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Exemplaire auteur

The challenge of archaeologists using geophysics in urban areas

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INTRODUCTION

Geophysical prospecting, even if now used routinely for managing cultural heritage questions in open areas, suffers in currently urbanized environment from various difficulties which makes its use non-trivial. A certain number of constraints in the urban environment are generally well known: presence of mechanical vibrations, electromagnetic noise, presence of infrastructures, furniture, pedestrians, cars above the surface, presence of underground modern services (water, gas, electricity, fibers, etc.), and most obviously, presence of above ground structures which tend to fragment into small pieces the areas that can be measured. Others like the very high heterogeneity of the subsoil (rubble and a highly complex multi-phase stratigraphy) remains the biggest challenge for the geophysicists and ultimately for archaeologists during the interpretation process.

The very good results obtained over abandoned roman towns for example are due to the conjunction of facts that are seldom encountered in today's city centres: low depth of structures (< 1 m); existence of some destruction phase that has cleared up the rubbles and made apparent walls or their negative counterpart; existence of a single phase of construction of the urban layout. The situation of today's cities is closer to the one of "tells" in middle-east countries.

If the first archaeo-geophysical surveys in cities were very 'punctual' and were often limited to the study of religious buildings or parks, in recent years the appearance of new methods such as the electrostatic method (also called CCR – Capacitively Coupled Resistivity) or motorized ground radar (GPR) allow the investigation of very large areas. Two examples are developed: the research conducted in Alexandria twenty five years ago and a newer one not yet published, carried out in 2018-2019 in Brussels.

CASE STUDY #1: Alexandria, Egypt

This case study represents the first large experiment done in a modern city. Following an idea of J.-Y. Lempereur in 1995, we (Albert Hesse *et al.* 2002) were looking for traces of the old causeway (Heptastadium, a causeway of 1155m long) described by Strabon and others (Aristée, Plutarque, Sénèque) between the old town of Alexandria and the island of Pharos in Egypt. This causeway is sometimes described as an embankment (χωμα) that could form a bridge (with piles?) and an aqueduct which connects the old town to the island of Pharos. There was before our work only one hypothetical route that was proposed by Mahmoud Bey

Al-Falaki last century and situated halfway between the two banks of today isthmus. But looking at topographic features (orientation and width of the old roads, parcels in the 1930 cadaster, altitudes and the distribution of sewers), Albert Hesse proposed another route closer to the west bank of the isthmus. This hypothesis focused all the geophysical work in this region and four methods were used in 1997 (Seismic refraction, EMI, GPR and Electrostatic imaging) mainly along six modern roads (approximately 100 m apart) crossing the hypothetical trace of the Heptastadium.

We will not discuss into details (cf. Hesse *et al.*, 2002) the results of these geophysical profiles in a very difficult environment (very low resistivities due to the presence of salted water, decompacted sediments, high industrial noise). Seismic refraction and GPR were not successful but Electrostatic data and to a lesser extent conductivity data (EMI) made possible the delimitation of resistive bodies at a depth of roughly 4 meters.

Nevertheless, it is clear, as was expected since the beginning of this work, that the Heptastadium does not constitute a perfect linear geophysical anomaly (Fig.1). But on the other hand, the two methods show that there exists in the studied sector a slight eminence aligned in the right direction and composed of resistant materials contrasting with more loose alluvium on the sides, validating the hypothesis of some 'openings' across the Heptastadium for communications between the western and the eastern harbor. These geomorphological issues together with micro-topographical issues were important for strengthening the hypothesis of a causeway in the western part of the isthmus.

CASE STUDY #2: Brussels, Belgium

The program "*Voir sous les pavés*" ("Seeing under cobblestones") launched in 2018 for the study of the Grand'Place in Brussels, under the direction of François Blary (ULB) and Michel Dabas (CNRS-ENS), aimed to detect and map the archaeological structures under this square and nearby street without performing excavations. It corresponds in the case of Brussels to a set of large-scale integrated non-destructive surveys that prefigure what could be undertaken in other downtown areas. This project is actually part of a larger project launched in 2017: the BAS (Brussels Archaeological Project). It aims at finding the traces of the Brussels of the Middle Ages of which nothing remains on the surface. This research focuses on the study of all accessible underground structures and in particular cellars within the oldest area of Brussels known as "Pentagon". Grand'Place occupies the central position of this Pentagon.

Methodology

The current appearance of the Grand'Place is close to that of 1695, after the bombardment by the French. Before 1695, little is known: the square was probably much smaller, texts mention buildings but their location are unknown. One or more fountains existed and are depicted in some drawings. Also more ephemeral structures have existed: Gas street lamps, places for Christmas trees, market place, and podium for public executions. All these remains could eventually be detected by geophysics... Only a single very small archaeological excavation has occurred near the Town Hall and some occasional discoveries like a water well or a cave are known.

Before the surveys took place, it was possible to get a high definition (5 cm) aerial ortho-image and a map of the different utilities. But no georeferencing of these utilities existed and one of

the purposes of the survey was also to map all utilities under the main square and the streets around.

Four classes of methods were used simultaneously in the Grand'Place: ground penetrating radar (GPR), electrostatic method (also named CCR- Capacitively Coupled Resistivity-), Vertical Electrical Sounding (VES), and micro-topography (Fig. 2). The biggest challenge was to get authorizations to survey this UNESCO-square full of tourists, with security issues (2016 suicide bombings in Brussels), with heavy car traffic during the early morning when shops are stocked, and with a high tavern activity in the afternoon and at night ...

Several 3D-multi-channel radars (Stream X and C) were set up (Gianfranco Morelli, Geostudi Astier) to find a compromise between depth of investigation, spatial resolution and measurement speed. Simultaneously, a new prototype of electrostatic resistivity-meter "MP3" specifically developed for this project was implemented (S. Flageul and M. Dabas). It allows the measurement of electrical resistivity simultaneously for three depths of investigation down to 2meters. Positioning was done by a robotic total station and proves to be very effective in such a situation (compared to GNSS) even if it has to be moved several times during the survey of surrounding streets, and has to be guarded all day by an operator. It was used for all geophysical methods and consequently all data set were spatially coherent, saving lot of efforts during post-processing phases. The post-processing of these data made it possible to calculate a digital model of the soil surface (DSM) with a post-registration into the Belgian cartographic system (Lambert72) using some GPS control points.

The relatively simple processing and interpretation of the CCR data in a GIS has to be opposed to the very complex processing and interpretation of 3D-radar data: radar maps in the form of time-slices, using a representation of the amplitude (phase) or the magnitude (envelope), taking into account - or not - the topography were tested.

Results

Resistivity (Fig. 3) was very successful and able to detect several resistive structures that can be interpreted as the rest of old dwellings, and despite the signature of some utilities, generally depicted as conductive elongated anomalies, distinctive walls of houses were detected all over the Grand'Place. These anomalies were detected with the most superficial quadrupole ($a=0,5$ m), meaning that these anomalies are superficial. They are best seen with the 1 m dipole and have been confirmed with the different maps corresponding to the two orientations of the dipoles. The highest gradient corresponding to probably a massive building can be seen in the south-east corner (Fig. 5). The density of resistive anomalies is less in the western part of the Grand'Place. We think that this does not necessarily imply a lower density of constructions in this area, but perhaps deeper or more erased structures.

The phase of destruction and reconstruction of the XVII c. Grand'Place was clearly picked up especially in the South-Eastern part: the widening of the place to the East has resulted in a re-alignment of the houses that resulted in the destruction of the former front of the houses (pushed approx.10m to the North-East).

Among the know utilities, only one was clearly picked-up within the CCR data and corresponds to the trench associated to a water pipe. The other utilities were too small to be imaged by resistivity but were picked-up by GPR.

GPR results, despite many maps corresponding to the different frequencies used, to different processes, and even to different polarizations, were hard to interpret. Unfortunately Radar

penetration even at 200 MHz was low (1 m approximately); we have often encountered this situation and it is a drawback when using GPR in downtown areas. For Brussels, this can be explained by the low electrical resistivity measured both by CCR and confirmed by a single Vertical Electrical Sounding between the cobblestones.

Nevertheless, the GPR results demonstrated, beside a very high number of unknown utilities, the existence of the basement of two fountains and probably three water wells (Fig.4) which were not picked-up in the CCR data. The spatial resolution of GPR was necessary to detect these small-scale anomalies (compared to resistivity imaging). As an example of known structures, the place of the basement of the Christmas tree and the one of former water wells were discovered in the time-slice GPR maps (but were not known before our survey).

Surprisingly, signature of the dwellings and walls discovered with resistivity imaging was not so clear in GPR maps. Only GPR amplitude time-slices (and not envelope) thanks to a difference in texture was able to delineate these limits and we should admit that the confrontation with ER maps was mandatory to secure our interpretation.

We should admit that, without the information gained with old drawings and paintings, we will probably have missed some of the archaeological structures. We believe that the good achievement of this project is due to the integration of the archaeologists at every stage of the process. And of course, the archaeological interpretation of geophysical data from Grand'Place is a challenge which is not yet finished. All results will be published in a book, in a public leaflet and through a web-GIS.

CONCLUSIONS

Through these two examples, we have shown how we have tried to answer the three main questions dealing with geophysics in urban spaces: how is it possible to undertake a multidisciplinary research in large urbanized settings; how we have managed the acquisition, processing and integration of a large amount of data; and finally, how can we have interpreted and disseminated the results of such urban-scale projects?

In both examples, it was mandatory to use several classes of geophysical methods simultaneously to solve the archaeological questions: presence of the Heptastadium in Alexandria, presence of medieval buildings in Brussels. But also, the ancillary role of micro-topography was highlighted for both studies. The role of the electrostatic method (CCR) as a quick mapping technique was demonstrated even if the geometry of such system prevents from using it easily for large depth of investigations (>3m). Processing of CCR data is also very easy compared to GPR data. The high horizontal and vertical resolution of GPR data is nevertheless unavoidable in order to resolve small scale anomalies, define sharp limits of structures and ultimately interpret structures at a stratigraphic level.

Processing of data and integration of all types of data is also very important and is still a challenging part of this work. Our interpretation heavily relies on these processing workflows that can –and should- evolve during the interpretation process. Our experience shows that without extra information like old plans and drawings, our geophysical interpretation may remain very poor.

Finally, we can ask ourselves what exactly is the role of geophysical information obtained in such contexts? Is it only useful for archaeologists, or can we imagine a more integrated approach with geotechnical engineers, network managers, urban planners? Can it be used blindly as in the case of an archaeological diagnosis or does it have to answer specific

questions? Even if it is still an open question, our experience and certainly the Rome transformed project are throwing new bridges for our *connaissance*.

Reference:

A. Hesse et *al.*, L'Heptastade d'Alexandrie, Etudes alexandrines 6-2002, 191-273.

List of Figure Caption:

Figure 1 (from top to bottom, clockwise):

Position of the geophysical surveys in Alexandria (white square); Electrical Profiling using independent electrostatic quadripoles in Wenner configuration ($a=6$ m) along one of the streets (credit: A. Hesse); Map of apparent electrical resistivities obtained by krigging the data along the 6 profiles (Hesse *et al.*, 2002); Superposition of microtopography and Google Earth showing in yellow the proposed causeway for the Heptastadium (credit: A. Hesse, M. Dabas).



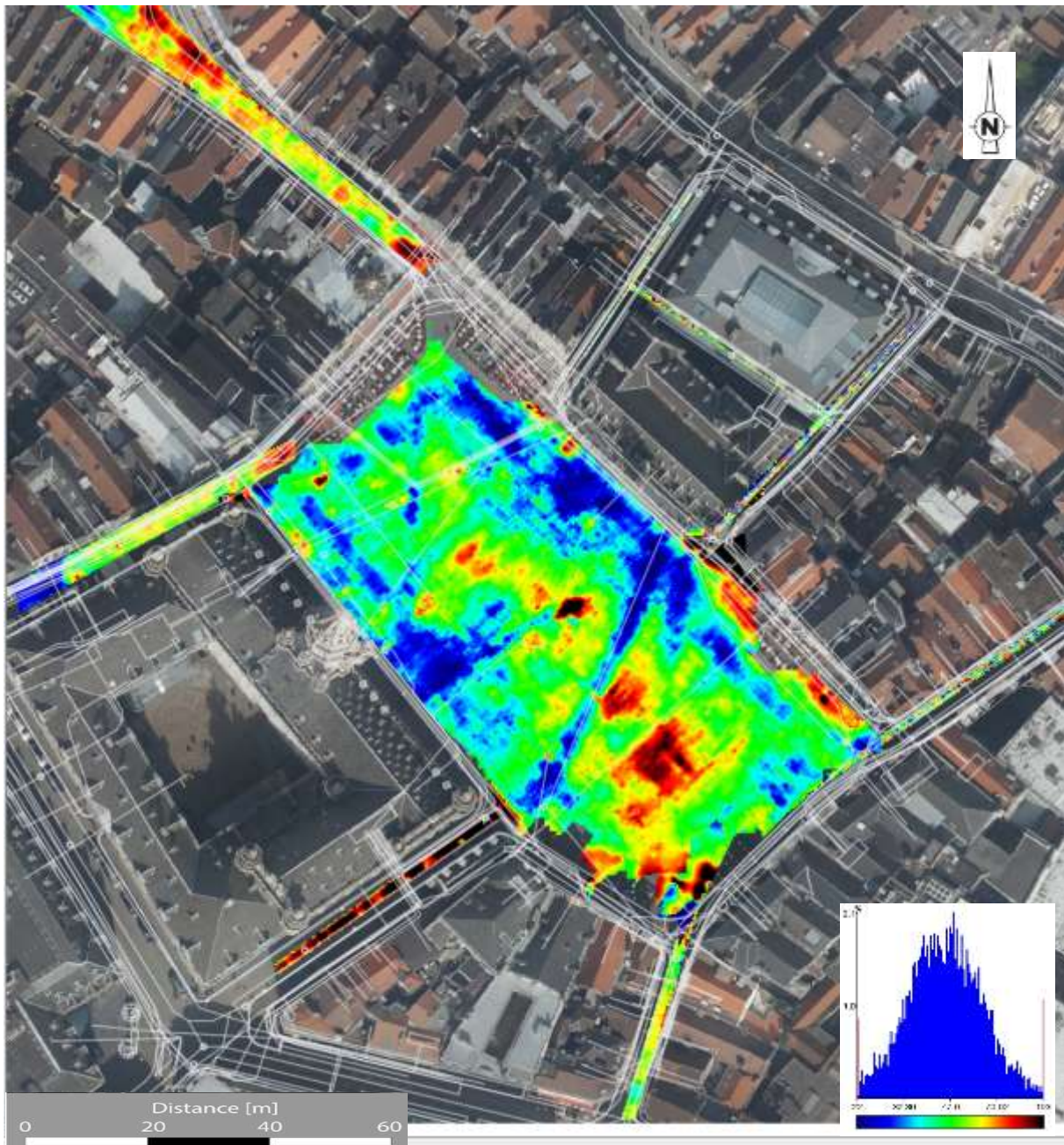
Figure 2:

MP3 prototype for measuring apparent resistivity, operators (A. Tabbagh and S. Flageul) are within a 'moving' safety zone delimited by yellowtape; Robotic total Station operated by B. van Nieuwenhoeve; GPR (StreamC 600 MHz and StreamX 200 MHz, IDS GeoRadar Corporation) G. Morelli and G. Catanzariti; Vertical electrical Sounding between the cobblestones in the Townhall (A. Tabbagh).



Figure 3:

Map of apparent electrical resistivities (22 to 103 Ohm.m) obtained with channel 2 (DOI: 1 m) of the MP3 prototype (charge coupled resistivitymeter) overlaid on 5 cm resolution orthoimagery (June 2016, source: cirb.brussels, Open licence) and utilities (in white). Processing and source: M. Dabas, www.chronocarto.eu [06/2021].



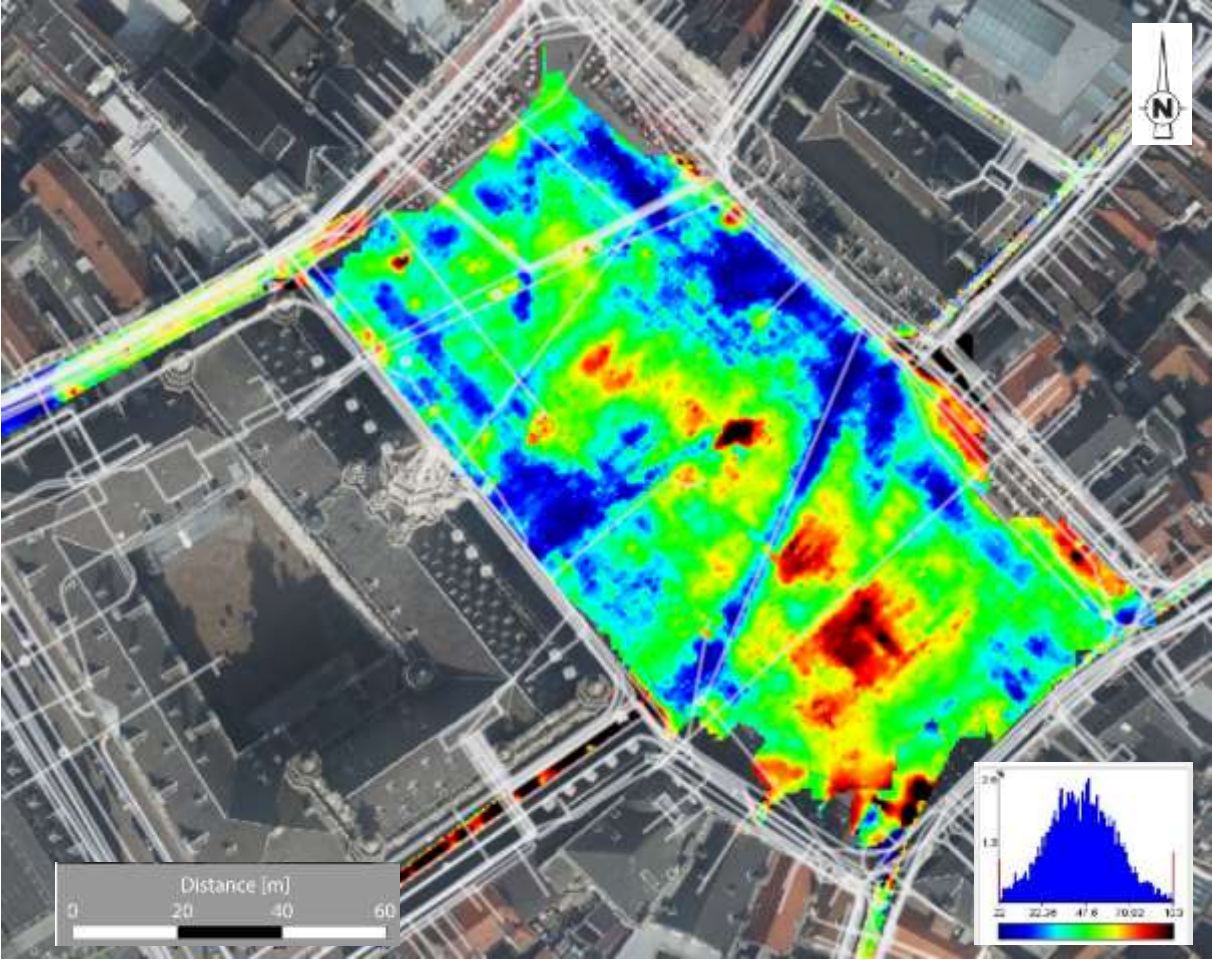


Figure 4:
200 MHz GPR amplitude time-slice centered on 0.22 m overlaid on ortho-imagery (June 2016, source: cirb.brussels, Open licence) and utilities (in blue). Processing and source: G. Catanzariti, www.chronocarto.eu [06/2021].

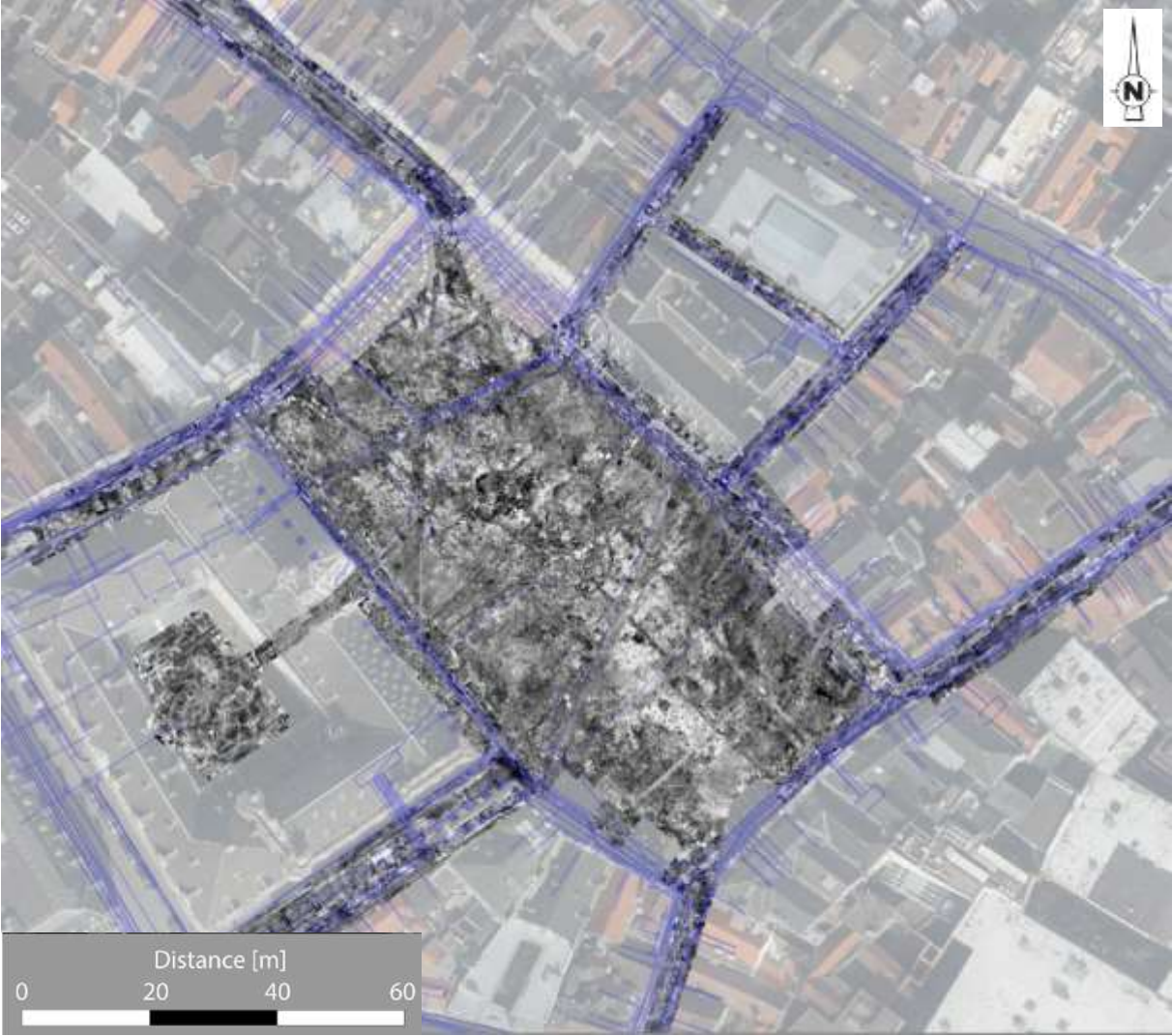


Figure 5:
First joint interpretation of resistivity maps and GPR time-lapse maps.
Processing and source: F. Blary [03/2019].

