DOCUMENTING LARGE ARCHAEOLOGICAL SITES, MANAGING DATA, PLANNING CONSERVATION AND MAINTENANCE: THE HERCULANEUM CONSERVATION PROJECT EXPERIENCE

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ABSTRACT:

Herculaneum, buried by Mount Vesuvius in AD 79, was only extensively excavated during the twentieth century, revealing a remarkable level of preservation but also fragility of what had survived of this Roman seaside town. By the turn of the century, the conservation challenges, paired with the limited capacity of the authorities to respond, was putting the archaeological site at risk. The Herculaneum Conservation Project ('HCP'), a public-private project underway since 2001, has helped turnaround this situation with the presence of an interdisciplinary team working all year round alongside the public authority, today the Archaeological Park of Herculaneum. With the site in a more stable condition, HCP's attention in the last ten years shifted to building up knowledge and competencies for the self-sufficiency of the Park authority in the face of core long-term management obligations. A new focus on conservation proposals that meet the site's needs but are suited to public tendering found its maximum expression in planning long-term site maintenance cycles. Through the voices of the practitioners involved, the paper recounts the resources and approaches that have been developed in this regard, in particular the specific GIS module that breaks down the archaeological site into the items to be maintained and their relative importance. This massive register of 'objects' - walls, architraves, doors, frescoes, mosaics, etc. – is the backbone of the three-year maintenance cycles developed by HCP adopting an innovative procurement framework for co-sourcing services and works in Italy, the first of which is now being implemented by the Park. A web-based application accessible by operators on site allows real time transmission of monitoring data and records of site-works underway to the database and GIS platform, satisfying immediate administrative needs and quality controls but also delineating the scope of subsequent maintenance cycles. Technological and management tools, shaped by, and responsive to, the needs of the site and their users (the heritage practitioners involved), have been put at the service of the entire life cycle of programmed maintenance at an urban scale, both administrative and technical aspects. This is part of a wider upward spiral of management improvements for the long-term sustainability of this important archaeological site.

1. INTRODUCTION

1.1 Context

The conservation and management of Herculaneum presents complexities borne primarily of the archaeological site's particular characteristics, not least areas totalling some 60.000 square metres and often up to 30 metre below the modern town. In particular, the restoration works carried out in conjunction with open-air excavation over a 30 year period in the last century (Camardo, Notomista,2018), reinstated a substantial portion of the ancient city but left us today with an elaborate mix of both ancient and modern elements, and many of the latter problematic. The fragility of the original structures and decorated surfaces was frequently addressed through the use of more robust modern elements, ranging from iron and reinforced concrete lintels to roof coverings of various typologies, to frames that support upper floor levels. The mix of such elements makes conservation and maintenance of the Herculaneum site very complex, not only because of the very close proximity of old and new but also because of the diversity of the components and their needs.
Back in the mid-twentieth century, maintenance activities commenced shortly after restoration work but this virtuous precedent came to a gradual halt in the last decades, provoking an escalation in decay that brought the site to the brink of disaster at the beginning of the new millennium (Thompson, 2008). This trend has been fortunately interrupted thanks to the combined action of the public authority, today the Archaeological Park of Herculaneum, the Packard Humanities Institute and other partners within a long-lasting public-private partnership, the Herculaneum Conservation Project (HCP) now completing its second decade of activities.

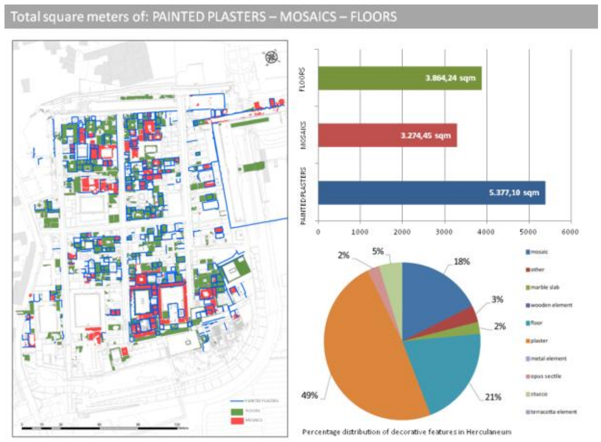

Figure 1: Distribution and quantities of main decorative features in Herculaneum.

Given that it was primarily lack of maintenance that led to Herculaneum being nearly lost for a second time, it is undoubtedly the reinstatement of a site-wide maintenance programme that can be considered the most significant long-term legacy of HCP. With support from HCP's pool of interdisciplinary expertise, the technical staff of the new dedicated public heritage authority created in 2016 are already taking forward the first three-year cycle as part of a broader handover process of knowledge and practice accrued in nearly 20 years of HCP.

1.2 Methodology

A challenge of planning maintenance at Herculaneum lies in finding sufficiently flexible and adaptable solutions that pay due recognition to the intrinsic maintenance characteristics of both ancient and modern elements but also how they respond to change (chemical, mechanical or anthropic). The must also accommodate other variables in the wider management environment such as funding or staff shortages or changing climatic conditions.

Such methodologically dynamic planning work for complex maintenance at an urban scale drew from the outset on analyses made possible by existing geographic information systems (GIS) resources HCP had developed but the need to evolve a dedicated GIS support for maintenance became quickly evident.

Could a tool link the site's features and their needs with the outcomes of information requests and interdisciplinary exchange among practitioners on the front-line of mid- and long-term conservation decision making in all stages of maintenance planning, implementation and evaluation?

This paper seeks to describe the data processing and management system that emerged for site maintenance with the aim of illustrating the importance of user-led technological resources for greater management and conservation effectiveness at an urban scale, a case study that is potentially replicable in other contexts.

2. PLANNING MAINTENANCE: OBJECTIVES

In recent years, the conservation sector has seen the continuous and growing use of geographic information systems for the proper archiving and management of data over time (Letellier, Schmid, Leblanc, 2007). The advantages of the use of GIS in such large-scale and challenging sites as Herculaneum are easily understood, although within the scope of HCP the approach that was pursued from the outset was to use GIS not only as a tool for gaining insight but also for planning.

Indeed, for more than 15 years specialist knowledge from all the conservation disciplines involved has continued to enrich the HCP database, whilst in parallel a team of archaeologists specialized in information systems continuously managed this "body of knowledge", giving back to the interdisciplinary team interpolated data extremely beneficial for building knowledge as well as for management and strategic purposes.

In addition, the regular archiving of material *post operam* relating to works undertaken on site within the scope of HCP has enabled continuous methodological and cost-benefit audits, useful to refine gradually the scope of the projects.

In the context of such a long and substantial public–private partnership as that of HCP, the management of 'what follows' is of particular importance. Since 2009, therefore, the HCP team has worked to build up a shared vision for handing over to the public authority the wealth of knowledge gathered and transferring those approaches that have proved most effective.

The launch of a cyclical and repeatable maintenance programme represents the heart of this vision that focuses on the handover from private to public body. Indeed, with works carried out our conservation proposals awaiting tender processes for the most vulnerable areas of the archaeological site, the HCP team could focus on guaranteeing the sustainability of conservation approaches in the long term, in such a way that the dynamics that caused such damage to the site at the end of the last century could not reoccur. To this end, a cyclic maintenance programme was viewed as the most suitable means for establishing a conservation '*status quo'*. In the same way, the dedicated simplified 'maintenance' GIS was considered the core tool for transmitting the knowledge and supporting PA-ERCO in developing long-term strategies.

When planning for a first experimental project of cyclical maintenance began, it was clear that the principal aim was to design a complete system that included maintenance interventions and monitoring services that lent itself to management by the public partner in the long term. Departing from and honing down existing HCP information technology tools was of paramount importance, so as to make the most of over 15 years' worth of data. For this reason, from the outset there was consensus regarding the need to root the maintenance planning process in two practical support frameworks: a reworked GIS and a flexible procurement environment for outsourcing services and works. The Italian law for public works is notably rigid (Della Torre, Petraroia, 2007) allowing limited flexibility in timing and resources for projects during implementation phases. The relatively new contractual framework called "Accordo Quadro" emerged as a suitable framework uniting works and services and offering unprecedented levels of flexibility and adaptability and over long timeframes (Pesaresi, 2013).A three-year timescale was identified for the maintenance cycles with interim annual evaluation and fine-tuning of maintenance needs and with margins for season specific actions.

It became clear that, with a dedicated maintenance GIS evolving alongside the Accordo Quadro contract could host the planning, implementation and monitoring cycles, a long-term maintenance 'system' for the public authority was in sight. The dynamism of the dedicated GIS as a maintenance planning tool for works and services could accommodate the constant need for data adjustments during implementation phase, gathering results and elaborating them for future use.

The existing HCP GIS had been built for more general purposes and had reached an excessive level of complexity for this purpose. The design a new geographic information system that worked in parallel with the 'mother' GIS incorporating only the data useful for maintenance purposes, a new 'Maintenance GIS', would not only allow the manipulation of data relevant to works and services within the cycles but also still permit interpolation and queries of pre-existing data held in the HCP database.

The most ambitious goal, and perhaps the most rewarding, proved that of planning maintenance works directly within the GIS in such a way as to bond conservation language with ICT language and to verify the limits and the replicability of the system. Through this complex process, the archaeological site has been converted into a 'site system' to function both as a database of both archaeological and decorative features as well as being adaptable for use in bi-dimensional management, typical of the GIS.

3. *OBJECT-ORIENTED* DATA ARCHITECTURE

In-depth analysis of the actual needs of the site, in terms of conservation and management issues, was carried out during the phase of designing the Maintenance GIS. This demonstrated, on the one hand, the aim to guarantee, in the standardization processes, such "specificities" typical of a complex site such as Herculaneum and, on the other, was carried out in line with simplifying the procedures for

collecting data, in accordance with the processes typical of routine maintenance.
The quantity and diversity of the elements that are present at Herculaneum, ranging from carbonized wood to the restorations that took place in the first half of the twentieth century, require the adoption of a flexible approach, which, however, has to dovetail with the need for repetitiveness and monitoring over time, which are common to maintenance operations.
In the face of such constraints and prerequisites, extensive standardization work was carried out, addressing the archaeological site in its entirety while being mindful of the possible relationships that existed between the various objects in question and their geographic position inside the site (Schulz, Dong, Zhang, 2015).
Responding instrumentally to a series of fundamental questions (what? where? how much?) considers the very nature of what comprises the historic-archaeological heritage of Herculaneum and has, without a doubt, helped to define the guidelines within which to develop the design of the information system (Figure 2).

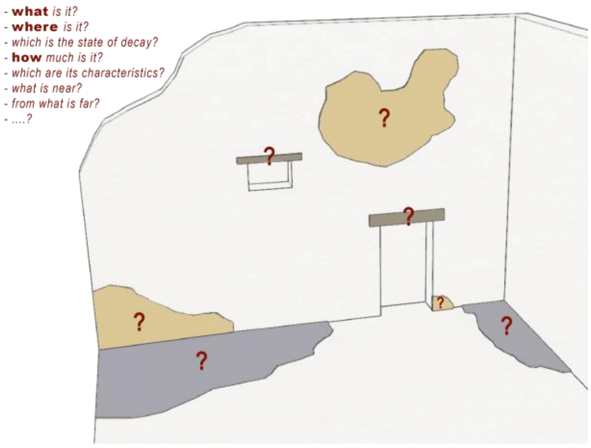

Figure 2: Example of different elements in the archaeological site of Herculaneum and related base-questions to build the Maintenance GIS.

From a strictly IT point of view, the typical logic of *object-oriented* programming (Weisfeld, 2019) has been applied in the definition of the Maintenance GIS database, with particular attention paid to the existing relationships between different elements. Every "object" of the site has been accounted within the system as an "instance" of a "class", defined on the basis of:

- *properties* = the inherent characteristics
- *methods* = the different typologies of maintenance and conservation intervention
- *events* = monitoring of the status of conservation

Figure 3 below summarises the conceptual model (left) applied to the site of Herculaneum and the logical model (right) used for the implementation of the Relational Database Management System (RDMBS):

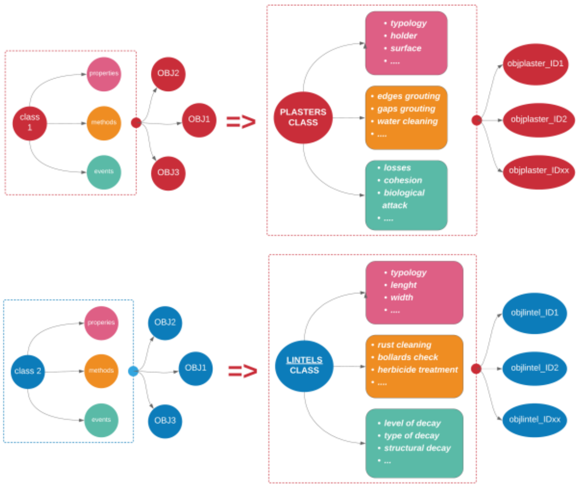

Figure 3: Conceptual model of the object-oriented system used for the implementation of the RDBMS.

This basic structure enabled the construction of a dynamic database that is capable of adapting itself to the needs of the site and of the operations expected in its maintenance.
In particular, one of the main advantages has been the possibility of an "infinite" expansion of the classes in terms of potential redefinition and reclassification of the elements present on the site. Of significance, with a view to long-term management of the data, has been the opportunity to relate, i.e. inherit, the properties and methods belonging to other classes of objects, making the most of the concept of class-based inheritance, which is typical of *object-oriented* computer logic. It should be stressed, however, that the ability to be able to broaden the range of types of action required (or *methods*), for example on the basis of anticipated technological advances specific to that particular class of objects, makes it possible to keep the information associated with a single instance updated without having to interfere with the structure of the entire system.

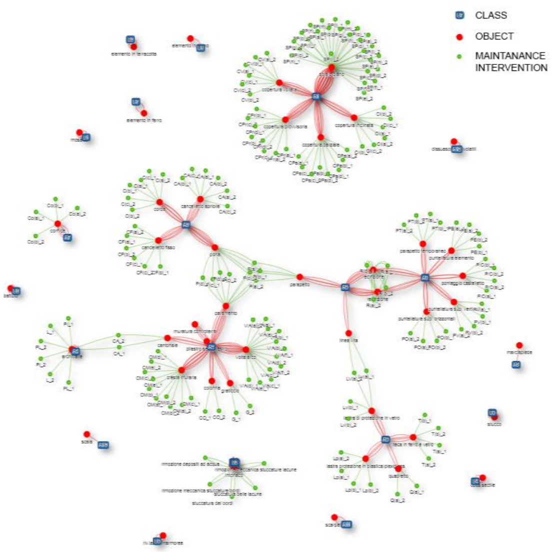

Figure 4: Example of relations between objects and maintenance interventions shared through different nodes (network created with vis.js - https://visjs.org/).

Furthermore, this turns out to be valid also with the potential for extending maintenance not only to the specific area of conservation but also to the overall management of the

archaeological park. For example, it is possible to imagine new classes, such as that of "visitors", with which to associate characteristics drawn from investigating *audience* as opposed to visitor behaviour, preferences, feedback mapped using targeted data collection or automated sensors.
In this phase of implementation the database is made up of 12 classes for the architectural elements (see table below) and 10 for decorative features, for a total of 8,000 recorded objects and 200 standardized maintenance operations linked to the individual classes (see an example in Table 1).

Table 1:

CLASSES	OBJECTS
STRUTTURE DI COPERTURA	copertura inclinata
	copertura parziale
	copertura provvisoria
	copertura voltata
	solaio piano
SCALE DI SERVIZIO	scala
SCARPATE	scarpata
DISSUASORI ANTIVOLATILI	dissuasore antivolatili
STRUTTURE IN MURATURA	cantonale
	colonna
	cresta muraria
	graticcio
	muratura controterra
	paramento
	pilastro/semipilastro
	volta/arco
ELEMENTI DI CHIUSURA	cancelletto apribile
	cancelletto fisso
	corda
	porta
ARCHITRAVI	architrave
ELEMENTI PROVVISIONALI	parapetto temporaneo
	ponteggio/castelletto
	puntellatura elemento
	puntellatura sup. orizzontali
	puntellatura sup. verticali
	recinzione
TECHE/ESPOSITORI	lastra di protezione in vetro
	lastra protezione in plastica/plexiglass
	quadretto
	teca in ferro e vetro
CORNICI E CORDOLI	cornice
ELEMENTI DI PROTEZIONE/SICUREZZA	linea vita
	parapetto
	recinzione
MARCIAPIEDI	marciapiede

Organised in this way, data is managed using a MSSQLServer database and a *web-based* application that is accessible both via *browser* and a specific Android App.
Authorised users, with different levels of access, input the data directly using simple interfaces. The process of *data-entry* is benefited by the option to input it directly into the App using speech recognition; photographs can be taken directly from whatever device is being used and automatically uploaded to a remote *storage* system set up at server level.

Figure 5: Login page of the web-application built to manage alphanumeric data connected to GIS

A second part of the application is dedicated to the handling of summary data by the team of heritage practitioners supervising the works. In this section, it is possible to conduct qualitative validation of the recorded data, prior to issuing progress reports that correspond to the planned project expenditure, as well as monitoring the site's state of preservation.
Using a series of charts, supervising architects and conservators can inform their quantitative tracking of day-to-day decay occurring on the site with hard data which is then the basis for programming future works.

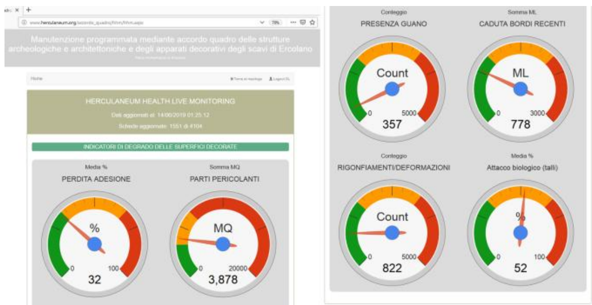

Figure 6: Gauge charts (created with Google Charts - https://developers.google.com/chart/interactive/docs/gallery/gauge) used to visualize dynamic data to monitor the state of decay of the site.

4. MANAGEMENT OF SPATIAL DATA

Each object recorded in the database has its own spatial representation within the GIS, in order to meet the requirements of spatial analysis for the monitoring and programming of activities. Spatial data relating to maintenance constitute a further layer of information that is added to the broader GIS for the Herculaneum archaeological site, which was built and rolled out in 2004 with data sourced from a number of different areas besides conservation.
At the base of the GIS platform sits the so-called urban cadastral plan of Herculaneum. It treats the subdivision of every space present within the site according to a specific codification based on archaeological and use criteria (*insulae*, *domus*, shops, public areas, etc.). The *features* that are used to represent these "urban areas" act as virtual spaces for spatial queries through which alphanumeric information that is archived in the Maintenance GIS can be analysed.
The 3,000-plus polygons into which the archaeological data is broken down (including the outdoor areas) allows for a very detailed monitoring range for every single part of the archaeological site, which can be defined according to different needs. An example is the mapping of those areas open and closed to visitors which undergoes regular updating.
By means of simple spatial queries and *geoprocessing* that

are typical of the GIS environment, the user has a powerful tool for monitoring current activity on the site and for planning maintenance interventions according to the variations in the flow of visitors over the course of the different seasons.

Figure 7: example of spatial analysis for the identification of lintels (red lines) in areas open to the public (green areas).

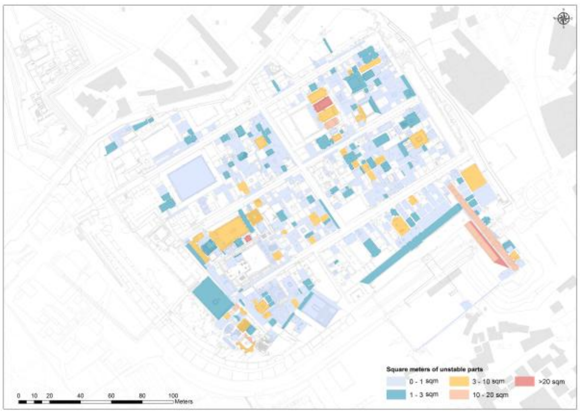

Figure 8: example of GIS quantitative maps of unstable parts of decorative features, used to design and quantify future works.

The Maintenance GIS sits within a much broader view of the Archaeological Park of Herculaneum, which is investing in strategic planning of activities in the medium and long term. Only this type of approach will be able to guarantee the effective operation of the data platform over time, and beyond the life of the HCP initiative. Above all, it should be stressed how the system's sustainability relies on the extent to which it is used by users, and on their ability to keep the data regularly updated, an essential factor in ensuring proper management and recording of the interventions.

5. MANAGEMENT OF MAINTENANCE INTERVENTIONS

Every object that is inserted in the database thus corresponds to a segment of the archaeological site that is significant from a maintenance point of view. It is therefore not directly referred to places (rooms, areas or other) but linked to the architectural and decorative elements that require maintenance. As mentioned above, each object has characteristics associated with it that were compiled and described by individual professionals from the HCP belonging to a specific conservation sector (architect, conservator-restorer, engineer). This resulted in technical sheets defining both general characteristics, relating to the typology that the object belongs to (e.g. structural features) and unique/specific characteristics (e.g. the presence of plaster on a modern lintel).

The technical sheet represents the 'live' part of the database in the sense that it is constantly being updated and improved, adding information about the object. These updates occur during allotted periods ('decay mapping' stage) or at the end of programmed interventions (*post operam* stage). The state of conservation and the state of maintenance are determined by giving weightings in order to be able to assign a final value, which is useful to programme on a priority basis. The object's 'mother' data sheet cascades down to a further two data sheets that focus just on maintenance: one is a description of the intervention and the other relates to its cost. In this way, once the inputting of all the information into the data sheets has been completed and once the sheets have been linked to the intervention sub-sheets, it becomes possible to launch the actual design of the cyclical maintenance for the whole site. The allocation of values to the state of conservation is joined by the assignment of values of 'maintainability' (the extent to which the object can be subjected to maintenance). This process has made it possible to attach an expected timeframe for the intervention to take place (e.g. every 5 years or every season), and consequently permits constant checking of the reliability of these assessments.

The design has been founded on the results of the various queries to the GIS, and especially those interpolating characteristics associated with the objects with other factors already present as data in the pre-existing HCP GIS (e.g. opening to the public, foot traffic, etc.). Such interpolations have produced thematic maps that enabled the architects and conservator-restorers to identify which objects require maintenance, where this maintenance needs to be done, how, and at which level of hierarchy/priority (e.g. for safety reasons, such as lintels or plaster situated high up in areas that are open to the public).

The parallel presence of the data sheets regarding the specifics of the intervention and the financial costs enabled an accurate estimate of the budget required for works and monitoring services, especially those aimed at updating the state of conservation/maintenance.

6. IMPLEMENTING THE SYSTEM: THE OPERATING "MECHANISM"

One of the most interesting aspects of the data system put in place for maintenance at Herculaneum is the opportunity seized to outsource, together with the works, the updating of the 'mother' data sheets utilizing the flexibility of the 'Accordo Quadro' procurement route.

The system establishes, as described above, a web-GIS operating platform that can be managed by different individuals and directly on-site, subject to final validation by the supervising architect of the public authority in charge of the works. In this way, the public authority delegates the verification of the site conditions to external contractors but maintains control mechanisms thanks to the constant online monitoring, which makes it possible to perform, among other things, targeted inspections, comparative analysis with previous data and direct feedback.

The web-GIS interface also facilitates the inputting of *post-operam* data and monitors the progress of works (from the beginning through to the end). Again in this case, the supervising architect of the public authority can consult the online data and then check the progress of the works in person, as necessary. It is an operating mechanism in which users, even if outsourced, are placed in the right conditions to work correctly and in a framework of methodological clarity.

At the same time, the supervising architect and the team that supports him or her can alternate between direct inspection and online checking, and management of the works becomes more light-touch whilst maintaining full control.
The first three-year maintenance cycle, commissioned by the Park authority on the basis of HCP’s plans, will close its first year of activity in late 2019. The HCP and Park teams are working together to assist, monitor and manage the contractor in this pilot implementation phase, a critical and rich testing ground to assess the functionality of the system, its operability and potential difficulties for the public partner who has the long-term mandate to guarantee continuity in the care of this archaeological site.

7. CONCLUSIONS

From the early years of HCP, the role of the data manager and GIS in creating a dynamic platform to facilitate interdisciplinary decision making was a strength of this public-private partnership (D’Andrea, Thompson, 2009). Great importance has been attached to the coordinating role in the management of data, which has ensured a standardized capturing of information, prescribing the "reading rules" for the single elements that have been entered and linking them correctly to the georeferenced system. This has culminated in all current campaigns of conservation works unfolding on site at Herculaneum in 2019 having a dedicated specialist in data management figuring officially as part of the supervising architect’s official team governing the implementation of public works contracts.
Consensus regarding the importance and potential of the Maintenance GIS for Herculaneum among all the diverse disciplines that make up the HCP team has been unerring since the long-term maintenance planning began, and in recent times also among the very committed new Park staff. The Maintenance GIS is the keystone of the site’s future where a systematic approach to the deployment and updating of data is integral and fundamental to every phase of the site’s maintenance ‘life cycles’. It is shared pathway in managing the outsourcing process, the services and works, the recording and aligning of the different needs of the site. It is a sophisticated meeting space for those with a mandate to conserve its cultural significance through the care of those important attributes that convey its multitude of cultural values. User-led deployment of new technologies is proving, in the case of Herculaneum, a significant factor in securing lasting improvements to understanding and decision making in management of the site. However, a critical view is always necessary, as is pragmatism and honesty in the face of shortcomings, and the capacity to revise and adapt an evolving system in perpetual balance, also in response to changing conservation conditions triggered by new challenges such as climate change.
With the first trial year successfully completed, there will be revisions to be made to the system that is being road tested in 2019. Maybe the time will be ripe to compare results with other experiences near and far (Mauro, 2019) and explore the extent to which the approach at Herculaneum can be re-applicable. Can it address other complex archaeological heritage places even in the face of diverse constraints arising from specific management environments, be it acquiring and using data, works procurement traditions or cultural conditions at a site that shape maintenance traditions significantly?

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