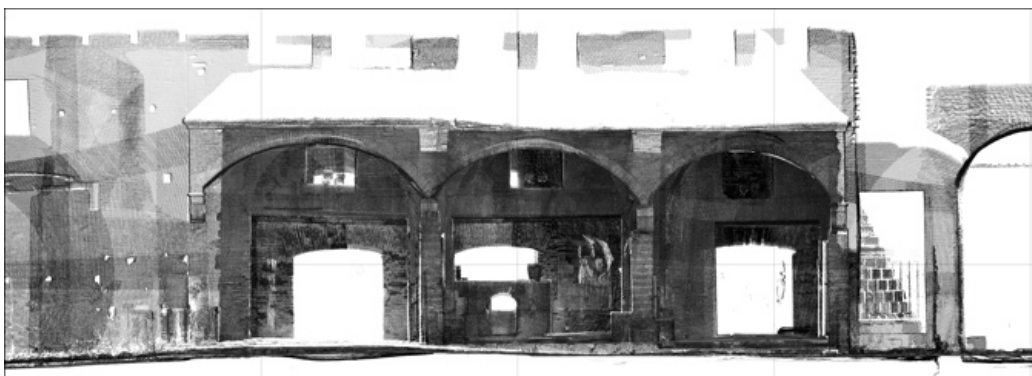
If there are errors in the map by Gismondi – and there doubtless are – they may prove to be the result of the very difficulty that could be not avoidable using un-developed



technique of measuring, namely, that the modern optical measuring technology employed to project complicated three dimensional structures into two-dimensional representations in accordance with certain mechanical hypotheses, may overlook significant details, essential adjustment, or piecemeal extension that can be caught only in intricate or carefully constructed three-dimensional models that reveal not only what took place in the construction process but how and in what sequence.

Thus, many researchers concentrate on street layout, the location of public buildings, the presence or absence of conscious planning, the degree of unity thereby imparted to the layout of that city, and the ideas (such as axiality and celestial orientation) which may or may not have determined it as discussed in section 3.

Additionally, in 2012, one of the most important conclusion to be drawn from the laser-scanning survey undertaken in two buildings; the House of the Painted Vaults and the Termopolium, is an unique fact that this technology can provide the sections and elevations as transparent views (Fig.9). This technological innovation made it possible to open up completely new possibilities of analysis for architectural structures. The building techniques used in those buildings can be shown to be derived from practices that were already current in Rome at the beginning of the second century, when the city was rapidly developed.



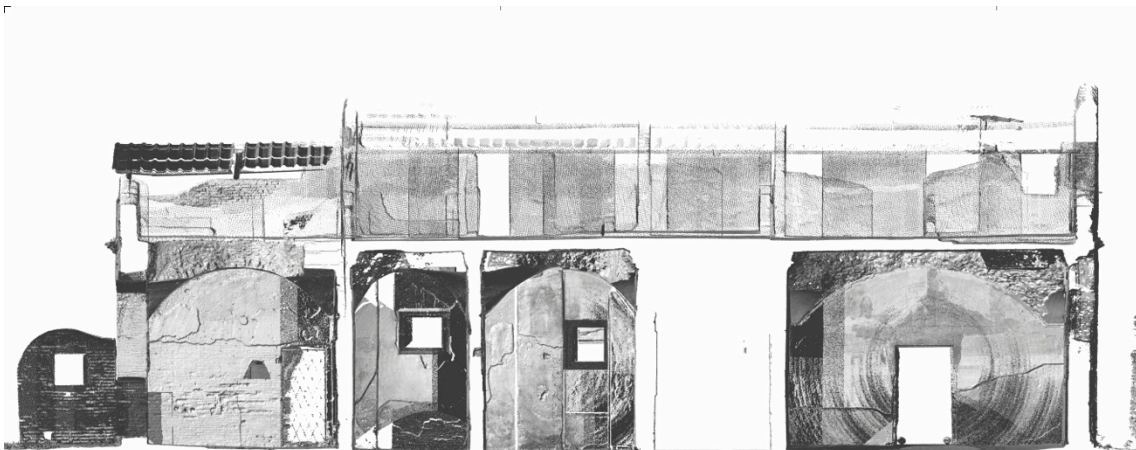
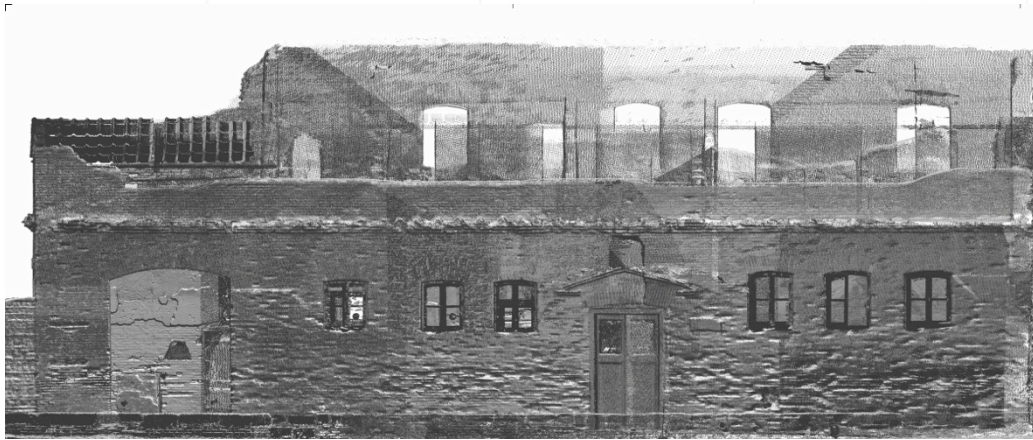
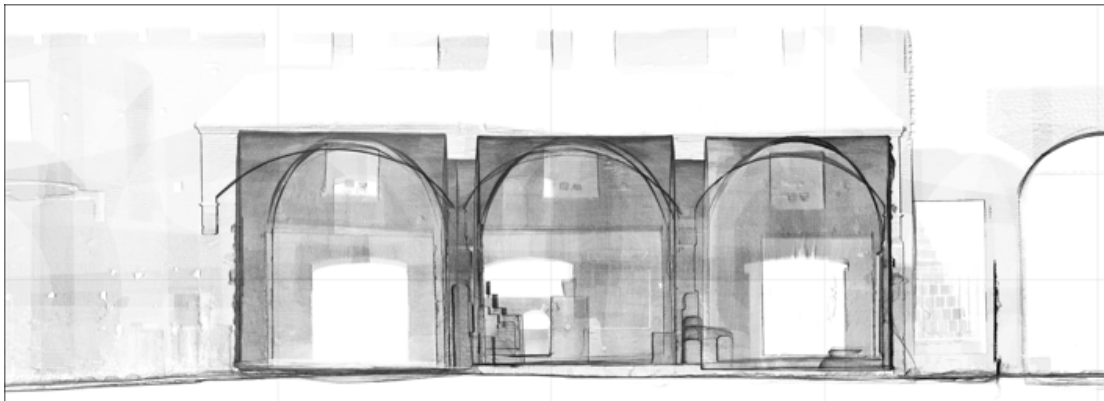


Fig.9 Elevations and Cross Sections (above: Termopolium, below: the House of Painted Vaults)

However the cross vaults of the House of the Painted Vaults in the later period (the late third century) has thin walls and vaulted ceilings, and could be observed to have no structural relationships to the above floor.



## **2) Brief topographical survey and Housing against floods**

Laser scanning along the streets reveals a fact that the Forum in the republican period, of which the surface is suggested to be 20-30 cm below the previous ground level, has been constructed on a low plateau sloping gently downward towards the east and the west. Exposed republican surfaces of the Decumanus Maximus through the previous east and west gates of the fortress do not only show the topographical feature around the Forum but we find trenches giving places sporadically to the republican surfaces along that main streets. Less clear is the evidence for the republican surface in the east area, and the roles and purpose of the raising ground, but some basic observation on the raised surface of Decumanus Maximus in the final phase can be made from the result of laser scanning (Fig.10).

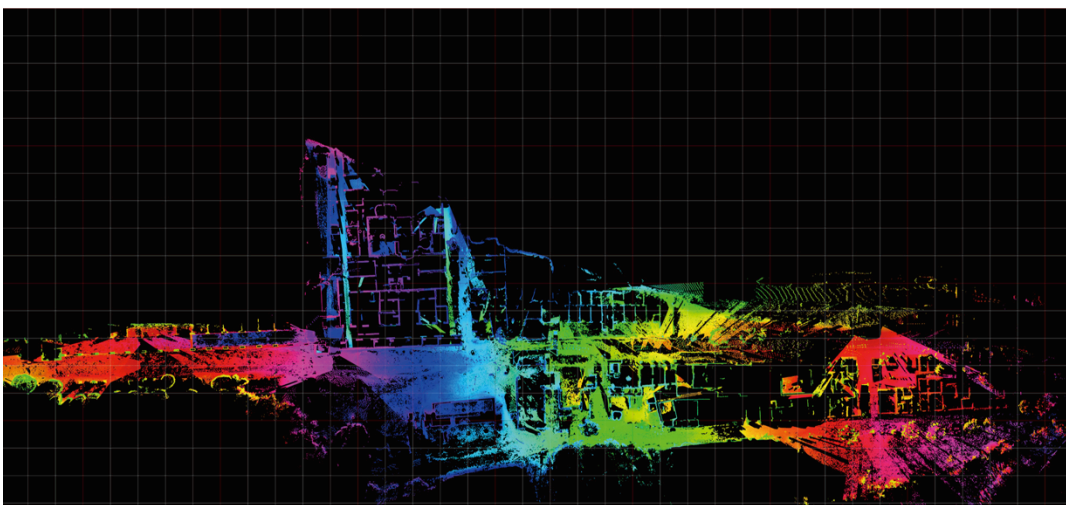
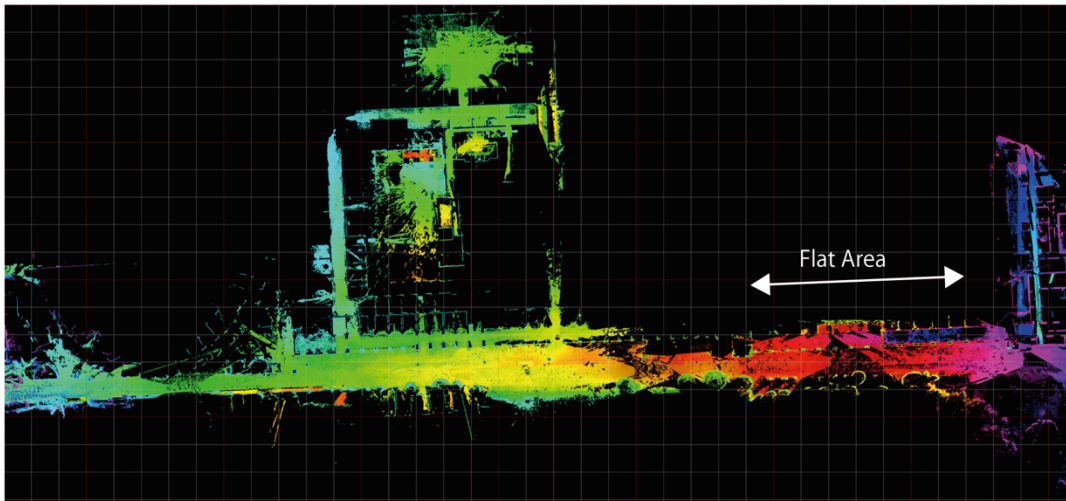
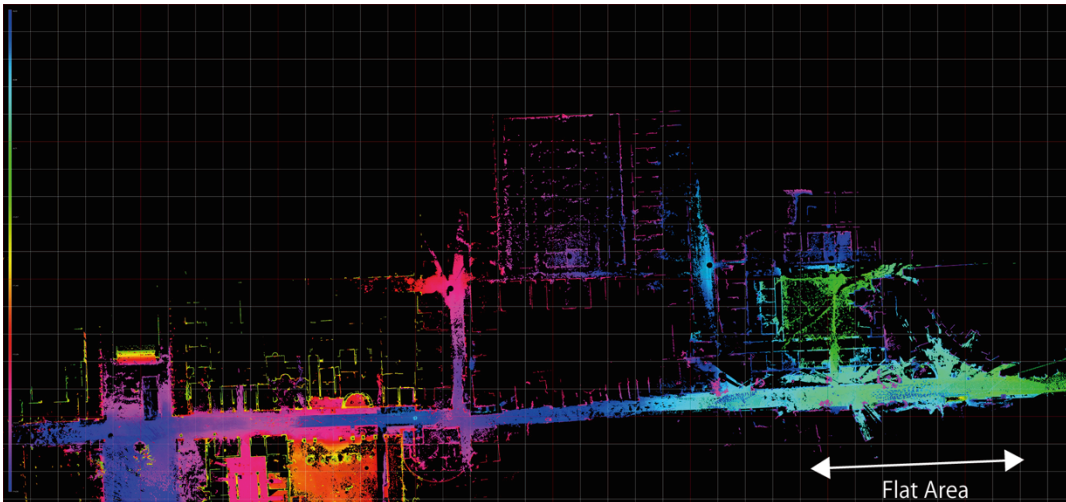


Fig.10 Eastern part of the Decumanus Maximus  
(Height of the surface is described in colour; 4m from red to red)

And in observation, the block plans inside the previous Roman fortress are totally different from eastern area beyond the Via dei Mollini intersecting the Decumanus Maximus, and the town wall inclosing that fortress had been constructed on a tongue of flat ground bordered by gentle downward slope outside the previous gate, which continues straight downwards towards the intersection with Via degli Augustali, 1.5 m (5 RF) below the intersection between the Decumanus Maximus and the Via dei Mollini. And the front area of the block of the Quattro Tempietti was constructed on the flat ground, and the front street of the Theater slopes downwards for entire length 180 m till the east end of the Portico di Nettuno, 2.6 m (8. RF) below the flat ground at the front of the Quattro Tempietti. The Portico del Tetto Spiovente occupies the flat surface; approx. 120m long, of the Decumanus Maximus and a gently sloping Decumanus Maximus downward to the Porta Romana; approx. 60 m long, appears at the east end of the Portico del Tetto Spiovente.

In Decumanus Maximus gently sloping eastwards, there are the front area of the block of the Quattro Tempietti and the Portico del Tetto Spiovente, which have those entrances from the front main street set on each flat platform, and the streets running north-south; the Via dei Grande Horrea, the Via della Fontana, and the Via degli Vigili have not been linked to the Decumanus Maximus, of which the surface was 80-90 cm below those streets. The essential feature of the whole structure of the Decumanus Maximus can, moreover, be demonstrated quite conclusively by an examination of the point cloud data, and the surface of that main street was assembled in stages rather than commonly raised as a unit.

In the report of our survey from 2008 to 2010, we recognized the existence of the houses against floods as below.

“The probability is that even the smallest colony and military fortification had some sort of access to the river, indicated by the results of investigations in 2008 and 09 along the main streets and the Forum area of Ostia and below prior to the raising of the water level of the Tiber in the winter. The land on the colony in the Republican period was dangerously low lying and may have been subject to serious flooding in the winter.”

Laser-scanning along the streets led us to the possibility that there is a variety in the front structures of houses facing the streets, which have thresholds set at high levels

and steps approaching the above floors. And the rising ground after flood could make it difficult to plan and construct the buildings as below in that report.

“The pavement on the early ground level in the Republican Sacred area still survives in front of the Temple of Hercules in the final phase, which may have been annual subject to floods. As the depressions have occurred in the Republican Sacred area and the Forum, due primarily to a major change of ground level, the floor level of the surrounding buildings has gradually raised, keeping access to the streets front. And then it is not unlikely that the preparation of the future leveling-up of the streets front, which may be shown in the thresholds of the shops approximately 70 cm above the surface of the Via dei Balconi. On the other side, it seems very probable that water level at the winter flood reached to those floors of those shops. The floor of the platform of the Capitolium, which has been reconstruct in the mid of the second century AD., may be constructed to be just above the possible highest level of the water.”

Most of the alluvial or easily moved deposits caused by annual floods, on which a relatively large number of wall stood under the development of the city, were so stable that there was no need for independent foundations; the builders merely set the wall on a broader footing, of which more courses rose above ground than were laid below. A fact that the ground level in the final phase had risen approx. 1.5 m since the republican period suggest that the new buildings constructed in the imperial period could prepare for the rising ground after floods and that the high ceiling could be installed in anticipation of rise of ground in the future.

On the other hand, in all probability, changes took place more frequently and in a more piecemeal fashion than is normally realized by archaeologists. It is, of course, difficult to be precise about this, because our method of laser scanning is only describing the surface of structures in the final phase; but we may suspect, for every major rebuilding programme, there were minor adjustments and modifications which have left some trace in architectural details.

Whilst the concrete ceiling of the Termoporium, 3.9 m (13 RF) high, which was formed of three cross-vaults supported with the aid of three quadripartite piers in the corners, are unusually low for Ostian tabernae, the corbel for floor beams in the surviving parts of the walls of the Insula dei Giove e Ganimede opposite across the Via Diana, indicate a height of 2.9 m (9.5 RF) height from the floor, which has been raised 0.75 m (2.5 RF)

above the ground (Fig.11). And then the height of those ceilings above the ground, 3.6 m is 1 RF below the level of that of the Thermoporium. Additionally the top level on the platform of the Capitolium is closely same as that of the ceiling in the Insula dei Giove e Ganimede (Fig.12).

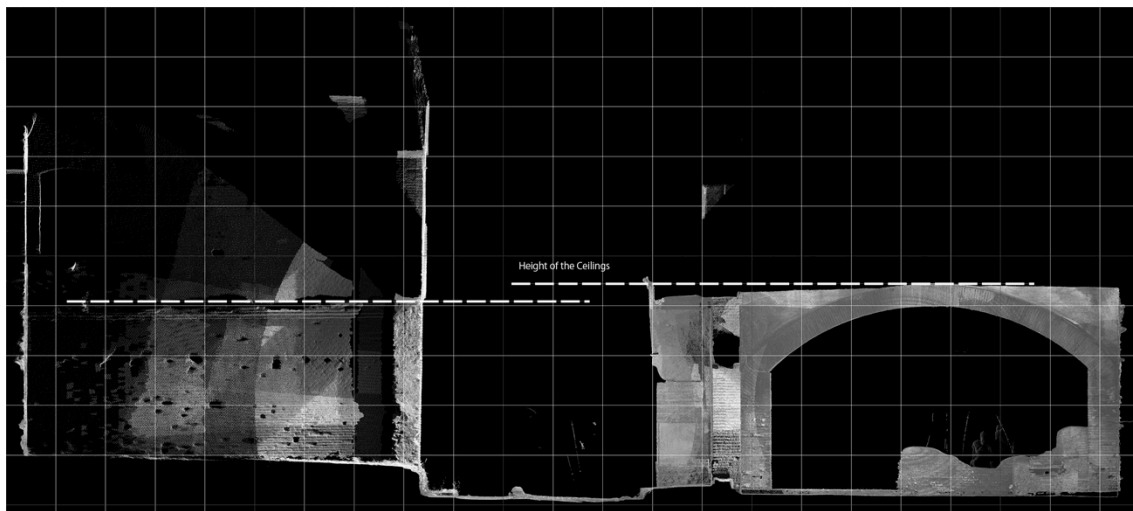


Fig.11 Cross Sections of the Thermoporium (right) and the Insula dei Giove e Ganimede (left)

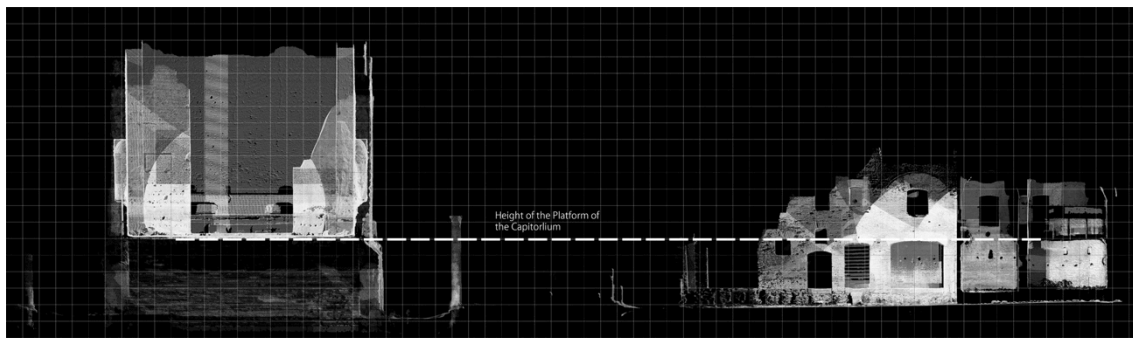


Fig.12 The Height of the Platform of the Capotolium

On the other hand, the area enclosed by the Via Epagathiana and the Via della Foce, the street and building plan clearly are tokens of a piecemeal development, within which the republican sanctuary represents the first phase and the House of Cupid and Psyche in the northern part the last (Fig.13). We can measure difference of approx. 3.0m between the ground level of the Temple of Hercules; 6.3 m below the platform of the Capitolium and the ground floor level of the House of Cupid and Psyche; 3.3 m



below the platform of the Capitolium. The difference between the ground levels of the Forum, which is 5.6 m below the top of the platform of the Capitolium, and the republican sanctuary including the Temple of Hercules is conclusively 60 cm (2 RF). The level of ground floor of the House of Cupid and Psyche, which is the same as that of the Insula dei Giove e Ganimede, has been though raised 50cm above the surface of the path accessible from the Via della Foce.

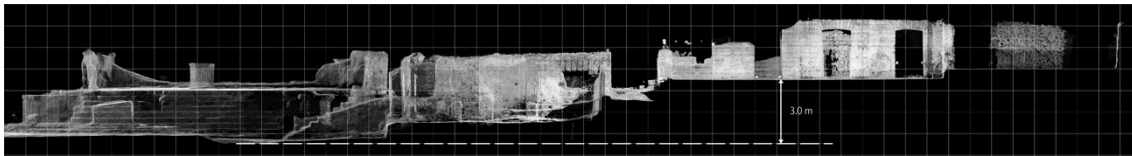
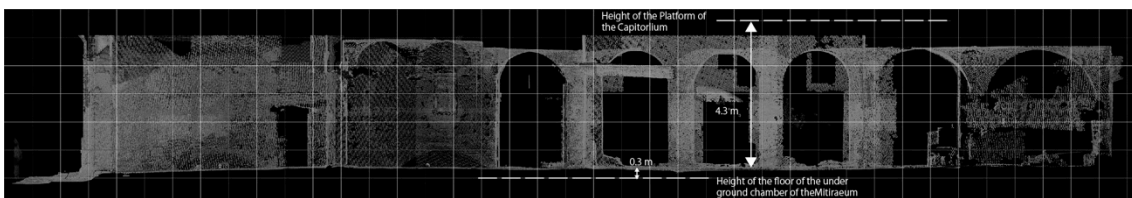


Fig.13 The difference in the ground level between the Temple of Hercules and the House of Cupid and Psyche

The lowest is the courtyard of the Horrea Epagathiana (Fig.14); 4.3 m (14 RF) below the platform of the Capitorium, which is surprisingly only 30 cm above the floor level of the underground chamber of the Mitraeum.



Finally there is a case for the possible and practical application of planning regulation in the ceiling height of the ground floors of Termopolium, Insula dei Giove e Ganimede, and Horrea Epagathiana, which has cross-volts 4.2 m high (14 RF) and 30 cm below the platform of the Capitolium. Furthermore the height of a vaulted ceiling of the east entrance to the Mitraeum is also same as that of the platform of the Capitolium (Fig.15). Flood regulations require, we can suggest, that the flood attack be avoided in evacuating onto the first floor and the safety level is represented on the top floor of the Capitorium.

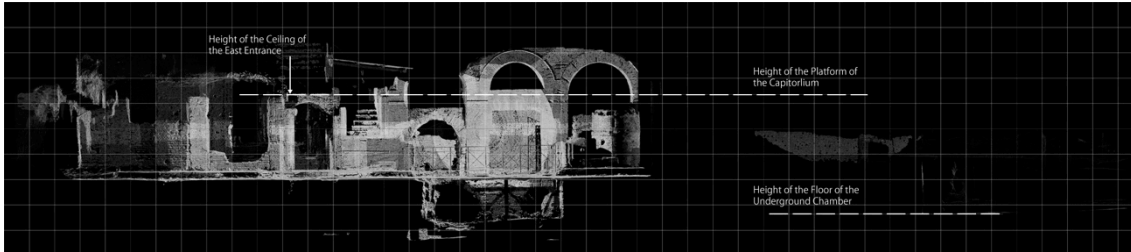


Fig.15 East entrance to the Mitraeum

### 3) Alignment of streets and buildings in Ostia

The importance of good site-preparation and good foundations for the ultimate stability of a structure was well known to the Romans, and the buildings in Ostia are no exception.

Finally we give some preliminary analysis of the alignment of Ostian streets and buildings in its western part (Fig.16).

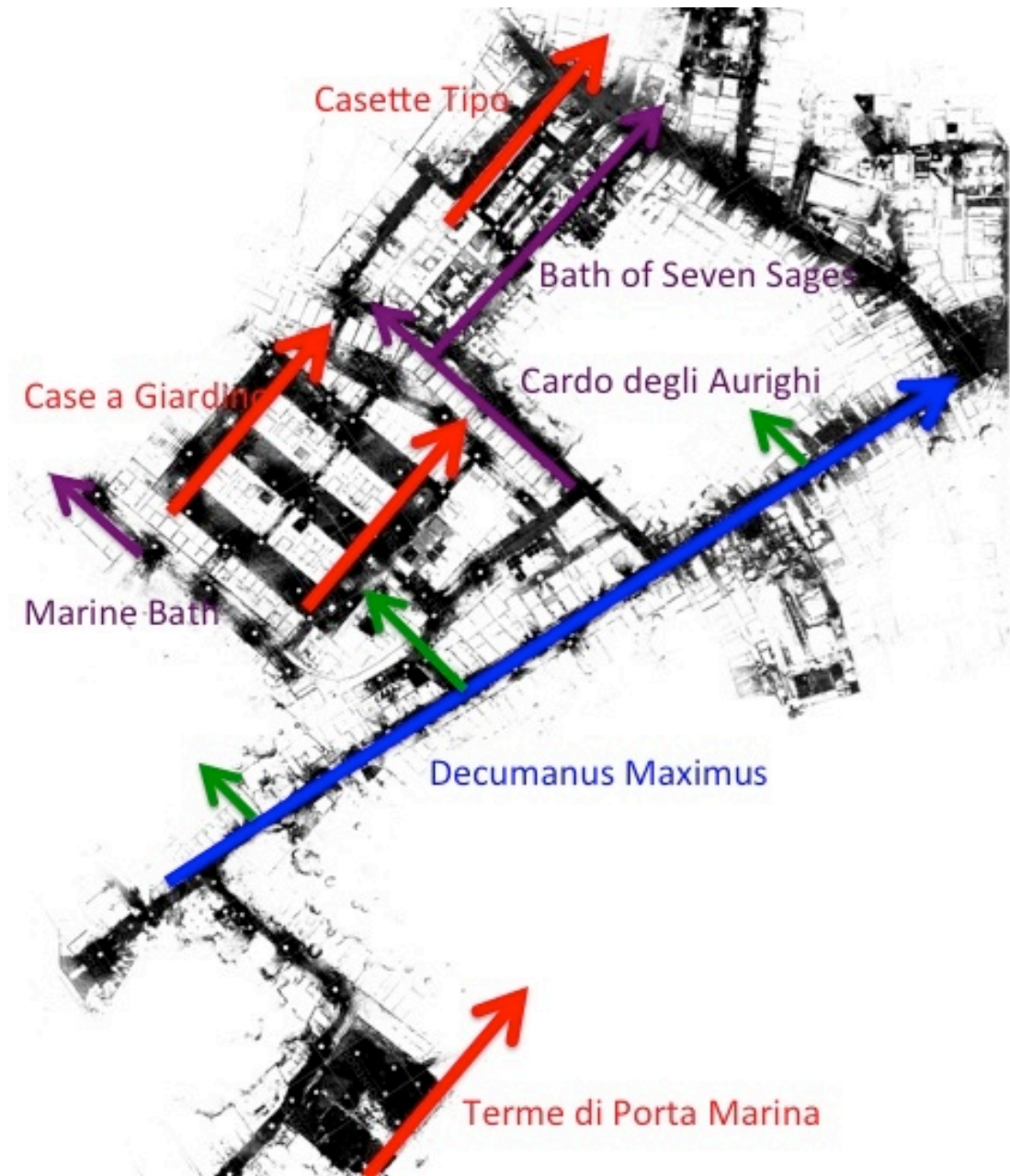


Fig.16 Alignment of streets and buildings in the western part of Ostia

The main outlines of the town plan of Ostia had already been established early in the first century B.C., when Sulla enclosed the city within the circuit of walls that still remain the effective limit of urban development throughout antiquity.

The growth of the settlement beyond the circuit walls in the 1st century AD expansion, the Hadrianic city allowing for the complete renewal of the urban fabric in the later 2nd century, the drastic changes of the 3rd and 4th centuries where decay is as common as renewal.

In the western part of that town, the rule of perpendicularity was applied in the limited areas along the streets, and in the inner most parts the axis of the buildings have been turned. Many archaeologists suggest that those alignments could come from the allotment of the land in the countryside outside of the first fortress. There are arbitrary relationships between the axis of buildings and alignment of the streets. Ostian builders seem to replace the rule of perpendicularity by that of linearity.

In Ostia four main alignments of streets can be identified.

First Decumanus Maximus is forming a straight alignment in contrast with Via della Foce gradually zigzag in plan. Some buildings and blocks facing this street partially follow this alignment.

Second, an axis deciding the plan of new Hadrianic buildings; Casette Tipo, Case a Giardino, and Terme di Porta Marina.

Third, Tabernae facing Cardo degli Aurighi makes a right angle with the axis of the Bath of Seven Sages. This alignment, which could follow the extended town wall, is parallel with the Marine Bath.

Fourth, an alignment deciding the town block Reg. III Insula II appears at insulae IV and VII.

In the later 2<sup>nd</sup> century, builders in Ostia had also an increasingly wide choice for essential elements of urban planning under the restriction imposed by having to incorporate the element of Republican buildings, and often exercised it with regard to aesthetic and as well as practical considerations, which may be far from the modern urban planning.