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Nella nuova Collana del Dipartimento troveranno posto i lavori dei colleghi, ma anche e soprattutto i lavori dei più giovani che si spera possano vedere in questo strumento una concreta occasione di crescita e di maturazione scientifica.

Looking to the Future, Caring for the Past

Preventive Archaeology in Theory and Practice

Proceedings of the 2013-2014 Erasmus IP Summer Schools in Preventive Archaeology:
Evaluating sites and landscapes. Methods and techniques for evaluating the archaeological value

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Cover: Aerial view over the Valley of the Cesano River (Marche, Italy). Cropmarks into the foreground and the Roman town of *Suasa* in the middle background (photo © Pierluigi Giorgi).

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The limits of archaeology

The title of this paper refers, obliquely, to Robin Osborne's (1987) influential book on the Greek city and its countryside *Classical Landscape with Figures*[1]. We start with this reference, in part because much of the content of this paper will refer to issues relating to the interpretation of archaeological land/cityscapes, but also because Osborne's title contrasts the alluring figural representations often found on classical pottery with the frequent absence of people within the archaeological record itself. This may seem paradoxical to a reader who may be more familiar with exceptional urban finds, such as the human figures captured at death in the volcanic ash at Pompeii: and yet archaeologists, ultimately, depend on indirect or proxy evidence to recreate past societies and economies. For instance, it is readily apparent that much archaeological interpretation may be derived from the study of ceramics recovered from excavations: beyond simple technological statements the quality of ceramics may indicate status and the function of a vessel may suggest the economic role of a settlement. The source of such objects can also indicate social or trade networks, whilst decoration may even illustrate people and their actions. Yet, in the end, pots are not people and archaeology relies on a chain of theoretical speculation or experimental observation when it infers the nature of past societies from the artefacts that excavation uncovers.

Of course, this should not suggest that archaeology is in any sense inferior in comparison with other disciplines. Indeed, on this basis archaeology might even be said to have some characteristics that may be compared to fundamental or exploratory science. In theoretical aspects of astrophysics, for example, the object of investigation may, or need, never be observed directly but instead can be inferred from a residue or a consequence of action. Instead archaeology should be appreciated as a 'two cultures' discipline. Its subject of study is humankind and their works but it relies, fundamentally, on science to provide much of its data. This includes absolute dating technologies to support chronology, paleoenvironmental sciences to recreate past economies and climate, and numeric sciences to synthe-

[1] It should be noted that Osborne also appeared to borrow this title from an earlier travel book with this title and published in 1947 by British cartoonist, Sir Osbert Lancaster.

sise the vast amounts of physical data generated by excavations or extensive landscape studies. Not surprisingly, computing has played an increasingly major role within the development of archaeological studies over the past twenty years or more and the development of, for example, the standing international conference on archaeological computing (http://caa-international.org/about/) exemplifies this process.

Landscape archaeology and prospection

Such processes have, perhaps, been most obvious in the development of landscape studies within archaeology. Osborne's 1987 book and contemporary publications, were responding to the large landscape databases generated by a flurry of large archaeological field survey projects across the Mediterranean during the preceding decades[2]. It is hardly surprising that geographical information systems emerged as a key technology to assist in the process of understanding the mass of spatial information generated by such studies[3]. Great claims were made for these technologies and equally strong rebuttals were delivered at various times – usually in reference to the rather naive theoretical context of the published studies and the relatively simplistic analyses applied[4]. Consequently, it remains true that computer-based archaeology retains a subaltern role within much archaeological debate. However, the last decade has seen step changes in the facility of pervasive technologies to explore rich archaeological contexts to the degree that, in some instances, the extent of emergent data, whilst not necessarily replacing the lack of figures within a landscape, may have a positive formative value in theoretical terms[5].

One suspects that few other aspects of archaeological practise demonstrate this better than geophysical prospecting and the study of the site[6]. With respect to ground-based geophysics, many of the early applications in archaeology were driven by the need to identify suitable areas for excavation within sites that were already known. The work was characterised by the relatively small scale of projects carried out and the relatively low value of such surveys, in larger interpretational terms, to archaeologists. There were fundamental reasons for such a situation and not least amongst these was the minimal expectation of archaeologists themselves for the technologies beyond the role of site investigation. It is also true that the instrumentation available was not actually conducive to large area surveys in terms of its capacity to record data or, perhaps, the design of the equipment itself[7].

Through to the beginning of the current century progress was largely determined by the rapid development of more powerful instrumentation. Workstations developed exponentially in terms of processor power, whilst field instruments acquired an enhanced capacity for data logging and processing in their own right. Restrictions on the acquired data and storage capacity can, to some extent, be equated with a potential increase in the physical scale of application, either in data resolution or spatial extent, and this has its own significance given the observations on the expanding theoretical aspirations of the archaeological community noted above. In some ways, the most exciting area of development associated with geophysical prospection has been associated with processing and visualisation software (Neubauer 2001a). From the days when printed plots were physically pasted together for examination, today's specialist software provides a host of algorithms for processing, georeferencing and display of data as well as blending and fusing of multiple datasets (**Fig. 1**).

In some senses a developmental peak occurred during the 1990s with a series of surveys dedicated to the exploration of Roman urban centres and some detailed commentary should be made on the nature of exploration within Roman cities and towns. It is significant that the authors of this paper have si-

[2] E.g. Hitchner 1988, 1990; Alcock 1993; Sarris, Jones 2000.
[3] Chapman 2006; Connoly, Lake 2006; Trinks *et alii* 2012; Neubauer 2004: Neubauer *et alii* 2012b.
[4] Gaffney, van Leusen 1995.
[5] Gaffney V. 2008
[6] Gaffney *et alii* 1998; Gaffney C. 2008; Gaffney, Gater 2003.
[7] Gaffney, Gaffney 2006.

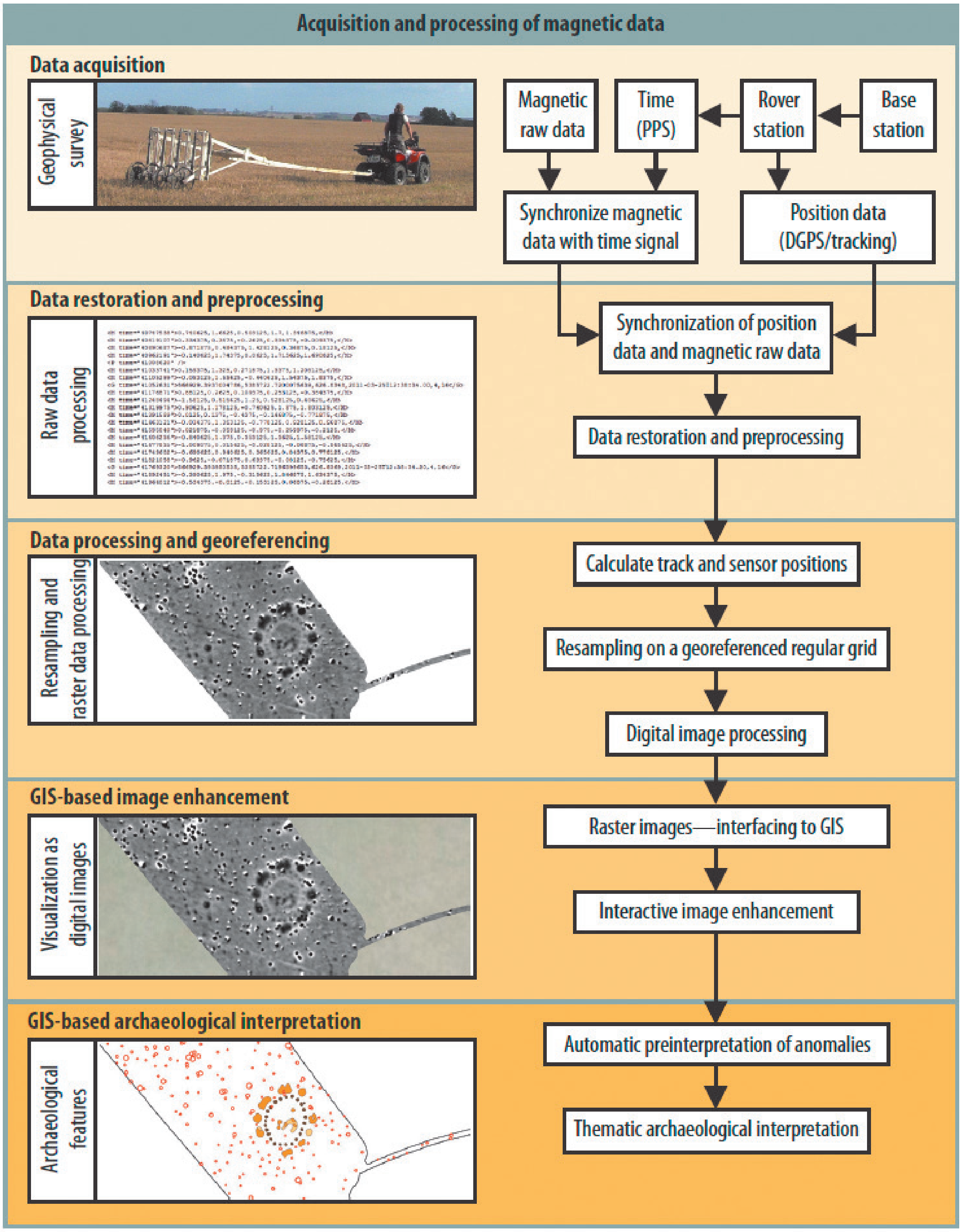

Fig. 1. Typical flow chart for processing magnetometer data, LBI ArchPro 2011.

gnificant experience of such sites. These early experiences were formative and the opportunity to work as part of teams excavating Roman towns preserved, essentially complete, provided an introduction to the archaeological complexity not of urban excavations but of research within specifically Roman, urban areas. This is a distinction that is deserving of some consideration as we would separate the issues of deeply stratified archaeological sites within contemporary cities or major towns with those sites, for example Silchester in the United Kingdom or *Carnuntum* in Austria, which have been preserved almost in their entirety and are available, theoretically, for extensive investigation. Whilst certainly not denying the value of all sites to contribute to our knowledge of the process of urbanisation, settlements which provide relatively unfettered access demonstrate qualitative differences in terms of the nature of investigations that may be carried out and the research agendas that might be forwarded.

These observations become important when one appreciates that the archaeological significance of cities across the area of Roman influence is not a simple phenomenon and that the questions one may ask of an urban centre may vary across the Roman world. The apparent, or presumed, unitary nature of Roman urban form has sometimes distracted from significant procedural variation associated with sites underlying contemporary cities as against the relatively smaller number of sites which have avoided major development. In the former group, a primary methodological requirement is to identify key strata within a mass of later development and to construct a larger interpretative position from a mosaic of detached datasets[8]. These sites have sometimes been viewed, in some sense, as superior to settlements that did not continue as urban centres or those that did not develop in a manner consistent with the expectations of Mediterranean archaeologists[9]. However, there is a growing appreciation that the latter group can now be seen to provide important information on the aspiration of local communities in the past and their varying requirements from urban development and that this provides an alternative and substantial contribution to our knowledge of urban form derived from classical sources or Mediterranean type-sites[10].

It is suggested that the differences involved are of scale and resolution. Many, important, investigations of major urban centres have provided a high-resolution snapshot of settlement development from the detailed excavation of relatively small and frequently dispersed development sites. The information provided, supported by the integration of serendipitous historic finds, may provide an excellent synthetic data source. The archaeology of London is an excellent example where the cumulative database now allows sophisticated historic analysis and one anticipates, given future commercial development of the historic core, that this can only get better.[11] However, the opportunities provided through such work are rarely the product of a single research agenda and the restrictions of a database whose results are derived from non-archaeological decisions may only be resolved when *ad hoc*, random investigations ultimately bear fruit. Many former urban areas, however, may always be beyond the reach of archaeologists and any restrictions in terms of key research agendas may never be adequately resolved.

The opportunities provided when provided with access to an entire urban site are very different but face equally demanding interpretational challenges. There can be no doubt that such sites provide the opportunity for directed research, but the extent of the areas involved clearly pose problems in terms of traditional archaeological intervention. Whilst excavation will always be required to provide fine grained chronology and other supporting evidence, there is a knowledge/opportunity-cost in any decision to commit substantial resource to invasive research on these sites. If the decision to excavate is taken then it must clearly be on the basis of the best available evidence and here we must acknowledge that, in many areas of the empire, well preserved sites do not equate with well understood settlement practise and that, elsewhere, the urban form of the majority of such sites remains unknown. Of course, in the past there have been attempts to remedy such a situation using a range of traditional methodologies. The investigation of Silchester is a case in point. Here the Society of Antiquaries carried out

[8] Carver 1994.

[9] Sears *et alii* 2012.

[10] Lawrence *et alii* 2011.

[11] The numbers of publications associated with the historic development of London are numerous and the publication output of the Museum of London demonstrates the range and quality of available data (http://www.museumoflondonarchaeology.org.uk/Publications/)

extensive trenching to explore the city structure in the earlier 20th century[12]. Alternately, the aerial photographic study of Wroxeter, also in the United Kingdom, produced a plan of that site that probably influenced a generation of archaeologists and their interpretation of Romano-British towns[13]. In both cases the limitations of these single methodologies was such that the results gave the impressions of relatively low density settlement, usually associated with elite, public or, at best commercial building, surrounded by significant blank areas. These results inspired a generation of site reconstructions often characterised as 'garden cities' which were generally devoid of buildings not associated with governance, worship or the dwellings of the roman equivalent of the middle or upper class. The urban poor were apparently not always with us! Of course some settlements may well have been characterised by low density settlement. The work by the British School of Rome at *Forum Novum* in the Sabina has suggested that towns, even at the heart of empire, might only require certain buildings to carry out the legal functions of government[14], and these settlements may not have needed a significant urban population to deliver such services. However, in the case of large, preserved towns in Roman Britain at least, there has always been the suspicion that such plans were incomplete. One of the significant challenges in urban studies has therefore been to provide mapped data from preserved towns that was both extensive and adequate for the purposes of the archaeological research questions asked.

The opportunity for remote sensing to add substantively to the issues of Roman urban form have been recognised for more than two decades now and work, for instance on multiple sites in Italy by Keay and Millett, exemplify such trends[15]. Other projects, including that by the ZAMG Archeo Prospections team at *Carnuntum* in Austria provide longer term histories of prospection and exploration. Here a survey programme was initiated in 1991 and continued by the Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology (LBI ArchPro) after 2010[16]. Roman *Carnuntum*, the capital of the province of Pannonia, was situated at the river Danube east of Vienna[17], large scale application of digital aerial archaeology, airborne remote sensing and ground based geophysical prospection has provided substantive insights into the nature and structure of the city. Application of geophysical prospection in the 90s has been supported by a project involving the digitization and georeferencing of all available aerial images collected over seven decades in order to provide a map of the Roman cityscape and its hinterland[18]. This early example of the target-oriented combination of digital photogrammetry and GIS-based interpretative mapping added a multifaceted and comprehensive data source to the traditional excavation records and find archives. Further GIS-based studies using this large dataset has generated novel analyses and developed our understanding of the urban layout of the Civil Town and the canabae legionis surrounding the main legionary fortress[19].

In detail, the combination of earth resistance survey, caesium magnetometry and ground penetrating radar at *Carnuntum* had provided a high resolution geophysical data volume covering 1.2 km^2 by 2001[20]. The development of instrumentation[21], new methods of data visualization including the animation of GPR depth slices, data fusion[22] and GIS-based mapping and archaeological interpretation[23] further combined to make the work at Carnuntum an exemplar for integration for prospection

[12] Boon 1974.
[13] Wilson 1984.
[14] Gaffney *et alii* 2004.
[15] Keay *et alii* 2000.
[16] Neubauer *et alii* 2012a, Doneus *et alii* 2001; Neubauer 1999.
[17] Eder-Hinterleitner *et alii* 2003.
[18] Doneus 2011; Doneus *et alii* 2001a; Doneus, Neubauer 2005.
[19] Doneus *et alii* 2013.
[20] Neubauer *et alii* 2012.
[21] Neubauer *et alii* 2001; Neubauer *et alii* 1996.
[22] Neubauer, Eder-Hinterleitner 1997.
[23] Neubauer *et alii* 2002.

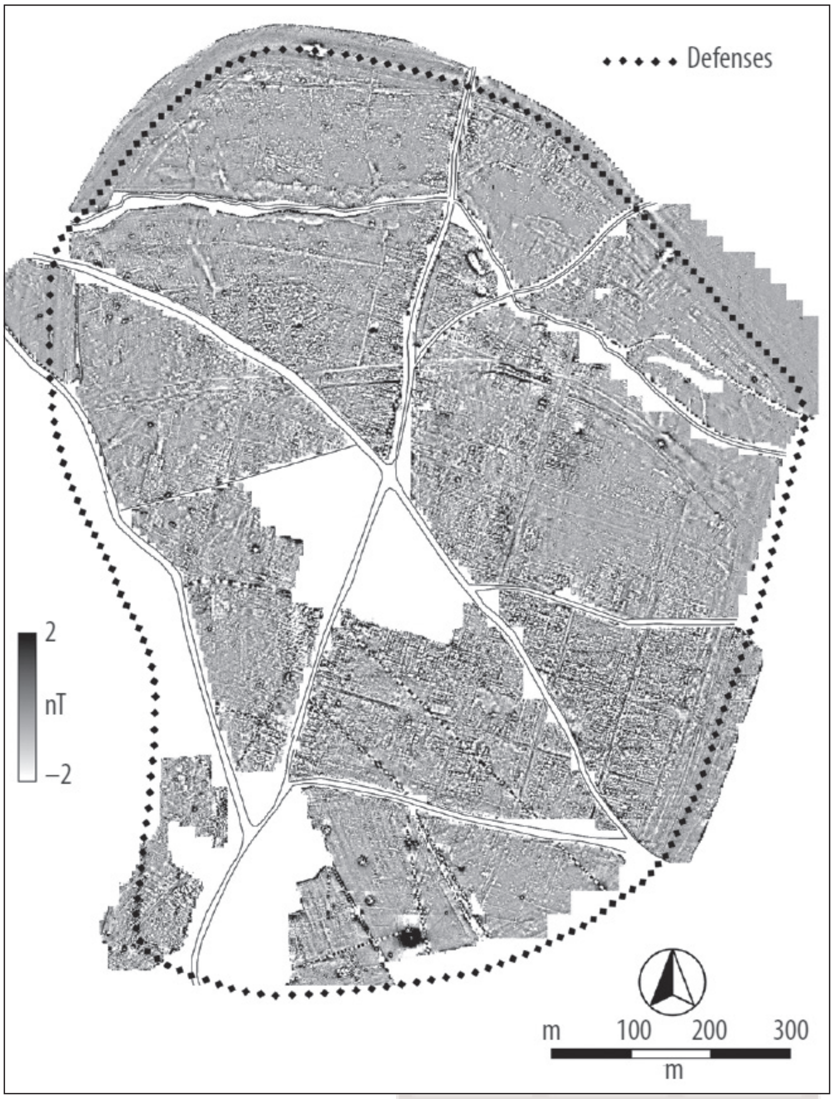

Fig. 2. Image of the magnetic data of the Roman City of Wroxeter collected by GSB Prospection and the AMLaboratory of English Heritage using Geoscan Research FM series magnetometers.

methods[24]. The discovery of the civic forum of Carnuntum and its initial virtual reconstruction based on the geophysical data clearly showed the potential of integrated non-invasive prospection methodologies[25], and in 1998 a 3D GPR data set was analysed in detail to provide a 3D interpretation model of the buried remains[26].

Within Britain publication of the work at Roman Wroxeter also demonstrated this process at the end of the twentieth century at least (**Figs. 2** and **3**)[27]. A large number of people were involved in this project and teams from Britain, France, Germany the USA and Japan, private companies, governmental institutions and amateur groups all contributed to this large survey which, at the time, was among the largest ever attempted. The extent of the magnetometer survey and the consequences of the work in terms of known structures are apparent in **Figure 2**. The numbers of known structures increased by nearly 100% over the AP estimate at the beginning of the survey[28], and although there are still gaps within the plan there is greater confidence now in how this might be interpreted in extensive terms (see **Table 1**).

[24] Neubauer 2001b.
[25] Neubauer 2014; Kandler 1999.
[26] Neubauer *et alii* 1999.
[27] Gaffney, Gaffney 2000; White *et alii* 2013.
[28] Wilson 1984.

Insula No.	No. of Buildings (AP)		No. of Buildings (Survey)	
	Private	Public	Private	Public
Northeast quadrant				
II	5+	–	12+	–
III	2+	–	4	1
XVI	14	–	22+	–
XVII	–	–	–	–
XVIII	–	–	3+	–
XXX	6	–	8	1
XXXI	1	–	11+	–
XXXII	2+	–	6	–
XXXIII	3	–	6	–
XXXIV	–	–	7+	–
XXXV	1+	–	7+	–
XXXVI	1	–	6+	–
Sub-total	*35*	–	*92*	*2*
Southeast quadrant				
V	2	2	2	2
VI	6	–	6	–
VII	3+	–	3+	–
IX	7+	–	7+	–
X	5	–	6+	1
XI	3	–	4	–
XII	6	1	11+	2
XIII	1	1	1	1
XIV	–	–	1+	–
XIX	1	–	5+	–
XX	1	–	6+	–
XXI	1	–	5+	–
XXII / XXIII	1	–	2	–
XXIV	2	–	3	–
XXV	–	–	–	–
XXVI	3	–	8	–
Sub-total	*42*	*4*	*70*	*6*
Southwest quadrant				
I	1	–	3	1
IV	1	1	1	1
VIII	18+	2	18+	2
XV / XXIX	11	–	11	–
XXVII	–	–	7	–
XXVIII	–	–	1+	–
Sub-total	*31*	*3*	*41*	*4*
Northwest quadrant				
XXXVII	1	1	6	1
XXXVIII	1+	–	1+	–
XXXIX	1+	–	4	–
XL	+	–	1+	–
XLI	+	–	4+	–
XLII	+	–	5+	–
XLIII	1+	–	13+	–
XLIV	1+	–	7	–
XLV	+	–	9+	–
XLVI	+	–	7+	–
XLVII	+	–	3	–
XLVIII	+	–	3+	–
Sub-total	*5*	*1*	*63*	*1*
Total	**113**	**8**	**266**	**13**

Table 1. Recorded structures from Wroxeter recorded from aerial photography and geophysical survey.

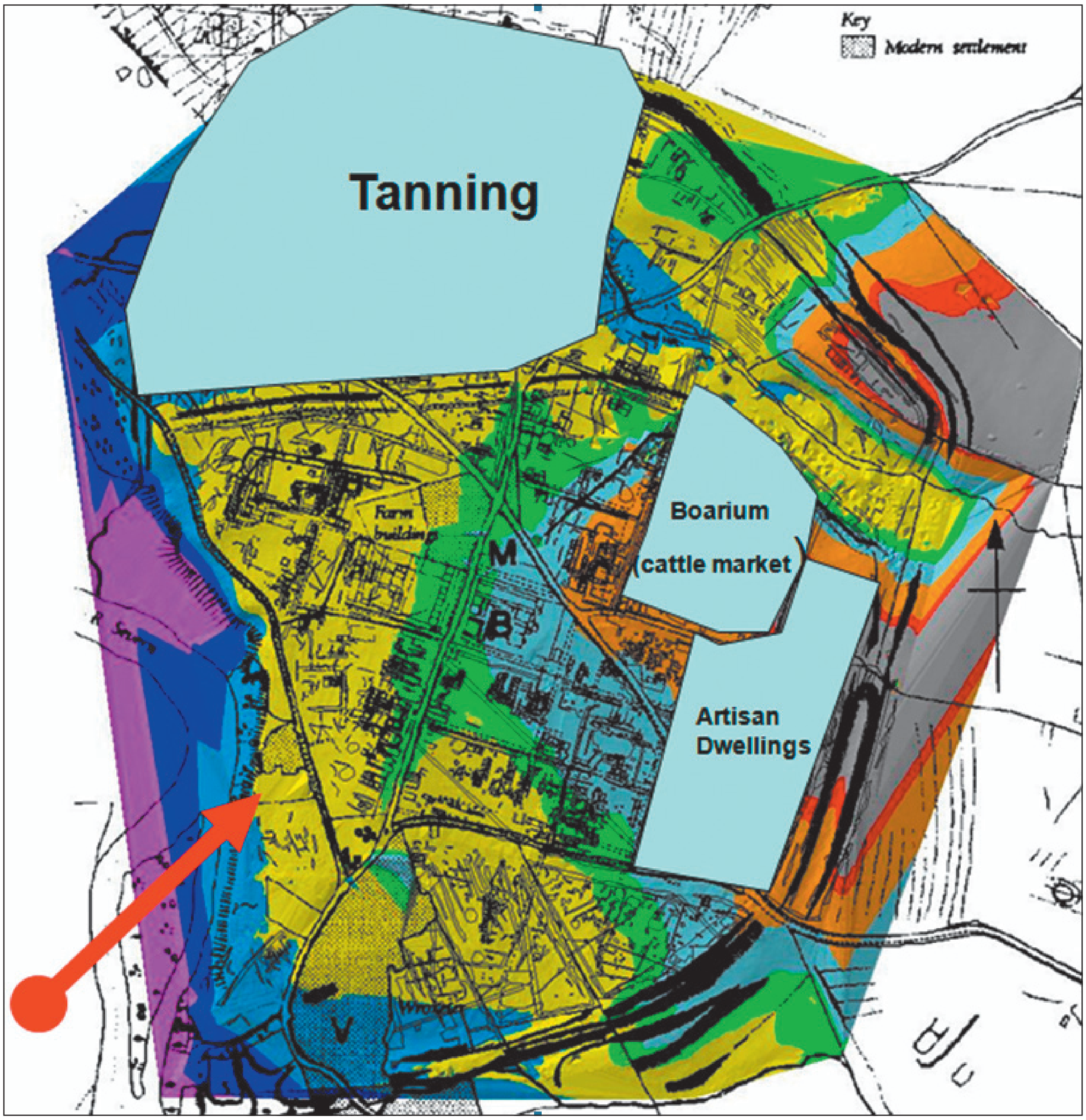

Fig. 3. Dominant wind direction and key functional areas in the north and west of the city.

There are, however, other qualitative values to the survey at Wroxeter that remain to be developed. The published remote sensing data is essentially a traditional 2D map. However, the structure of the town derives substantially from its extensive terrain and, perhaps other less tangible attributes which require extensive data to interpret. It is clear, for instance, that the northern part of the town is associated with the valley of the Rea Brook. The inclusion of this stream seems counter intuitive to a fortified settlement but the presence of large numbers of pits in this area suggests that the area is associated with tanning[29], and its peculiar urban form has suggested that Wroxeter resembles, in many respects, a british hillfort as much as Roman city. However, the presence of a putative *forum boarium* in the northwest of the town and emerging evidence for lower class/artisanal settlement in the east suggests

[29] Gaffney, Gaffney 2000 and White *et alii* 2013.

Fig. 4. Data capture at Wroxeter from the late 90s (a) and (b) as part of surveys by the Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology.

another guiding principle[30]. The dominant wind direction across the town is from the south west. This is reflected in the evidence for major fires adjacent to the forum being blown to the north east. This evidence suggests that the majority of the structure of the town may derive from a desire to restrict nauseous and potentially hazardous activities and the poor to areas downwind of the public and elite housing. In contrast to early reconstructions at Wroxeter the poor were very present but they had a designated place on the fringes of the city – and downwind from the rich.

Despite the importance of surveys at the scale of Wroxeter in the UK or *Carnuntum* in Austria in the 1990s, less than a decade later they do not individually appear so significant in terms of the

[30] Gaffney, Gaffney 2000.

Fig. 5. The Foerster Ferex Magnetometer to the north of the Temple of Zeus, Cyrene.

improved instrumentation now available. Instead it is the complexity of the datasets, and our capacity to integrate the data at the time of collection and within an increasingly innovative analytical and interpretative manner, that is the major opportunity and challenge. In particular, the general use of highly accurate positional devices has brought ground-based techniques to the foreground of landscape prospection rather than site-based mapping. Low-grade positional devices have been used for a number of years with electromagnetic devices, and their value for mapping large-scale changes relating to underlying former land surfaces and palaeochannels is now coming to fruition. The integration of accurate GPS systems within suites of systems is now enhancing the role of ground-based geophysical prospecting in a manner that was previously unimaginable and the outputs of such projects are beginning to be appreciated through novel research collaborations including the pan-European consortium combining the authors' institutions and the overarching Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology (archpro.lbg.ac.at). The project equipment resource, available to project partners, is characterized by mobility and close integration of GPS with multi-antenna GPR and multi-sensor magnetometer systems (**Fig. 4**). The speed at which the data is collected the LBI ArchPro collaborative is such that the cumulative data set acquired over two weeks of work at Stonehengeduring 2010 almost equates with the entire area covered by the Wroxeter survey over three years and multiple survey seasons of survey. More importantly, the density of data collection was such that the volume of data for the entire magnetometer survey at Wroxeter was probably exceeded at some point early during the first week of survey at the consortium's project[31]. Although still requiring additional processing the seamless nature of the primary data is apparent, whilst the density and positional accuracy of data provides a clarity of image, and confidence in interpretation, that had previously only been achieved by the exact, but frequently laborious and spatially limited, manual surveys of the past.

We are beginning to see the fruits of the extension of these new prospection technologies in various projects dedicated to the study of urban form. The use of multiple sensor technologies with

[31] Gaffney *et alii* 2012.

Fig. 6. QuickBird satellite image of Cyrene showing magnetometry grids (QuickBird Satellite image © DigitalGlobe).

GPS integration at Cyrene (**Fig. 5**)[32], for instance, has begun to provide novel results even within cities in North Africa which are frequently presumed well understood as a consequence of the extensive structural remains; the surveyed areas shown on **Figure 7** are the result of less than two weeks' survey in 2007. The results from Area 5 (see **Figs. 6-9**), which encompasses two *insulae* immediately to the north of the agora and to the south and west of the central theatre, demonstrate this well[33]. Plans produced by previous excavations showed limited indications of walls in this *insula*: for example, Goodchild's map of 1967 and Stucchi's plan of 1975 shows the traces of the outside of walls apparently demarcating an *insula*. But the new work makes clear the extent of the structures and their importance in the study of the evolution and function of structures in Cyrene's Upper Town in particular but also the city more generally[34]. The clear visualisation of walls in this survey area suggest buildings of considerable size which suggests an official or public character: its location and size (if one single construction) might denote a market complex, although we cannot exclude a substantial domestic residence or residences (*domus*)[35].

[32] Cuttler *et alii* 2007; Gaffney *et alii* 2008; Sears *et alii* 2012.

[33] Sear 2006, p. 292.

[34] White 1984, Fig. 1; Stucchi 1975, Figg. 5-8.

[35] See Sears *et alii* 2012 for a detailed discussion on the relationship between the surveyed area, the rest of the town and movement through the surveyed area.

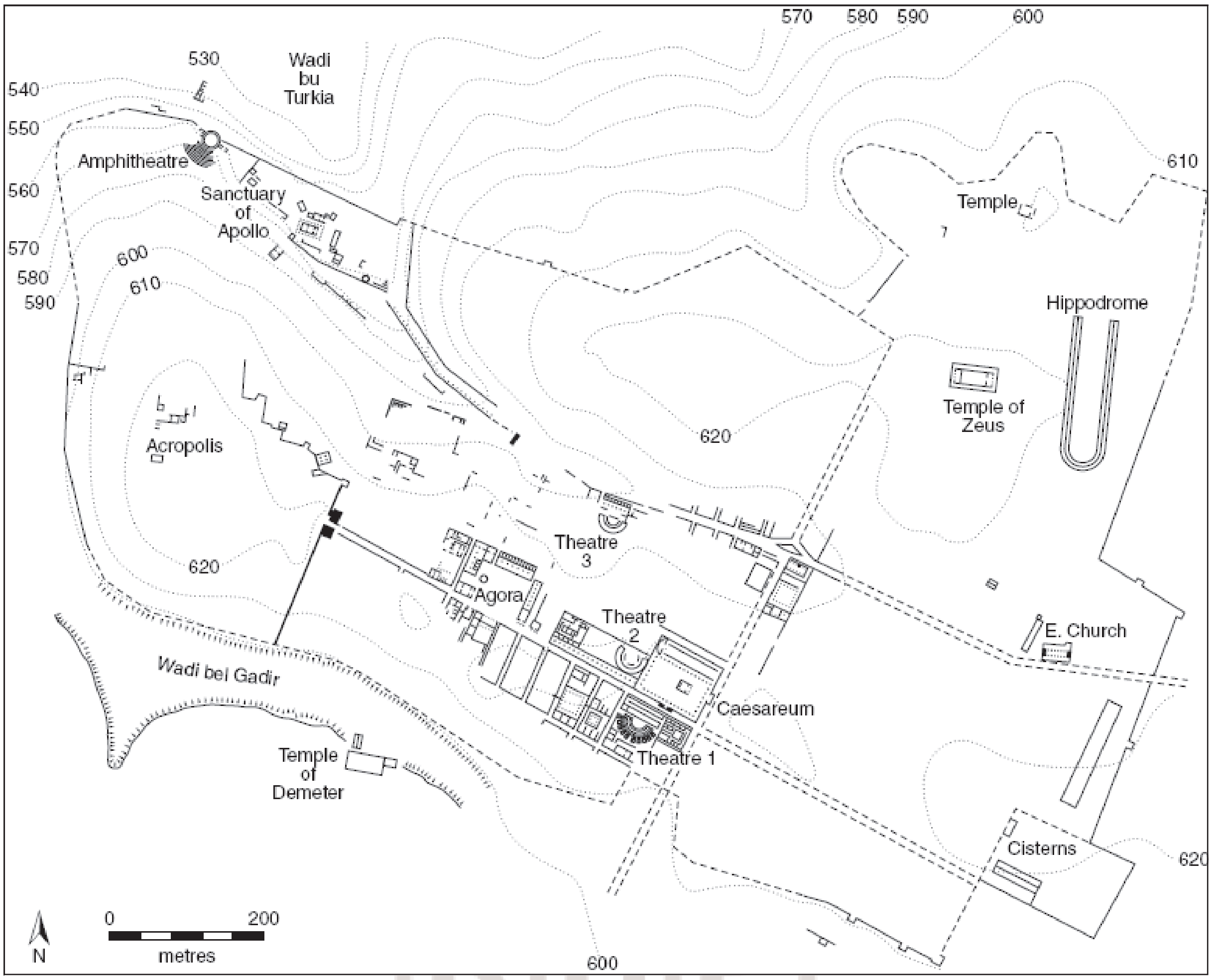

Fig. 7. Plan of the Hellenistic to early Byzantine city of Cyrene (Sears *et alii* 2012, Fig. 7.1).

The increased use of laser high definition survey technologies over the last decade is also of significance. These technologies, which occur as ground (HDS) or air-based (ALS or LiDAR) applications[36], may produce near continuous measurements of the surface of the ground or of archaeological structures. In respect of wider urban landscapes, the resolution of such data can approximate that of traditional ground-based remote sensing, and therefore provide important information on individual features i.e. below the scale of the site; the technology may lie in the intermediate position that 3D terrain data hold between the site and extensive remote sensing survey, aerial photographic or air or satellite sensor data. HDS Structural scanning, however, provides significant opportunities for Roman archaeologists studying those towns where substantial structures may exist above ground. Here, probably for the first time, urban archaeologists may be able to integrate structures and geophysical features in a true three dimensional volume and to use this to interpret the behavioural space of towns in a dramatic and novel manner. Some steps have been taken towards this by a team from Bradford and Birmingham in a survey of the mausoleum and 'peristyle' of Diocletian's Palace in Split[37].

The Split project was designed to examine issues associated with the articulation of imperial space through an integrated research project that encompassed both 3D visualisation technologies and sub-

[36] Challis 2006; English Heritage 2006a.

[37] See Gaffney *et alii* 2012 for a more extensive examination of the work and results.

Fig. 8. Cyrene: Agora with surveyed areas (Sears *et alii* 2012, Fig. 7.7).

surface exploration using ground penetrating radar. Diocletian's Palace is the perfect complex for an investigation of the potential of integrated 3D modelling as a research and digital preservation tool. The considerable excavation and heritage management projects undertaken by several projects since the 1950s has provided a wealth of archaeological results that allows us to situate the current work in an increasingly understood (pseudo-)urban environment whilst the site is not so well understood that further archaeological exploration and visualisation would not have a considerable research impact. Additionally, Split, because of the extent of its standing structures, albeit embedded within later medieval buildings, and its extensive archaeological deposits, allows the production of an explorable 3D model that encompasses the results from remote sensing in order to answer questions about the complex and its built and buried environment. In the first season of work a large model of the mausoleum, and its environment were captured by a Leica HDS6000 3D laser scanner and a GPR survey was carried out in the peristyle in front of the mausoleum (and the main streets of the complex) using a Pulse EKKO Pro Ground Penetrating Radar system with a variety of antennas (100, 200 and 500 MHz). The two volumetric models produced by processing the laser-scan and GPR data were then integrated within the Avizo solid modelling package to create a single 3D model (see **Fig. 10**).

The data from Split is now being used to test hypotheses of the use of the space of the peristyle between the mausoleum, the adjacent temple(s) and the entrance to the Vestibule and the former emperor's private apartments[38]. The geophysical data suggests that the original arrangements within the Peristyle may not be entirely matched in the current reconstruction and that further analysis might provide a different interpretation of the behavioural use of the structures and the, apparently empty space between. Given that the purpose of the palace was, in part, to assert the importance of Diocletian these and other immersive technologies clearly provide the opportunity to explore the ambience

[38] See Gaffney *et alii* 2013; there is a considerable academic debate on whether 'palace' is an appropriate term for the complex and the function of the peristyle, see in particular: Swoboda 1961, p. 81; Duval 1961, 1971, 1991; Dyggve 1965; McNally 1989, pp. 9, 17-19, 34-35.

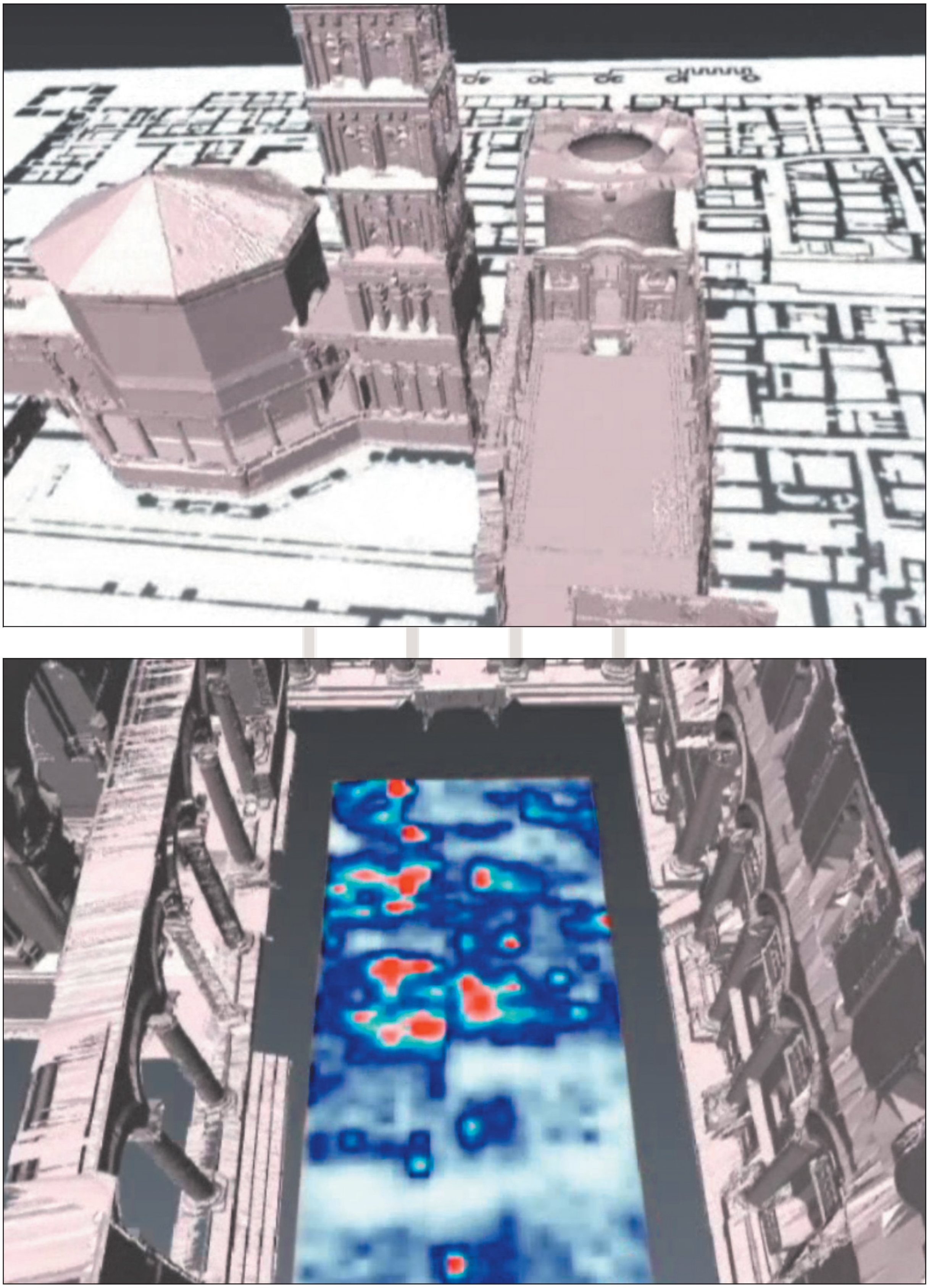

Fig. 9. Top: laser scan model of the exterior of the mausoleum and peristyle overlying map of the modern city. Below: GPR data integrated within the larger volume model.

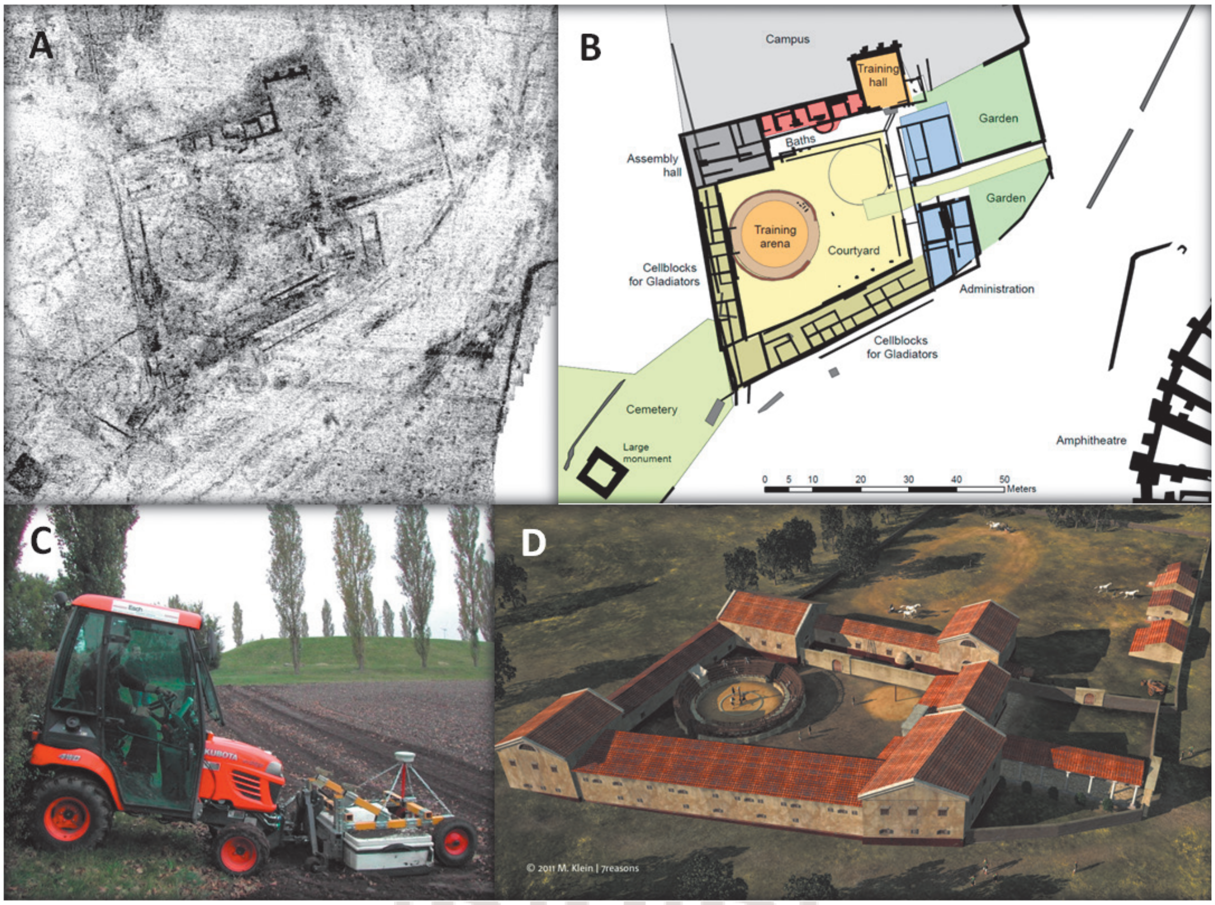

Fig. 10. A: high-definition GPR depth-slice (80 cm below surface) showing the foundations of a ludus. B: corresponding archaeological interpretation of all prospection data. C: MALÅ Imaging Radar Array. D: Virtual reconstruction of the ludus.

of a site or structure and these novel, qualitative elements have largely been missing in the majority of published narratives.

The value of such data is further illustrated in the recent discovery of a gladiatorial school at Carnuntum and the range of virtual outputs derived from such work (carnuntum.7reasons.at). In 2011 a multidisciplinary team of archaeologists, geophysicists, soil scientists and IT experts led by the LBI ArchPro revealed the remains of a complete Roman school of gladiators (**Fig. 5A**), using a combination of aerial photography, caesium magnetometry, multi-receiver electromagnetic induction measurements and high-definition ground penetrating radar[39]. The *ludus gladiatorius* was located outside the gates of the civil town to the west of the ruins of the 2nd century AD amphitheatre, which a contemporary inscription suggests was the fourth largest in the Roman Empire[40].

The self-contained training and living quarters of the *ludus* cover approximately 2800 m^2 located in a walled area of 11 000 m^2 (**Fig. 5B**). A single, easily controlled entrance to the complex faced the amphitheatre to the east. To the north, adjoining the school and within the walled compound, was an extensive open *campus*, which most likely offered further practice areas and enclosures for wild animals. Inside the courtyard was a separate circular training arena with a diameter of 19 m and, at the centre, clear evidence of the *palus* (**Fig. 5D**), a wooden pole used for gladiatorial practise[41]. Around the closed

[39] Saey *et alii* 2013.
[40] Neubauer *et alii* 2014.
[41] Futrell 2004; Meijer 2005.

courtyard was a larger building complex including a 100 m² heated training hall, an extensive bathing complex and an assembly hall. Additionally, the data also contains traces of the small cells provided for each gladiator, an administrative wing and housing for the school's owner. The stairways suggest that the barracks of the school may have been two to three storeys high. Aside from these structural data the high resolution data revealed part of the public water and sewer network, hypocaust floor-heating systems, paths and gateways. The cemetery for the gladiators was also discovered near the School, clearly separated from other burial areas of the city.

Although it is estimated that over one hundred *ludi* must have been built during the Roman period[42], the *Carnuntum ludus* is an exceptional find and the only comparable structure is the partly excavated *Ludus Magnus* near the Coliseum in Rome – although that building is today only partly accessible today and fewer details have been preserved[43].

The discovery of the *ludus* at *Carnuntum*, and the media response to the project imagery, assisted in releasing funds for a larger research project aiming to map the entire cityscape of *Carnuntum* over an area of 10 km². This has been achieved over three years by the LBI ArchPro (**Fig. 5C**) and the interpretative mapping is currently ongoing using novel GIS based visualisation and fusion toolboxes as well as a systematic approach towards a standardized classification of the mapped structures. The resulting detailed archaeological maps and plans of individual buildings, streets and Roman infrastructure permit the virtual reconstruction of the city layout and development of the ancient land- and cityscapes in three and even four dimensions. The output will ultimately provide scholars, planning authorities and the public alike with detailed information about the city. Finally, the non-invasive and sustainable approach to archaeological survey of Roman city sites is exemplary for time- and cost-efficient archaeology, integrating site as well as surrounding landscape, in a manner in full compliance with international standards set by agreements including the Valetta Convention (Council of Europe 1992).

An important point follows from this observation. The significance of these new technologies is not simply their power, but the application of the continuous measurement and analysis of space and the extension of the analytical sphere to virtually every part of an urban landscape. The resulting three dimensional datasets of archaeological sites and their surrounding landscapes demand adequate integrated archaeological interpretation and the development of novel concepts of dynamic analysis, including temporal relations and attributes. Therefore, a remaining challenge is the transformation of the acquired data into information that is accurate, readable and ready for future use. An integrated, easy-to-use multi-purpose toolbox, with a common graphical interface, supporting prospection experts as well as period or regional specialists may also require easy-to-use tools for dynamic visualization and integrated archaeological interpretation, data archiving, information retrieval and long-term maintenance.

However, powerful as these technologies are, the description of space is not interpretation, and infinitely finessing the resolution of data cannot satisfy our disciplinary aspirations to explain the past. The physical environment itself is a quantifiable research asset that requires incorporation within wider interpretative schema. Historically, there is little doubt that landscapes (urban or rural) were imbued with meaning to past societies and, even today, we frequently study our physical and natural context in its own right and appreciate the ability of landscapes to manipulate human action as a consequence merely of its existence. In this context, physical scale can become a driving force in its own right, and an emergent goal, possibly the ultimate goal in computational archaeology and large scale archaeological prospection specifically, is the approximation of the individual, or being, in the world, within these extensive, interpreted, digital environments.

[42] Meijer 2005.
[43] Colini, Cozza 1962.

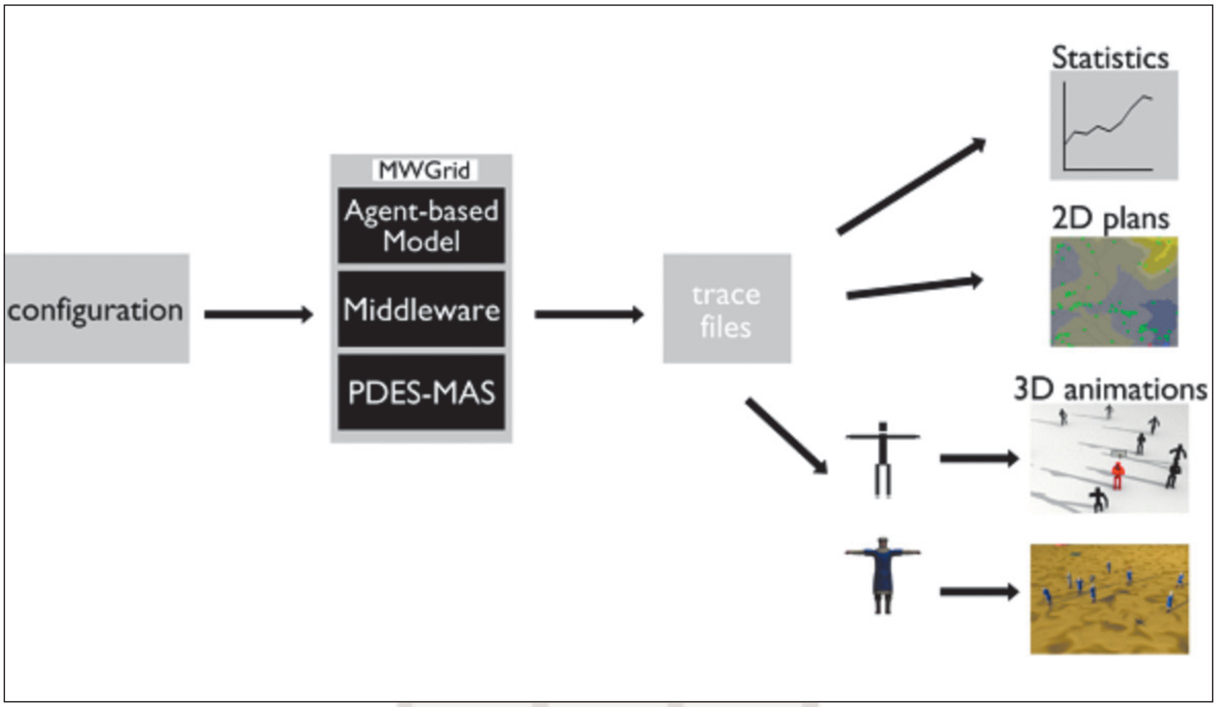

Fig. 11. MWGRID architecture.

Figures in a landscape?

It is no surprise, therefore, that Agent-Based Modelling (ABM) has recently emerged as an area of interest for historical disciplines as a means to explore the effect of individual action within reconstructed environments. Applications, to date, have been relatively limited and examples include the analysis of resource exploitation by Native American groups of South West Colorado[44], and the process of evolution of complex societies in the Fertile Crescent[45]. It is notable, that most recent studies have generally involved the analysis of small-scale groups at individual or household level rather than larger societies but the availability of large, even exascale, computing may change the capacity of technology to answer archaeological problems relating to the actions of individuals.

An example of such work carried out at Birmingham is the "Medieval Warfare on the GRID" (MWGrid) project[46]. The project builds on a series of parallel research developments in Birmingham and Princeton relating to the analysis of medieval military logistics and the development of novel computational infrastructure designed to investigate complex systems (**Fig. 11**). The project seeks to capture and analyse behavioural action at a larger scale, involving tens of thousands of agents within the context of modelling logistical arrangements relating to the battle of Manzikert (AD 1071), a key event in Byzantine history in which the Imperial army was defeated by the Seljuk Turks. The Byzantine army has been marched through a digital representation of various sections of the Asia Minor terrain to study the effects that the environment, resource availability and decision making have on the well-being of a large military force. The representation of the Asia Minor terrain is developed using a unique set of data including multi-spectral satellite mosaics, vegetation maps, geology maps, elevation models and historical maps incorporating detailed topography, route and demographic data.

Considering how important the outcome of the battle was to the Byzantine Empire, the Seljuk Turks and the modern republic of Turkey, the historical sources leave several significant gaps. Histori-

[44] Varien *et alii* 2007; Kohler *et alii* 2008.
[45] Wilkinson *et alii* 2013.
[46] Gaffney *et alii* 2013.

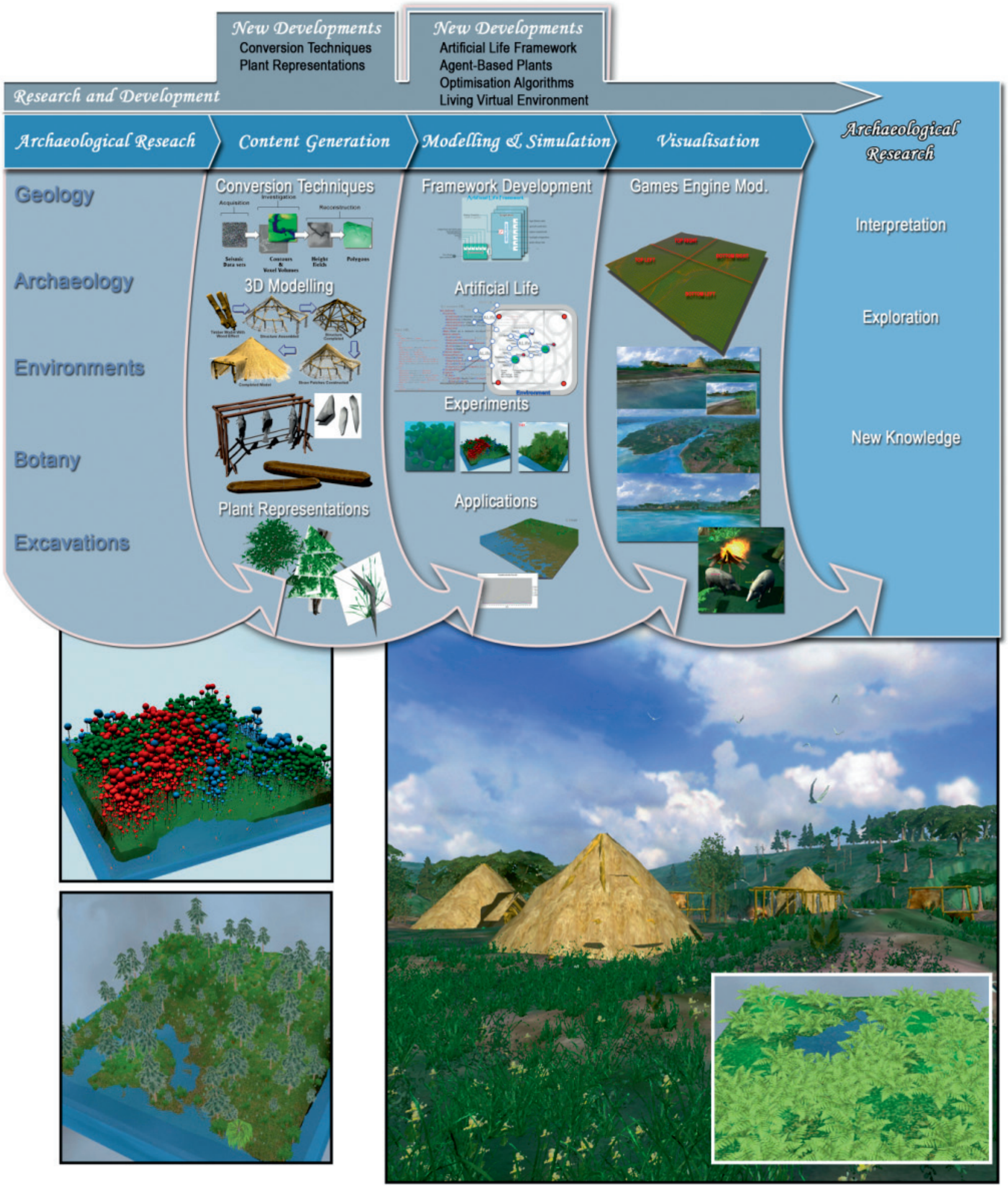

Fig. 12. Constituent parts of modelling "Doggerland".

cal sources are vague, contradictory or absent for such factors as how many people were in the Byzantine army or which route it took. Byzantine writers do not give numbers for the size of the Byzantine army, their foreign contemporaries give figures between 300,000 and 600,000[47] but these are largely motivated by a desire to emphasize the scale of the Byzantine defeat. Modern historians tend to put the

[47] Hillenbrand 2007, pp. 27-36.

figure at between 40-70,000 men[48] but there is a need to introduce new types of evidence into a debate where all currently available data sources have been analysed.

The MWGrid project centres on agents representing all the members of the army. The commander, through to the lowliest servant, occupy part of a military structure with one clear goal; to arrive at a destination in a fit state to win a battle. They act as part of a hierarchical organisation but have a certain amount of autonomous decision making capability and travel through an environment that contains a variety of resources required to complete their journey. Multiple executions of the agent-based model are required with different numbers of people and animals, different levels of food availability and different types of organisation and route planning. The simulation will record both the state and progress of the army as well as the effects on the communities impacted by the progress of the army. An army of between 40-70,000 people with attendant horses and pack animals requires over 100,000 agents in order to be modelled on a 1:1 basis. Clearly the processing power and the memory requirements needed for a simulation of the whole 6-month campaign at a high temporal resolution far exceed the capabilities of any conventional machines. Distributed simulation and the harnessing of distributed computing resources can be used to run models that will not effectively run on a single computer[49] but ensuring that the complexity of the model is appropriate to the question being posed can reduce the resources needed to simulate a system. For this reason, a number of smaller targeted models were created.

The need to model and visualise resources for ancient landscapes have further prompted studies using concepts from Complexity and Artificial Life sciences that take into account diverse interactions and adaptability to biotic and abiotic factors. This technique mimics nature's emergent phenomenon – global patterns emerge from the local interactions of simple rules embedded within agents. The application of the model on a small terrain as part of the North Sea Palaeolandscapes Project has been visualised using games engines (**Fig. 12**). This pilot study testing agents as virtual humans, explores survival and settlement behaviours based on resources and the environment (e.g. proximity to water). Agents have reasoning capability and memories that fade with the passing of time, identify object ownerships and family or strangers via tagging. With recent funding through an ERC Advanced Grant, this pilot study will be developed further and across a larger digital terrain perhaps integrating more sophisticated behaviour as well as hunting behaviours.[50]

The provision of a visually sophisticated front end to the analyses presented here may appear frivolous to many computer scientists, or even archaeologists, but there are issues that demand this level of additionality for Arts disciplines – and urban archaeologists stand to benefit significantly from such analyses. The vastly complex outputs of the projects at *Carnuntum*, Wroxeter or Silchester lend themselves to sophisticated visualisation and analysis. This is required, in part, to provide an accessible output for human observers but the concept of visualisation as an investigative tool in its own right is also becoming central to the perceived value of these technologies.

We can explore this in respect of, for instance, Diocletian's Palace. Such palaces are extremely rare but the interpretative issues are common to many archaeological landscapes. The cityscape is a four-dimensional puzzle in which spatial relations of monuments (in Cartesian terms) must be merged with archaeological and personal time (measured by the scale and spatial relationship of structures) and interpretational significance is situated both in the past through the, presumed, liturgical and social significance of the spaces to urban societies, and the present, where our personal appreciation of the surviving landscape or situation of a monument must also be gauged and represented. The archaeologi-

[48] E.g. Haldon 2008, p. 172; Norwich 1991, p. 346.

[49] E.g. Wittek, Rubio-Campillo 2012.

[50] The ERC Advanced Grant Project entitled "Europe's Lost Frontiers: exploring climate change, settlement and colonisation of the submerged landscapes of the North Sea basin using ancient DNA seismic mapping and complex systems modelling", began in December 2015 and will last 5 years, http://www.bradford.ac.uk/life-sciences/arch-sci/lost-frontiers/

cal problems of the Urbs, like any other landscape, are therefore quantitative, semi-quantitative and qualitative in nature. To represent this in any sense is a challenge but any solution will certainly require substantive digital assistance which goes beyond simple measurement, Serious Gaming based on the digital outputs described above provides one route for development and will generate environments where the user experiences an enhanced sensuousness of perception and approximations of time/space movement that can merge archaeometrics with ideational models. Like many other quantitative models there is no claim that such a reconstruction is 'real' in any sense. They are merely a representation of our interpretation, which may itself have an emotional impact upon the observer. However, there is an argument that this is a better representation of how archaeologists actually relate to their subject of study and as represented by much academic publication. In reality this tends to be more emotive than the abstract mapping within traditional articles suggests. At a time when our interpretations of Roman cities are becoming ever more sophisticated we must acknowledge that when archaeologists imagine the squalor of a Roman town they do not think in terms of greyscales or finely drawn plans but of people, places and smell and, ultimately, the majority of the figures in any landscape, or cityscape were the poor. *Viriconium Cornoviorum* may have been a pleasant place to live if you were a member of the elite households but even they could not have avoided the smell of tanning, the distress of cattle being slaughtered and, perhaps, the smell of the *lumpen proletariat* in their workshops when the wind was in the wrong direction. Finding a way to integrate these observations and to communicate them is the challenge of urban studies in the future.

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