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Multidisciplinary approach to analyse historical water infrastructure and urban transformations: the case study of the *Grabiglione Barisano* in the *Sassi* of Matera, Italy

The historical urban fabrics are the evidence of traditional knowledge and practices generated by urbanization processes that take advantage of the morphological characteristics of the territory. In the past, Matera represented an emblematic example of "smart city", in which the urban transformations guaranteed the ecosystem balance through the creation of a complex water infrastructures network. The most recent urban expansions occurred into the historical districts of the Sassi of Matera and their surrounding areas have led to the alteration of the "urban metabolism", causing dangerous consequences as uncontrolled surface runoff of rainwater and flooding. For these reasons, this study proposes innovative methodological approaches which can guide the development of sustainable solutions capable of preserving the built landscapes. This study analyses the transformations produced on the historical water infrastructure of the Grabiglione Barisano over time e the effects of these changes on the Sasso Barisano urban context, developing the process within the environmental unit of the "watershed" through an hydromorphic approach. The analysis of urban transformations within the watersheds allows us to understand the interrelations between urban fabric and hydromorphic characteristics of the territorial context, overcoming the usual sectoral scientific approaches that analyse separately the different fields of architecture and hydrology. This approach highlights how the construction activity conducted outside the perimeter of the Sasso Barisano watershed, apparently totally independent, has instead influenced the way in which rainwater acts into this historical urban fabric. This contribution proposes an integrated workflow that lays the foundations necessary for further research on the recovery and enhancement of this heritage, reproducible for other case studies.

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INTRODUCTION

The old districts of the Sassi of Matera represented the product of intelligent urbanization processes that respected the intrinsic environmental characteristics, in which the historical water infrastructures took advantage of the morphological characteristics of the territory ensuring interception, channeling and collection of water resources. In this environmental context the natural water courses of Grabiglioni, also called Fossi, have been used to regulate the surface runoff to be transferred to the Gravina Stream, ensuring the ecosystem balance with the other infrastructures that composed a complex integrated water resource management system [1;2]. Matera is located on the western slope of the Gravi na Stream, where its two tributaries watercourses, known as Grabiglioni, generated the particular morphology of the Sassi: the central rocky spur of the Civita and the two urban districts of the Sasso Barisa no and Sasso Caveoso (Fig.1) The past urbanization processes impacted on the natural environment, but at the same time, they guaran teed the ecosystem balance through the creation of different infrastructures, perfectly integrated with the Grabiglioni, such as palombari (public dug tanks for collecting water) and artificial channels. All these infrastructures, which in the past played a central role in the "urban metabolism" [3], have been neglected and transformed over time, irreversibly affecting ecosystem balance. For this reason, the current Sassi suffers from all the imbalances triggered within the historic urban fabric and by the surrounding urban expansions [4;5;6]. This critical condition, which characterizes the historical center of Matera is, however, a widespread condition in many other places and for this reason this contribution represents an important guideline for other researches on different case studies. This study analyses the transformations of the historical water infrastructure focusing on the Grabiglione Barisano over time and the effects of these changes on the Sasso Barisano urban context, developing the process within the environmental unit of the "watershed" through an hydromorphic approach. The hydromorphic analysis aims to highlight how all areas within a single watershed, although apparently independent, are closely related and, for this reason, the transformations produced on a specific area have effects on all the other areas belonging to the watershed.

METHODOLOGY

The analysis of a historical infrastructure provides critical insights into the processes of anthropic transformations of the environment and, consequently, the evolution of the urban fabric over time. This is all the more pertinent in the case of historical water infrastructures, which are intrinsically connected to the physical characteristics of a given territory, particularly its morphology and geological composition. In this regard, the proposed methodology (Fig.2) is structured in the two different necessary steps of the historical analysis, that provides a thorough knowledge of the territorial context, allowing to acquire relevant

Fig. 1 - The Civita and the Sassi historical districts into the current urban fabric of Matera.

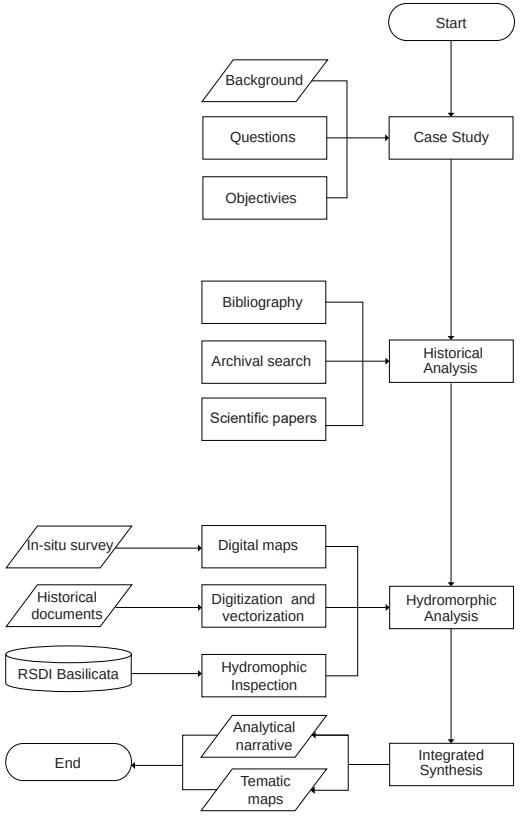

Fig. 2 - Flow-chart of the methodological steps with inputs and outputs .

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information about its evolutionary stages and the hydromorphic analysis identifies the morphological and hydrographic characteristics of the territorial context and the interrelations between urbanization processes and natural environment. By analyzing archive documents it was also possible to reconstruct the appearance of this infrastructure at the beginning of the twentieth century which to day appears invisible from the outside and inaccessible, through the digital redrafting process, while the hydromorphic analysis uses the basic concepts of the watershed and the hydrographic networks, which allow linking the morphological characteristics of a territory to its climatic conditions and hydrological response.

HISTORICAL ANALYSIS

The transformations produced over time up to the first half of the 20th century did not compromise the ecosystem balance. In fact, from the cadastral maps of 1875 and 1898 (Fig.3) it is possible to recognize that the two Grabiglioni, there referred as "Fossi", did not underwent significant transformations: pedestrian paths developed parallel to the direction of the watercourses narrowing the riverbeds; small bridges crossed the watercourses; long stretches of the Grabiglioni were completely topped and even some buildings were located above [6]. Completely different is the configuration of the Grabiglioni in the technical drawings of the first decades of 20th century, in which they appear completely roofed to realize the two main driveways and underground sewer collectors (Fig. 4). The 20th century was the century of massive urban expansion beyond the perimeter of the Sassi. A first expansion plan dates back to the 1930s, while the general urban plan made by the famous Architect Luigi Piccinato in the 1950s (P.R.G. Piccinato) led to the abandonment of the Sassi and the construction of modern neighborhoods characterized by the principles of organic architecture and balance with the rural environment. The urban plan variant from 1975 produced the exponential increase of the urban fabric and the town started to get its contemporary shape (Fig.5). The construction works of a sewer collector on the bottom of the Grabiglione and subsequent roofing for the construction of the road system at the beginning of the twentieth century are documented by the original projects dated 1912 and preserved in the archives of the Municipality of Matera and the Archivio di Stato of Matera. They consist of a general plan, elevation profiles and numerous cross-sections that illustrate in detail the geometrical characteristics of the infrastructure. The original profile of the natural soil, the shape of the collector and the height of the newly designed road are represented. These are particularly interesting documents as they constitute the only

Fig. 4 - Historical technical drawing extract of the Grabiglione Barisano roofing and sewer collector project from Archivio di Stato di Matera.

Fig. 3 - Cadastral map extracts of Matera in (a) 1875 and (b)1898.

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information available on an inaccessible object that is impossible to analyse from the outside [6]. At the same time, the archival search has uncovered historical documents that elucidate the constructive details of the infrastructure, thereby offering valuable insights into the materials employed and the building techniques adopted.
This evidence not only enhances our understanding of historical construction practices but also contributes to the reconstruction of technological knowledge embedded in the cultural and environmental context of the time. Such findings are indispensable for both the preservation of heritage and the informed planning of restoration or adaptive reuse interventions [4-6].
The sewer collector was constructed in concrete with an oval cross-section, featuring internal dimensions of 2.10 meters in height and 1.40 meters in width. The total footprint of the structure, including the concrete vault, measures 2.60 in height and 2.20 meters in width. It is equipped, at variable intervals, with a series of inspection manholes that provide access for internal examination and maintenance.
Therefore, they have been digitized with CAD software to be easily manageable with current technologies (Figs. 6;7;8). Knowledge of this infrastructure and its evolutionary phases is particularly useful in order to understand the behavior of the water flow inside the Grabiglione.

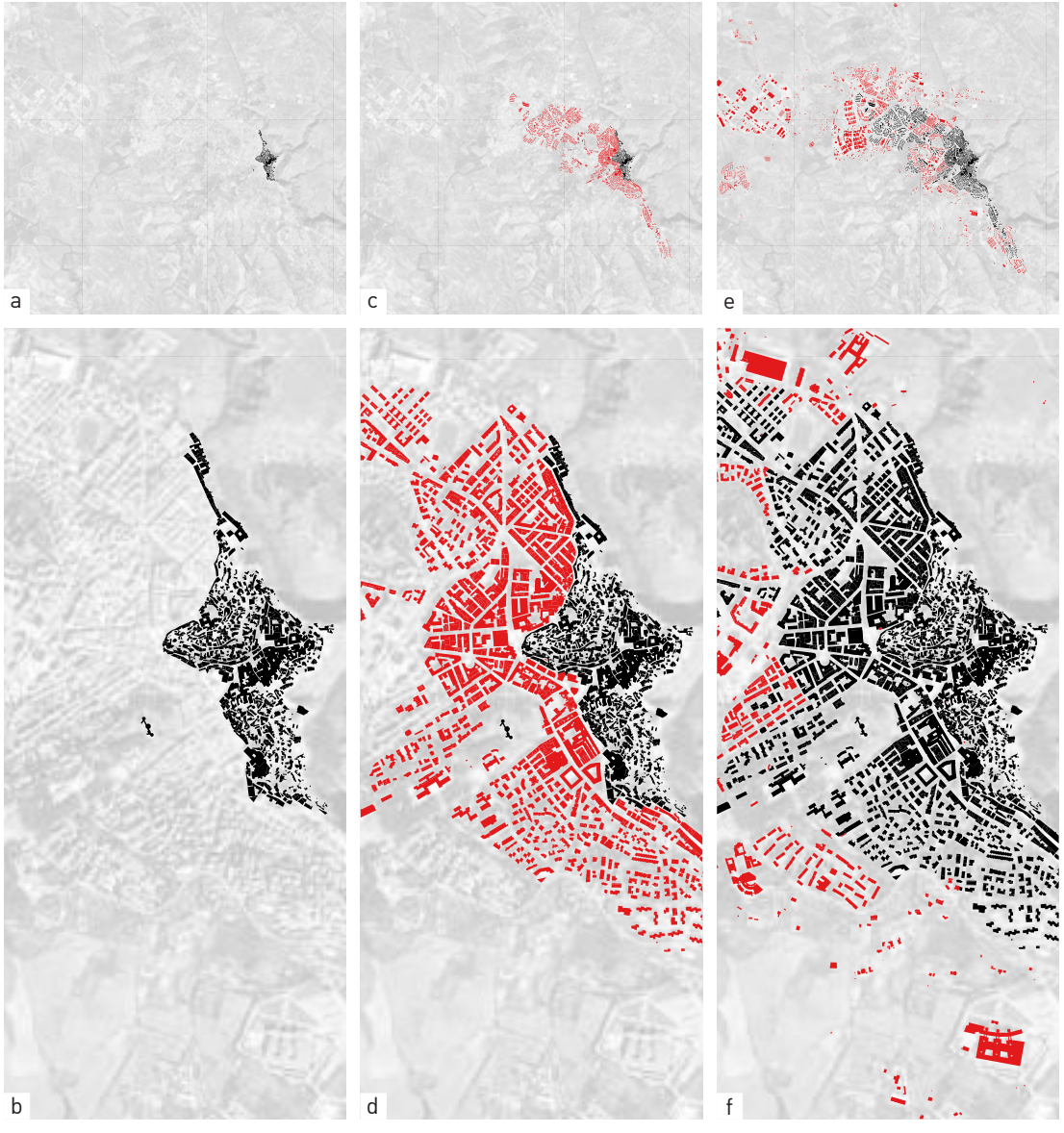

Fig. 5 - (a-b) Urban fabric of Matera in 1875, (c-d) urban fabric expansion from 1930 to 1980, (e-f) urban fabric expansion from 1980 to 2025.

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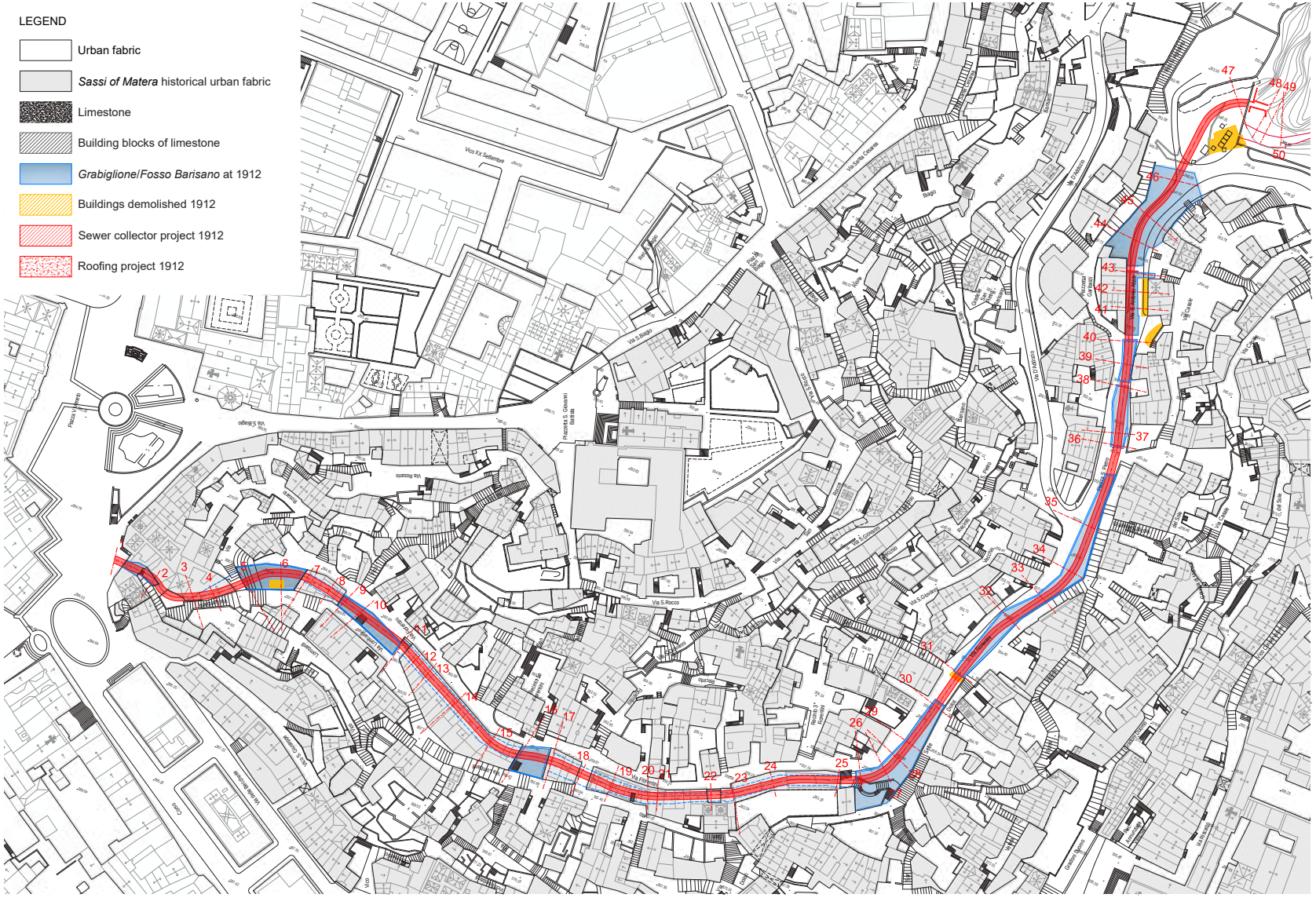

Fig. 6 - Plan of the Grabiglione Barisano water infrastructure overlaid on the current urban network.

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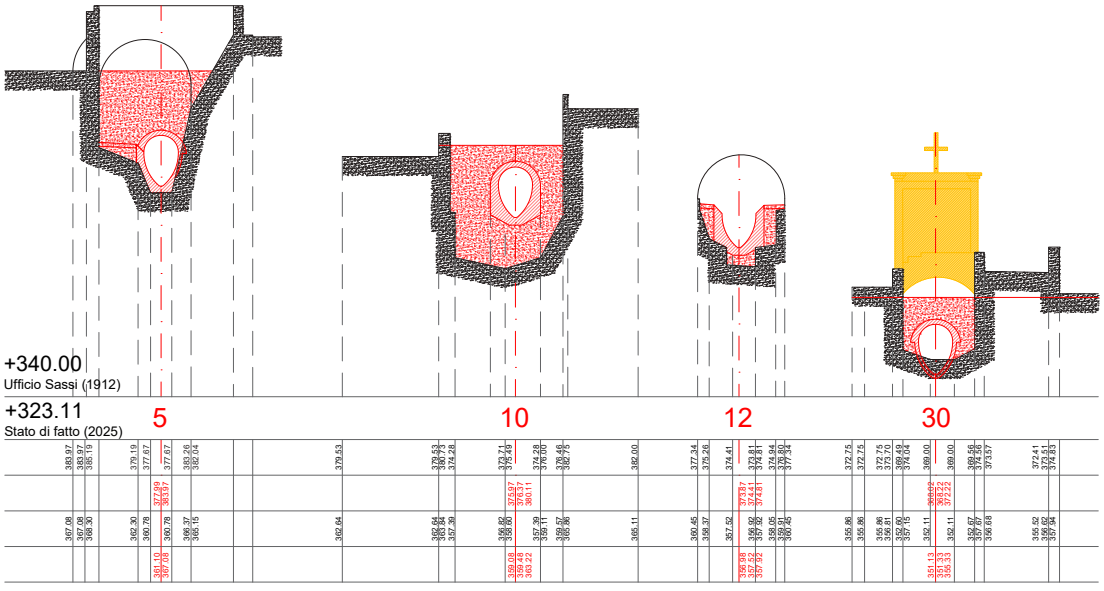

Fig. 7 - Vectorised cross section of the Grabiglione Barisano water infrastructure.

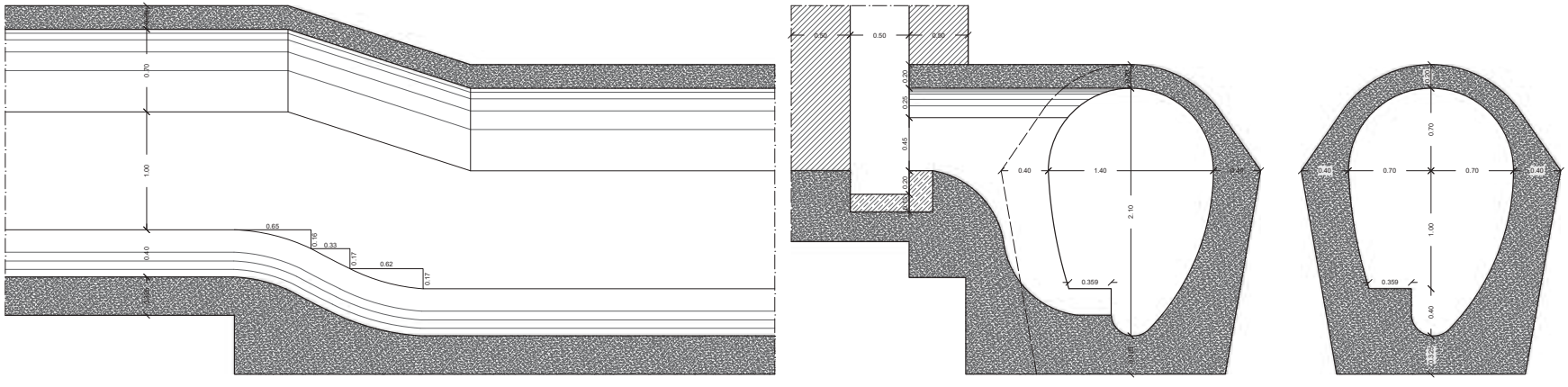

Fig. 8 - Vectorized details of the sewer collector located inside the Grabiglione Barisano.

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HYDROMORPHIC ANALYSIS

The hydromorphic analysis uses the basic concepts of the watershed and the hydrographic networks, which allow linking the morphological characteristics of a territory to its climatic conditions and hydrological response. For this reason an hydrological description is used to assess how an area responds to the changes it undergoes. This was made by processing the Digital Terrain Model (DTM), provided by RSDI Basilicata [7] (5m x 5m resolution) through the Q-GIS 3.4.13/GRASS 7.2.0 software. In this way it is possible to compare the urban fabric with the corresponding watersheds and hydro spatial network (Fig.9.) The area of the historical centre is divided into two independent watersheds, corresponding to the Sasso Caveoso and Sasso Barisano urban districts with their respective upstream areas (Fig.10). For this study it was decided to focus on the Grabiglione Barisano since the archival research led to a greater quantity of documents on the subject. Sasso Barisano watershed covers an area of approximately 1.21 km2 that from Macamarda and Lapillo hills reaches Madonna delle Virtù Street. The mainstream of this watershed coincides with Fiorentini Street and it has an average slope of 7%. Analyzing the changes that occurred in this area, it was noted that some specific transformations occurred in the second half of the nineteenth century, concentrated within the perimeter of the historic town, without however distorting the overall layout (Figs. 11;12). However, it is with the coverage of the Grabilgioni at the beginning of the twentieth century and with the urban expansion of the second half of the century that the situation changes radically. The area upstream of the watershed, historically used exclusively for agriculture, was rapidly occupied by construction, significantly affecting the permeability of the soil. In the Sasso Barisano watershed the impermeable surface increased from 56% (1975) up to 71% (2025) of the total area of 1.21 km2 (Fig. 13).

Fig. 9 - (a) Urban fabric of Matera at 2025, (b-c) urban fabric of Matera at 2025 and urban watersheds.

Fig. 10 - (a) Aerial photography and urban watersheds of the Sassi of Matera and their surrounding areas, (b-c) hydromorphic analysis of Sassi of Matera and their surrounding areas in 2025.

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Fig. 11 - (a) Hydromorphic analysis of the Sasso Barisano watershed at 1875, (b) hydromorphic analysis of the Sasso Barisano watershed at 1898, (c) hydromorphic analysis of the Sasso Barisano watershed in 1912.

Fig. 12 - (a) Grabiglione Barisano in 1875, (b) Grabiglione Barisano in 1898, (c) Grabiglione Barisano in 1912.

Fig. 13 - Diagram of the impermeable surfaces increasing from 1975 to 2025.

DESIGN-ORIENTED AND MANAGEMENT REFLECTIONS FOR HYDRAULIC-RISK MITIGATION

Although this research focuses on a single case study, the dynamics observed in Matera are emblematic of broader conditions shared by many historic cities in Italy and across Europe. Despite their distinctive morphological and cultural identities, such cities have undergone comparable phases of unregulated or weakly coordinated urban expansion, progressively altering the delicate environmental equilibria that historically informed their settlement structures. In this regard, the case study offers an illustrative example of a widespread phenomenon in which alteration and lack of maintenance, together with urban sprawl, of the integrated water-management systems has increased hydraulic vulnerability within historical districts. A return to pre-urban natural conditions is neither feasible nor desirable; nevertheless, contemporary planning and management practices must reintroduce an organic conception of the city as a unified environmental and infrastructural organism, rather than as a mere assemblage of autonomous architectural fragments. This implies that every intervention— whether minor or large-scale—should be assessed in relation to its surrounding context and to the downstream impacts it may generate within the wider urban system. With reference to the specific case of Matere here presented, the current urban regulation plan [8] divides the city into zones primarily on the basis of historical expansion phases and prevailing land uses. Considering the Grabilione Barisano watershed, it becomes evident that this basin intersects multiple zones that appear administratively disconnected but are, in fact, part of the same hydromorphological unit (Fig.14). Adopting the watershed as the primary environmental unit for evaluating the hydrological effects of urban transformations constitutes a significant methodological advancement, capable of transcending the rigid functional zoning that characterised twentieth century planning. Such an approach aligns with the growing emphasis on water-sensitive urban design and ecosystem-based management

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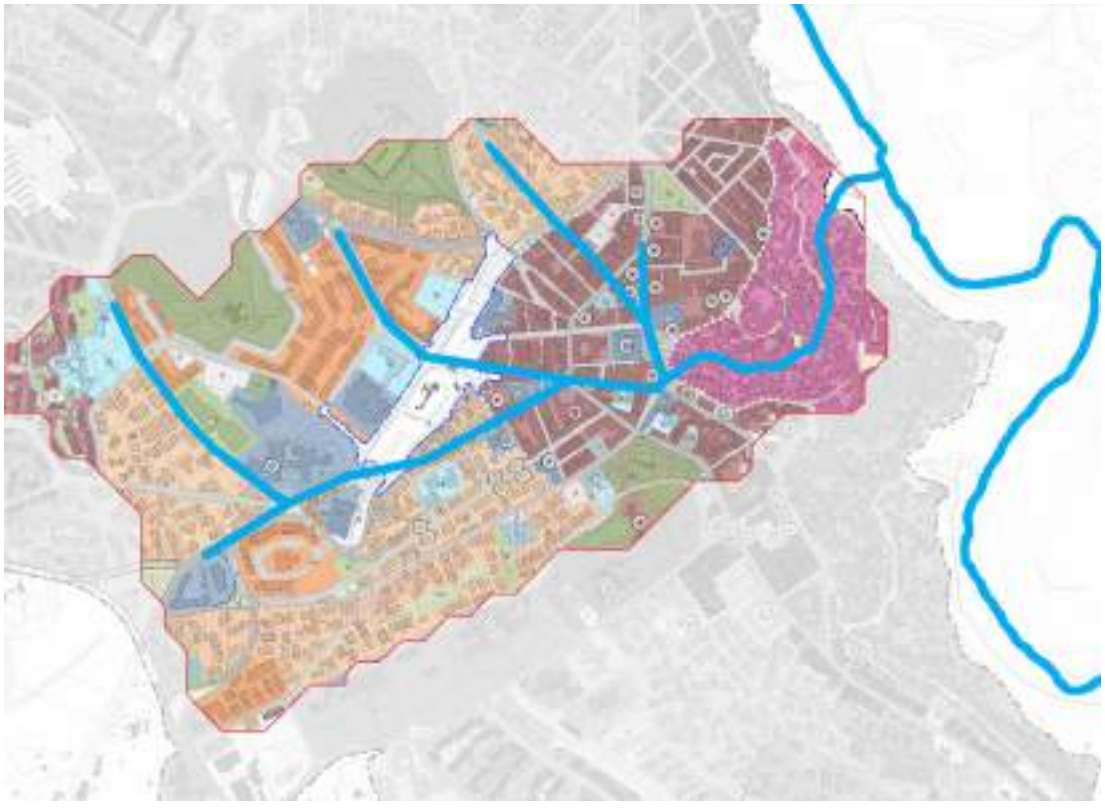

Fig. 14 - Sasso Barisano watershed superimposed on the Matera urban plan (RU 2021- P. 3 Regimi Normativi, d'Uso e d'Intervento dello Spazio Urbano).

frameworks, which promote integrated strategies aimed at reducing surface runoff, enhancing soil permeability, and restoring hydrological continuity at the basin scale.
These considerations highlight how design-oriented and governance tools—ranging from hydraulic compatibility assessments to nature-based solu tions—can support more resilient spatial decision making, particularly in historic contexts where the interplay between heritage, morphology, and hydro logical processes is especially fragile [6;9-13]. It is therefore proposed to foster greater awareness of the hydrogeological dimension of the urban environment and to advocate the adoption of the water shed as the minimum planning unit in future urban- planning instruments [6;9-13]. Such an approach would serve as interventions and anticipate their consequences in areas previously considered independent from one another [6;14].
The case of Matera—where historic water-management systems are recognised as UNESCO heritage yet lack a comprehensive management and maintenance plan—demonstrates the need for urban-planning instruments to give greater consideration to these issues. More generally, the historical hydraulic infrastructures of our cities, which remain in operation, should be systematically incorporated into planning frameworks to enable assessment of how upstream and the urban fabric they support [6;14]. Acting in this direction would make it possible to manage and mitigate the effects of extreme climatic events, which increasingly affect cities, causing flooding, risks to human health, economic losses, and damage to the Historical Heritage [6;14].

RESULTS

This scientific contribution has developed a multidisciplinary methodology for analyzing human induced transformations of the landscape and the irreversible effects of such changes on the "urban metabolism." In particular, infrastructures serve as emblematic examples of these transformations, as their implementation generates a significant impact on the physical dynamics of the pre-existing environment. The study of the historical water infrastructure of the Grabiglione Barisano has shed light on the careful attention historically devoted to the sustainable management of water resources. This was ensured through the adoption of practices specifically tailored to the intrinsic characteristics of the site, in full respect of the ecosystemic balance that had developed over centuries. This situation changed drastically in the early decades of the 20th century, with the construction of a sewer conduit placed within the natural streambed and the subsequent covering of the watercourse to allow for the development of a vehicular road providing access to the historic urban district of Sasso Bari sano (now Via Fiorentini). Despite these targeted interventions along the original watercourse, the modified system was still able to ensure the proper conveyance of surface stormwater runoff toward the Torrente Gravina, thereby preventing flooding and water damage to the dwellings within the historic fabric of the Sassi. The city remained confined within the boundaries of the historical center and was

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flanked upstream by extensive permeable areas, as the surrounding land was used exclusively for agricultural purposes [6;14].
Consequently, the sewer conduit was designed to accommodate the volume of surface runoff generated under these specific conditions. However, the rapid and large-scale urban expansion that occurred in the mid-20th century led to the widespread impermeabilization of the upstream agri cultural areas within the catchment of the Sasso Barisano. The result of these transformations has been a substantial increase in surface runoff, which now exceeds the discharge capacity of the early 20th-century sewer infrastructure. Increasingly frequent floods and inundations are the direct consequence of urban planning decisions that failed to account for the hydromorphological characteristics of the territory, driven instead by a logic of real estate speculation [15;16].

DISCUSSIONS AND CONCLUSIONS

Urban organisms are complex systems composed of countless elements. Urban planning has often considered the city exclusively as an anthropic fact, leaving aside the natural substrate, which although often altered, is perhaps the main component. Water is the main actor of the environmental system, therefore understanding its dynamics of relationship with the other elements is fundamental for a more complete overall vision possible.
This proposed approach, developed on the case study of the Sassi watersheds, highlights how the most recent transformations produced on the historical urban fabrics and their surrounding areas have led to the alteration of ecosystem balance, causing increasingly frequent critical consequences. In particular, the transformations of the Sassi upstream areas and the changes of the natural water collection channels of the Grabiglioni, altering the "urban metabolism", cause periodical critical conditions such as uncontrolled surface runoff of rainwater and flooding (Figs. 15;16).

For this reason, the adoption of a water-sensitive planning approach allows us to assess the compatibility of new building interventions and try, where it is possible, to mitigate the effects of past transformations. It is essential to promote integrated urban strategies in which the hydromorphic impact of urban changes is assessed concretely, as in the case of the Veneto Region, in Italy [17].
Matera, which in recent years has acquired an international resonance thanks to the recognition of the Sassi and their historical water resource management systems as UNESCO Heritage, in 1993, and the designation as European Capital of Culture 2019, could play the role of disseminator of "good practices" in sustainable and resilient urban planning.

Fig. 15 - Photography of the Fiorentini Street in Matera during the heavy rainfall events of 2019 [14].

Fig. 16 - Photography of the Sassi of Matera during the heavy rainfall events of 2023 [15].

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