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Experimental interpretative model of excavated hydric architecture of Matera city (Italy)

Subterranean spaces present a particular problem as a specific heritage typology, because of their own excavated nature, they are in many cases hidden from human vision, and therefore forgotten. This research aims to propose series of graphic and design strategies to enhance their value in order to fully understand what is hidden, what is not seen, underground architecture.
Based on the studies carried out by previous research, a process of critical reflection is proposed on different graphic interpretative models that will enable the representation of underground heritage spaces and which, in addition, provide a distinctive visual identity.
The main objective of these meditative processes is to improve the enhancement of this heritage typology by facilitating legibility for all the agents involved. The research approaches apparent oppositions such as the relationship between reality and interpretation, tangible and intangible. This experimental interpretative model is based on the case study of the Palombaro Lungo in Matera, Italy.

Keywords:
Underground Built Heritage; UBH; Matera; hydric supply; interpretative model; physical models; digital fabrication

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UNDERGROUND HERITAGE SPACES. THE EXCAVATED CITY OF MATERA.

The city of Matera has its origins in a troglodyte village, being one of the first human settlements in Italy. The underground city, i Sassi di Matera, is one of the most important, both in terms of extension and typology diversity as well as conservation. The human settlement at first was placed in natural caves, with orographic and geological generation. Later, new spaces were carved out from the rock while the community expanded, domestic spaces that were completed with external constructions at their entrances. Burrowing at different heights in the gorge has generated an extensive and unique ensemble, a complex of domestic carved architectures overlapping on the mountainside.
In the 20th century, with the growth of the modern city, il Sasso became gradually depopulated, and the poor conditions of the caves became evident. Scarce natural lighting and ventilation and their difficult access and topography changed the use of the caves to warehouses, often occupied by the most disadvantaged people. In the 1960s the caves were considered sub-standard dwellings and left vacant, nevertheless subsequently a series of measures and strategies were put forward at Institutional level to revalue and revitalise the area, which have led to a gradual urban regeneration. Matera was declared an UNESCO World Heritage Site in 1993 (Varriale, 2019)
In the subterranean city of Matera there are several types of underground carved buildings, mostly for domestic use (Viti & Lupo, 2021b). Other underlying architectures are associated with these, such as water tanks, silos, or icehouses (Viti & Lupo, 2021a). In addition to these typologies, other types of excavated architecture such as cave churches should be highlighted, which, in addition to their specific underground quality, have an additional interest at a pictorial and artistic level (Viti & Lupo, 2020b, 2022a, 2022b).

UBH Problem analysis y research aim

Underground Built Heritage, in addition to the problems that affect all heritage assets when it comes to documenting them, presents a series of conditioning factors specific to the underground typology (Varriale, 2021). On the one hand, these architectures are difficult to relate to the current city above ground level, in many cases remaining hidden, unknown and forgotten (Pace & Salvarani, 2021). On the other hand, their volumetry is characterised by being generated from surfaces of complex geometry, as the result of the extractive process of the material, a quasi-organic quality, which makes each space unique and singular (Corrao et al., 2021). The absence of volumes or spaces with recognisable geometric shapes makes their interpretation particularly complex for the intervening agents. For all these reasons, it is essential to consider and analyse the appropriate graphic methodologies beforehand when it comes to documenting underground architectural spaces.
The usual response is to carry out a volumetric surface scan from the inside, obtaining a defined model with a high degree of precision. Nevertheless, this research offers the result of a reflective process that considers whether a precision survey, such as point clouds, is really necessary in all documentation of heritage assets. The aim of this research is to present an experimental methodology applied to UBH generating a representative model with enough information to adequately describe the building, but also to improve its interpretation and comprehensibility, always in the case of a unique heritage typology such as excavated architecture.
The methodology of this research (Fig. 1) is based on a process of critical reflection on the suitability of different graphic techniques for the representation and correct understanding of underground heritage spaces. The methodology used is composed of several stages: firstly, deciding to work in a specific area, in this case the Basilicata region. After consulting different files and repositories, the existing documentation, both graphical and descriptive, is analysed, being decisive for the choice of the specific case study. In parallel, supported by previous research that deals with the complexity of hidden spaces in architecture, and expressly heritage underground spaces, specific lines of action are drawn. In this case, it is considered of special interest to draw up communication and representation strategies based on the generation of physical models. Analysing the limitations of the existing documentation and through the lines of action previously drawn, a series of three-dimensional models are developed that allow the heritage asset to be understood. These models are always based on 2D planimetry. Furthermore, this research, in its methodological objective, tries to combine the traditional processes of documentation and analysis of heritage with digital knowledge transfer techniques such as digital fabrication.

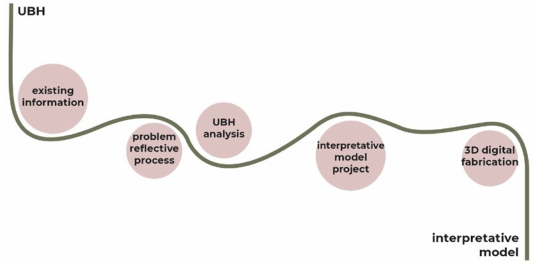

Fig. 1 - Methodological diagram

CASE STUDY. EXCAVATED ARCHITECTURE FOR HYDRIC USE IN MATERA

As a specific case study for the creation of a graphic representative model of the underground heritage typology, the below ground complex placed in the area around Piazza Vittorio Veneto has been chosen, a network of massive tanks used to store the city's water resources.
This part of the city is of special importance due to the density of different types of existing underground spaces, in this case used for water storage. The predominant typology in quantitative

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Fig. 2 - Underground spaces identified in the area around Piazza Vittorio Veneto used for water supply of the city of Matera.

terms is that of isolated cisterns, each containing small volumes of water. The largest water reservoir facilities were contained in the Palombari. Three can be identified in the square (Fig. 2): the palombaro tondo, the palombaro grande and the palombaro lungo, the latter having the largest capacity. The pozzo di raccolta is also remarkable for having a spatially large storage capacity when compared to the rest of the elements of this typology (Fig. 3) (Grano, 2020).

Hydrography of the city. Relationship with the orography

To understand the of Matera hydric infrastructures, it is necessary to take an orographic and geological interpretation of the urban centre and its immediate surroundings. Geologically, the underground spaces of the Sassi have been digged in the calcarenite rock stratum (Sabato et al., 2019), a porous material of low compacity.
The city is located on the boundary between the Murgia plateau to the east and the Bradanica fossa to the west (Manfreda et al., 2015) and its historic area is located on the edge of the mountain, which fosters the proliferation of inhabitable terraced and underground locations. With the growth of the city, the natural water drainage channels at the lowest points of the slopes, the so called grabiglioni, have become the main streets and

Fig. 3 - Comparative physical model of the section drawings of the palombaro tondo, pozzo di raccolta, palombaro grande and palombaro lungo (described from left to right of the image).

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thoroughfares of the Sasso, channelling the water below the street level. As can be seen in the Matera engravings of the late 17th century, there were two main grabiglioni, whose layout nowadays coincides with Via Fiorentini and Via Bruno Buozzi corresponding to the Fosso Barisano and Fosso Caveoso respectively (Fig. 4) (Acito et al., 2012; Viti & Lupo, 2020a).

Fig. 4 - Matera 1641-1702. Giovanni Battista Pacichelli. Source: Viti, E., & Lupo, T. (2020a)

The topography makes the location of both the Palombaro lungo and the other excavated water structures around Piazza V. Veneto a privileged place for water storage, as it is at the end of the catchment area before it is finally discharged into the Barisano del Sasso fosso, through the grabiglione that runs along Via Fiorentini.

Previous research on the case study and its surroundings

On the heritage elements in the surroundings of Piazza Vittorio Veneto, a series of investigations have been carried out previously that focused on the precise survey by using the point cloud. The three-dimensional survey of the Hypogeum at the boundary of the Sassi under the square is an example (Acito et al., 2012). Nonetheless the research [1] with the greatest scientific relevance is the three-dimensional survey of the palombaro lungo itself, by using three-dimensional surveys (Conte, 2008; Conte et al., 2010, 2016). In addition, other analyses have been carried out on specific topics such as constructive studies (Guida & Mecca, 2008). In addition to the research carried out on the hydric supply systems, point cloud surveys of the hypogeum located on the mountainside at lower levels below Piazza Vittorio Veneto have also been performed (Acito et al., 2012).
This group of underground spaces is of particular interest as a structuring factor of the city's configuration and evolution. Piazza Vittorio Veneto is also a strategic urban location as a boundary and a link between the Sassi and the contemporary city (Gómez Arciniegas, 2021).

Composition and formation of the Palombaro from other underground structures

The Palombaro Lungo was unearthed from the aggregation of a series of pre-existing underground spaces of different typologies. From a posterior dig of the remaining material between these spaces, together with the original spaces, a larger storage volume was obtained. The creation of this new infrastructure for the city was planned in 1880.
The complex geometry of the Palombaro Lungo, which is the result of the adhesion and integration of various existing excavated architectures, allows a spatial, typological, and geometric interpretation of the original spaces that generated it. Of particular interest is the way in which the different volumes intersect. This information is considered

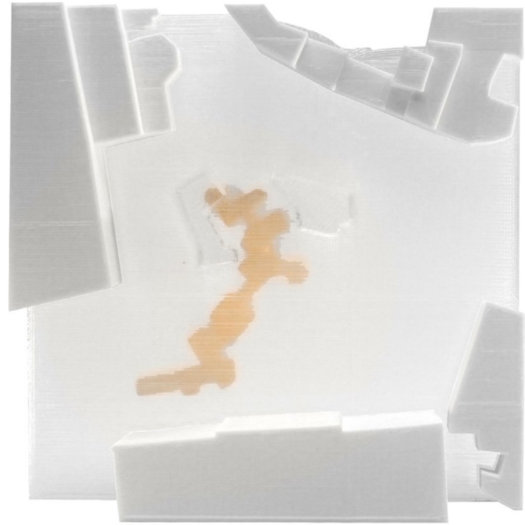

Fig. 5 - Plan view. Physical interpretative model of the palombaro lungo in the area around Piazza Vittorio Veneto.

Fig. 6 - Perspective view. Physical interpretative model of the palombaro lungo in the area around Piazza Vittorio Veneto. Underground view.

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especially relevant for understanding where the floor level of each one of them was. For this purpose, the following spatial analysis is carried out, generated from the existing planimetry.

At the morphological level, two completely independent concatenations can be distinguished. Firstly, the canteen, and its adjacent spaces and secondly, the concerie (tanneries).

The canteen consisted of a main space accesible from the Fosso sotto prefettura, and had a window opening onto the Fosso Santo Spirito, which today is the access to the palombaro lungo. In addition to the central space, there was another annexe at a lower level and of smaller dimensions. Under the main nave of the canteen there were two icehouses of different sizes (Fig. 7).

In addition to the canteen, the Palumbaro Lungo project integrates another series of existing underground spaces. Through another of the shafts in Piazza Vittorio Veneto, the fosso concerie, there was access to other spaces dedicated to the sale of furs, concerie (shown in orange), specifically four of different sizes. The two located further east were incorporated into the volume of the palombaro, maintaining its original geometry in the case of the one located to the north. Three existing adjacent cisterns were also integrated into the carved volume of the palombaro, increasing the empty volume underground.

As can be seen in the three-dimensional view of the floor surfaces, the different existing spaces have a different level, although in addition to the level of the access fosse there are two predominant levels, as can be identified in the section: An upper level that coincides with the main premises of both the canteen and the furrieries, where the lower levels correspond to secondary spaces and annexes to the canteen such as the icehouses. At an intermediate level are the cisterns that are attached to the palombaro.

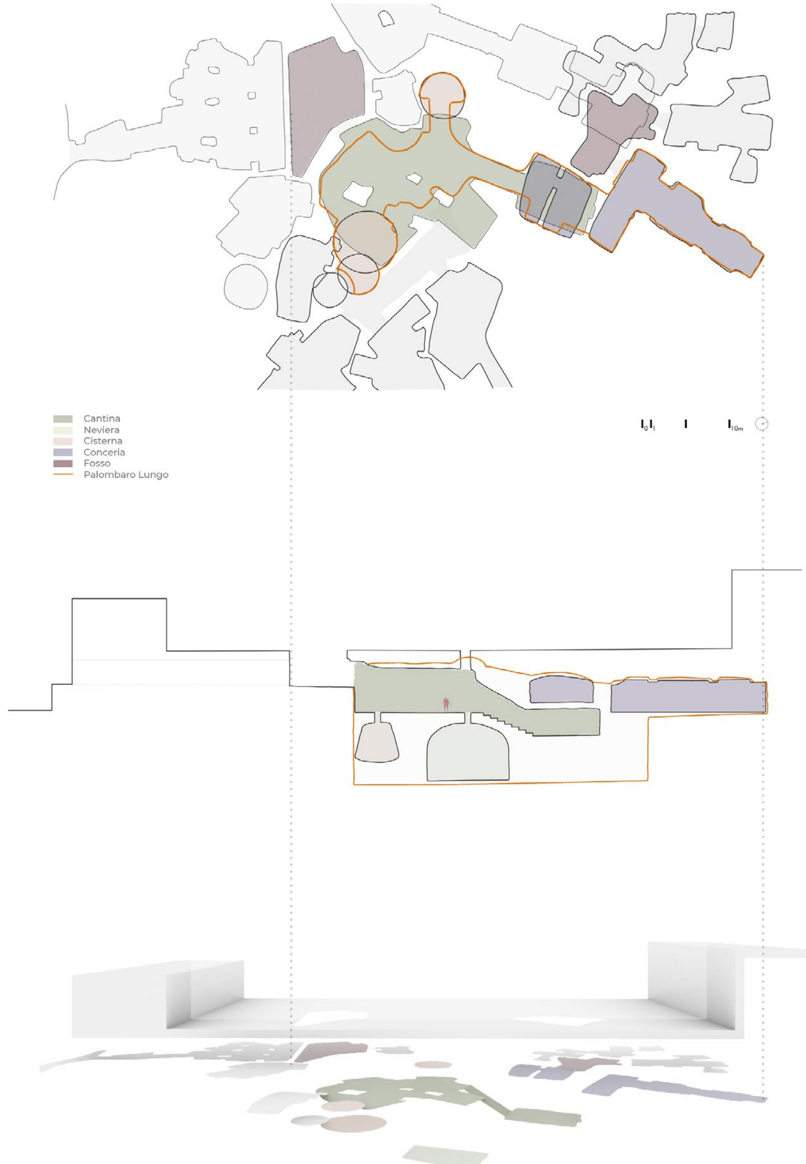

Fig. 7 - Plan, section and three-dimensional view of the set of spaces excavated before the formation of the Palombaro Lungo. 1870. In dark green the cantina, in light green the neviera adjacent, in purple the conceria and in pink the cisterne, the orange line corresponds to the contour of the volume resulting from Palombaro Lungo.

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INTERPRETATIVE MODEL OF PALOMBARO LUNGO PIAZZA V. VENETO

During the process of graphical interpretation of this specific architecture, a series of experimental interpretative models were proposed in an attempt to understand this heritage typology, dealing with key concepts of enhancement based on architectural representation.
To achieve this challenge, we used physical models that allow the observer to have different points of view. When it comes to representing spaces such as subterranean architecture, it allows the hidden and forgotten to be revealed (Fig. 8).

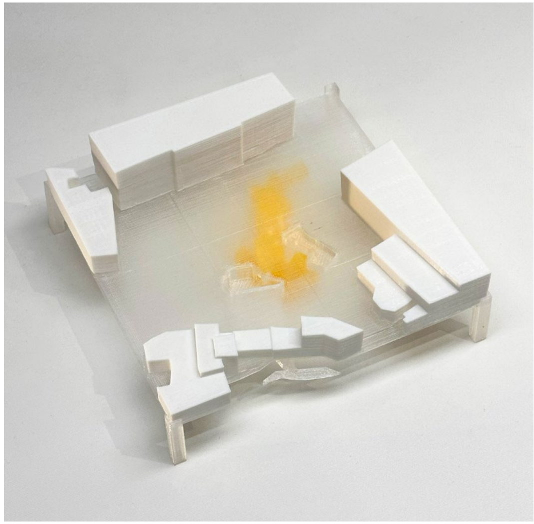

Fig. 8 - Plan view. Physical interpretative model of the palombaro lungo in the area around Piazza Vittorio Veneto.

The physical model as a tangible means of recognising excavated architecture. holding the air

As A. Campo Baeza in analysing the architecture of Manuel and Francisco Aires Mateus, underground spaces can be defined as a carved built volume in search of interstices (Campo Baeza, 2009).
A double conceptual correlation could be established between the underground and the virtual, firstly because of its hidden condition with respect to the emerging city, in most cases of difficult access, and secondly because it must be interpreted through a digital device. Both realities are difficult to perceive: to touch, to feel and therefore to understand, which makes the immersive process of spatial interpretation really complex.
Physical models make the inaccessible tangible. Working with the hands, touching, looking, turning, reading architecture. At the end of the process, they allow the spectator to have full knowledge of the specific object. To facilitate and simplify the reading and understanding of complexity (Riavis, 2019).
With the production of a physical model, a work of simplification and concretion is carried out, where the superfluous has no place, a process of synthesis of the really important information, which facilitates the spatial reading of geometrically complex spaces (Campo Baeza, 2013).
This reflection leads to the next stage of the thinking process, the geometric analysis of the hidden volume.

The structure of flat three-dimensionality

Based on the existing information, consisting mainly of a bidimensional graphic description, by means of vertical and horizontal sections with different levels of detail and time periods, as well as a textual description of the excavated space, we can make a first three-dimensional approximation of the complex geometry resulting from the excavation and the adhesion of the different existing spaces. It is now proposed to construct a three-dimensional model by assembling the different vertical sections. This spatial composition provides an approximate view of the volume of the palombaro. Although it is not a detailed representation, as its development is limited by the existing information, this interpretative model does provide additional information in comparison with the bidimensional representation (Fig. 9).

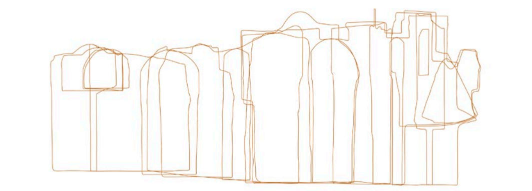

Fig. 9 - Group of section drawings describing the palombaro lungo.

From the lines of three-dimensionally assembled sections, a series of plans are created that contain each of the sections. Like an origami figure or a pop-up book, by assembling a collection of two-dimensional punch cards, a digital spatial model of the heritage asset is generated.
The next objective is to transform this virtual model into a tangible and malleable object that can be manipulated by hand. To do this, a series of volumes are produced using digital fabrication techniques, which, depending on how they are combined, provide a different view of the heritage asset, which, altogether in combination, provide a global view, complementing each other.
The following models were produced: On the one hand, the sections that function as a container element (in white) (Fig. 10), that are manufactured in two separate pieces. The upper piece delimits the space between the level of the square and the lower level of the access fosse to the palombaro; the lower piece is completely buried, limiting the lower levels of the excavated volume. With these two delimiting pieces, it is possible to appreciate and understand what the space of the palombaro

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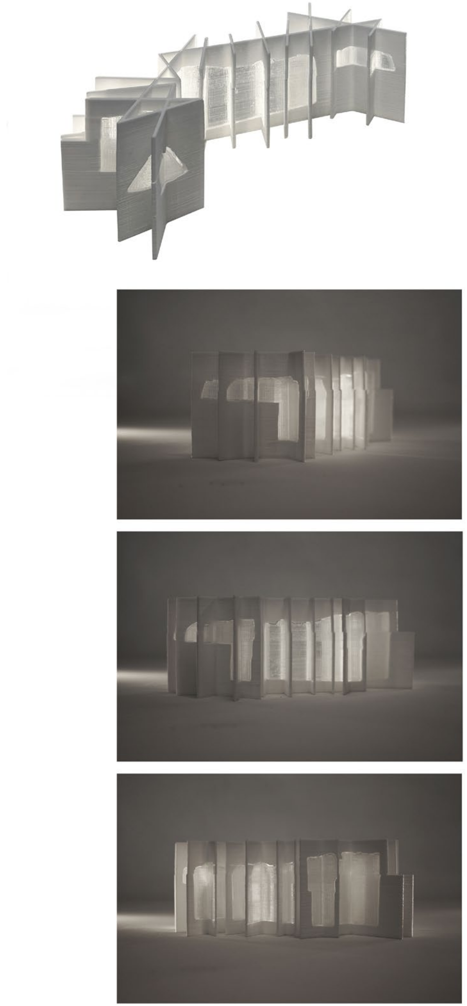
and the different naves is, but to make it easier to understand, a third translucent piece is made corresponding to the set of air sections of the volume of the palombaro, the "negative" of the container sections.



This duality between the opaque and the translucent (Fig. 11) allows us to understand, through the perception and direct manipulation of the physical model, the relationship between the material and the emptiness of this excavated architecture. This set of pieces also allows us to enjoy an immersive experience (Fig. 12), thanks to the light effects with the transparencies and the scale and size of the model, which to some extent resembles the experience lived with virtual reality glasses. The difference is that in this case the observer can choose the approach and the perspective to understand the volumetry of the void heritage space, and is also aware of the analytical operation proposed, that is, they also perceive the analytical operations that are suggested.

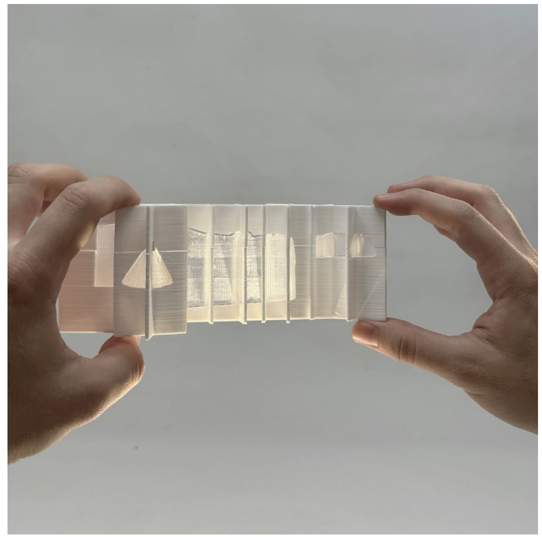


Fig. 10 - Interpretative model of section drawings. In white the pieces that represent the terrain, in translucent the volume of the palombaro.

Fig. 11 - Interpretative model of section drawings. Made with 3D digital fabrication

Fig. 12 - The physical model as a tangible means of recognising excavated architecture.

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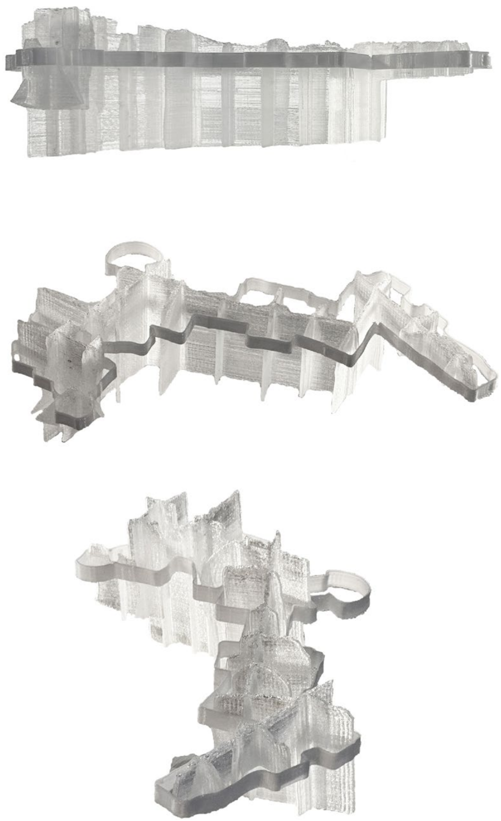
In addition to the interpretative model based on the solid and hollow sections of the palombaro, the following hypothesis is also proposed to improve the three-dimensional information of the heritage space, once the outline of the excavated space has been delimited with the previous model. To this end, the translucent part of the sections of the palombaro is combined with the horizontal section at the level where this space has its largest surface area (Fig. 13). With this strategy, the horizontal perimeter of the palombaro is also defined, as well as the walls that the set of vertical sections is not able to describe.



The set of sections not only defines the outline of the palombaro, of what is hidden, but also describes the surface topography of Piazza Vittorio Veneto. The height of each section depends on the elevations of the city in the surface, providing the model with topographical information on the different heights at which the piazza (square) is located, thus also showing the access to the palombaro. The model also shows the thickness of the terrain separating the exterior space from the underground at each point. In other words, this information makes it possible to relate the hidden space of the palombaro to the contemporary city, which was our primary objective (Fig. 14).

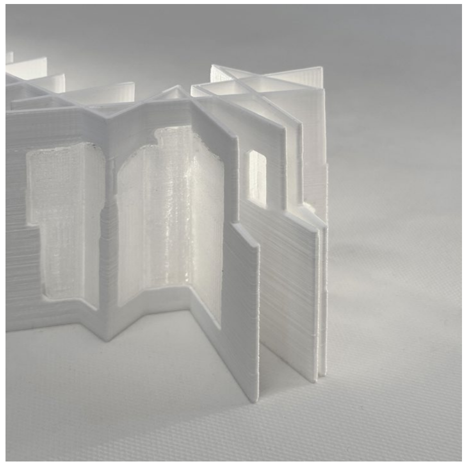


Fig. 14 - The outline of the model as a boundary definitor of the surface city

Fig. 13 - Physical model that combines the volume of vertical sections with the horizontal section of the palombaro.

The geometry of the complex, the solidified void

In this research, one of the strategies for the interpretation of hollowed heritage architecture is focused on understanding the emptiness, the void as a solid, a "built" volume that limits the air inside, or in this case, the water containing the cistern.
Several authors have worked, from different perspectives, on the concept of solidifying the void. Firstly, it is worth mentioning the methodology developed by Jorge Oteiza in his experimental laboratory, related to the extractive process of material, or stereotomy process. As Oteiza describes the simile of the procedure, "the stones half buried in the earth when extracted show the void, exposing any element that was in contact with the removed material" (VV AA, 2013). Oteiza begins his chalk laboratory experimental model as a work in progress, showing successive changes, being aware that the actions of extracting material from the pieces are irreversible (Huércanos, 2016). Based on this methodology, a series of concepts and dualities emerge that allow us to consider and qualify the model of representation, such as the concepts of perforation, void, texture, percolation, boundary conditions or the traces of the invisible (Juárez Chicote, 2016). These processes have in turn become teaching practices in our classes (Fig. 15).
Oteiza's experimental laboratory and the excavated architecture are very similar to the problem we are dealing with. Just as the chalk is carved in order to achieve a specific shape, the underground spaces are obtained through a process of extracting material, in this case earth from the ground. Both processes achieve a specific resulting volume. The first one is a solid carved volume and the second one, a void volume delimited by the solid. This exercise is of great interest in the reflective process on how to approach the representative models of underground spaces.

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Fig. 15 - Pieces obtained from the experimental chalk extraction process. Source: Archive of the Jorge Oteiza Museum Foundation. FD-22215. 88 x 140 mm.

Luigi Moretti performs a process of abstraction of the spaces from their surroundings and context with the aim of achieving a correct interpretation of the interior space. Whence, he bases his work on the solidification of the volume contained by the architecture (Ferrer Forés, 2020). To this end, Moretti defines the qualities of space based on four principles on which the perception of the interior can be appraised: geometric shape, dimension, density, and the pressure exerted by the shapes of the delimiting surfaces. It also establishes a diagonal condition favoured by the concatenation of consecutive spaces at different levels (Moretti, 1953). One of the most outstanding physical models is that of the church of Santa Maria from Guarino Guarini in Lisbon (Fig. 16), and shows in plaster the internal volumes of its main sequence. With these simplified geometric models, the plasticity of the spaces and therefore of the internal envelope (enclosure) is highlighted (García Pedrosa & García de Paredes de Falla, 2019). This process of abstraction that defines the interior spaces or content, as well as the concepts defined by Oteiza, provide the theoretical basis for a new interpretative model of the geometry of underground heritage spaces.

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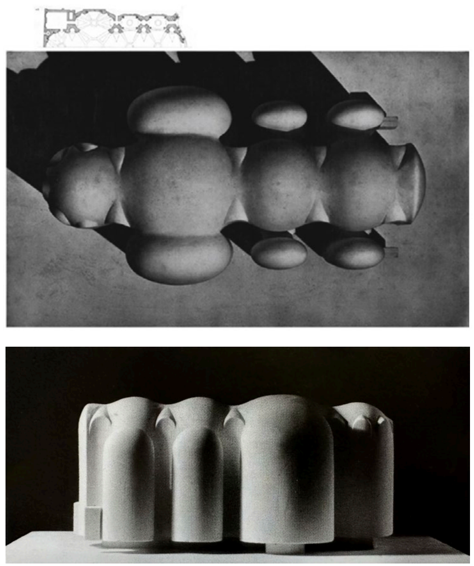

The objective of making a geometric understanding is none other than to comprehend the structure and logic of these spaces, which, due to their subterranean condition and as result of the extractive process, are made up of complex geometries (Acosta et al., 2022; Galera-Rodríguez et al., 2022). Based on the simplification of the geometry, a classification of each of the structures is first made with the help of the morphological and evolutive analysis of the Palombaro that was previously carried out. Each of the naves presents a predominant geometry, distinguishing the proportions between the vertical and horizontal dimensions.

Within this group of spaces, we can differentiate spaces, obtained from a circular floor plan, as a result of having been in origin isolated cisterns. Later they were included in the volume of the palombaro, with a straight vertical section. Among this second type, we must distinguish the naves with horizontal roof covers, which are the largest spaces, and the vaulted naves, usually connecting elements between the former ones.

Once the basic geometries of each space had been determined, a physical mock-up was created. The idea is similar, figure the void with a geometric simplification of the spaces, but instead of plaster models, digital fabrication techniques were used. In this thinking process on the depiction of excavated heritage architecture, a model is proposed that represents the void as a solid and each space as a continuous concatenation of volumes. Each space is represented as an independent piece that fits together, as in the process of anastylosis (Angulo et al., 2017), recovering the geometry of the hidden. In these interpretative models, the material of the solidified volumes is achieved by replacing Moretti's plaster with meltable material, where the traditional mould to obtain the cast of the plaster model is now generated by the heritage asset digital information model through a 3D printer Fig. 17).

Fig. 16 - Luigi Moretti. "Strutture e Sequenze di Spazi". S. Maria della Divina. Source: Moretti, L. (1953).

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Fig. 17 - Physical model of the geometric cutting of the palombaro lungo.

The use of digital fabrication techniques for the generation of interpretative models of historical patrimony has been a recurrent solution in research that seeks an accurate and reliable representation of the architecture (Millán-Millán et al., 2023) but printing also has other beneficial qualities for the documentation and representation of heritage, such as the capacity for quick reproduction of identical models, which favours dissemination (Scianna & Di Filippo, 2019). Nonetheless, the most interesting component of this research is the adaptive and changing capacity of the heritage interpretation depending on the fungible material used and the scale of the models (Mileto et al., 2021).

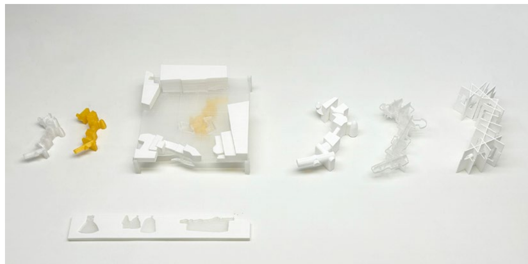

Fig. 18 - Collection of physical models made for the interpretative model of the excavated water architecture of Matera..

CONCLUSIONS

This research has proposed an experimental methodology for the documentation of excavated architecture that focuses on critical reasoning and the competence for abstraction, complementary and parallel to semi-automatic processes such as high-precision surveys where the observers' capacity for reasoning and interpretation is limited to the efficiency of metric capture. Searching beyond conventional representation systems is necessary when working on elements with a singular building process or configuration, as illustrated by this architectural heritage. No one doubts that high-precision surveys based on point cloud have been a revolution and a significant improvement in heritage documentation processes, but in many cases the work is limited to the capture of a huge amount of information. It is necessary to carry out a preliminary process of analytical characteristics that will define the graphic interpretative model that is to be achieved, and subsequently test the possibilities offered by digital methods of production for them to be applied. It is a challenge to go further, avoiding the methodological automatisms that have become customary in the documentation, management, and conservation of heritage.

This research establishes an experimental interpretative model for the documentation of UBH based on the modelling of physical objects that can be touchable and manipulated, but which also leave the analytical process visible such as the use of sections, opacities, and transparencies. Being manipulable and palpable, it can also be observed from an infinite variety of perspectives. The aim is to achieve a personalised and unique experience, where the interpretative capacity of each observer is enriched by their own perception of the procedure followed, of the decisions taken, transcending the idea of offering the user only the real and perfect obtained information. It is a matter of thinking of this heritage object not only as a final product, but as a conceptual construction.

In a nutshell, this investigation manages to convert something practically intangible such as excavated architecture, into something tangible on the basis of a representative and analytical model, and to improve or increase the act of perceiving, with the analytical mechanisms applied.

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NOTE

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