A Digital-Twin-Oriented Monitoring Framework for Traffic-Related Environmental Hotspots and Future Nature-Based Solutions in Catania

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Abstract. Urban Digital Twins need integrated observations of different systems to consider complex interactions among mobility patterns, environmental conditions and urban greenery. Within the UISH (Urban Intelligence Science Hub) ecosystem, this work proposes an integrated monitoring framework for the city of Catania (Italy). It combines air-quality sensing, traffic monitoring and selected site characterization relevant for future mitigation-oriented studies. While the wider architecture includes radar-based traffic sensors, environmental multi-sensor platforms and portable devices, this work highlights on the AirQino-based monitoring layer, which acts as the main environmental observational backbone of the proposed framework. It consists of 1 mobile unit installed on a public transport bus and 11 fixed stations deployed across transport and green-infrastructure contexts, such as the Famà parking area and Fontanarossa parking area and the Falcone-Famà traffic-green interface. The framework is supported by a spatial design rationale based on representativeness, multi-criteria prioritization, constrained sensor placement, and deployment feasibility, while also incorporating traffic-data integration, privacy-aware local video analytics, and institutional coordination.

The contribution of the paper lies in the formalization of methodological and operational models for integrated urban monitoring. In this sense, the Catania case provides a real-world example of how a sensing architecture may be designed to support Urban Digital Twin development and to enable future analyses of traffic-related environmental hotspots and Nature-Based Solutions in complex urban settings.

Keywords: Urban Digital Twin · multi-sensor monitoring · air quality · traffic monitoring · green infrastructure · Nature-Based Solutions

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1 Introduction

Contemporary cities are increasingly exposed to connected pressures related to vehicular traffic, air pollution, urban heat, and the uneven distribution of green infrastructure. These issues are often addressed through sector-specific approaches, with mobility, environmental quality, and urban mitigation strategies being treated separately. However, such fragmentation limits the possibility of understanding how traffic-related pressures interact with local environmental conditions and how urban interventions may be planned and assessed in a more integrated way [1–3].

On the global scale, ongoing urbanization is exerting increasing pressure on environmental systems, natural resources and local biogeochemical cycles, while also intensifying climate and pollution vulnerabilities in metropolitan regions [4].

In this scenario, the management of mobility and air quality is no longer only a logistic challenge, but also a crucial environmental and public-health problem. Vehicular traffic is typically known as one of the main urban causes of damaging pollutants, including nitrogen dioxide (NO_2) and fine particulate matter ($PM_{2.5}$ and PM_{10}), whose concentration levels are closely linked with respiratory and cardiovascular risks in heavily populated areas [2, 5].

These terms are notably essential in Mediterranean cities, where heavy urban fabrics, restricted ventilation, high solar vulnerability, and the increasing frequency of heatwaves grow both pollutant accumulation and Urban Heat Island impacts. In this respect, Catania symbolizes a highly related case study. Previous studies have demonstrated that its urban microclimate is highly affected by built density, decreased vegetated cover, and local morphological environment, with important effects for heat preservation and environmental quality [6]. Accessibility and mobility issues within the current metropolis further help the need to understand environmental stress not only as a climatic event, but also as a spatial and functional outcome of urban structure [7–9].

In this framework, green infrastructure planning has progressively been recognized as a key strategy to improve urban climate resilience and environmental quality. Such interventions, usually framed as Nature-Based Solutions (NbS), are foreseen to provide pollutant absorption, microclimate management, and heat mitigation, although their current impact is determined by site-specific urban circumstances as well as on the organic status of vegetation [10–13]. Yet, despite the close interrelation between mobility, air quality, thermal stress, and urban ecosystem health, both scientific research and administrative practice have often adopted siloed methods, generating split and partial explanations of urban environmental dynamics.

To overcome these limitations, recent research has moved toward integrated methods able to simultaneously deal with mobility, environmental quality, and green infrastructure within a regular analytical framework. In parallel, the Smart City pattern has advanced the use of Internet of Things (IoT) networks and mixed urban flow data as a basis for real-time monitoring and flexible governance [14, 15]. However, the simple availability of sensors does not certainly cause practical urban understanding. What is progressively required is a structured frame able to join traffic-related pressure, environmental effects, and moderation directed urban elements within a logical operational architecture.

In this regard, Urban Digital Twins have emerged as encouraging frame for integrating different data sources, simulation models and decision-support tools within logical

urban intelligence environments. A Digital Twin of a city should not be realized as a simply virtual description or a static vision system; its real value lies in the possibility of combining real-time sensing, domain-specific models, and compatible data layers to support complex urban decision-making [16–21]. More commonly, the Urban Intelligence paradigm underline the transformation of raw data in multiple domains into operational knowledge, thus supporting evidence-based organization and prospects scenario-oriented governance.

The case of Catania is especially suitable for developing such an approach. Within the Urban Intelligence Science Hub (UISH) framework, the city is treated as a pilot environment in which thematic components devoted to mobility and environmental quality interact with a shared data infrastructure and future decision-support functionalities. In this context, monitoring cannot be conceived as an isolated technical activity. On the contrary, it becomes the observational layer through which traffic conditions, environmental responses, and site-specific urban characteristics can be jointly interpreted.

Despite the growing attention dedicated to Urban Digital Twins, an important methodological gap remains between conceptual system architecture and the operational design of integrated monitoring systems in real urban contexts. Clear frameworks are still needed to define how traffic observation, environmental sensing, and the characterization of urban contexts potentially relevant to mitigation can be jointly organized before the empirical phase.

Against this background, this paper proposes an integrated monitoring framework for the city of Catania, aimed at connecting air-quality and microclimate sensing, traffic observation, and site-specific urban characterization within a unified Digital Twin-oriented architecture, in order to support the identification of traffic-related environmental hotspots and the future assessment of Nature-Based Solutions in traffic-exposed urban contexts.

The paper lies in the formalization of a methodological and operational framework for multi-source urban monitoring, grounded in a real deployment process involving environmental sensors, traffic-related sensing infrastructures, and selected sites characterized by differentiated exposure and mitigation potential. Within the broader sensing ecosystem, the present contribution specifically focuses on the AirQino-based monitoring layer, as it provides the main environmental observational backbone for the selected transport- and green-infrastructure-related case studies.

The conceptual framework of the proposed Digital-Twin-oriented monitoring system, highlighting the transition from multi-domain sensing to future urban assessment, is summarized in Fig. 1.

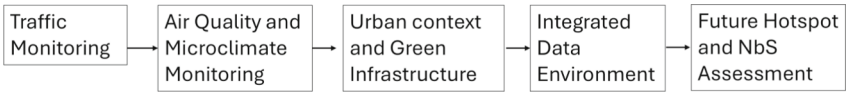


Fig. 1. Conceptual Framework

2 Background and Project Framework

2.1 Urban Intelligence Approach

The proposed framework is developed within the broader Urban Intelligence perspective, which reinterprets the city as a complex system of interacting with subsystems rather than as a set of isolated functional sectors. Within this view, mobility, environmental quality, infrastructure, and urban services are represented through thematic Digital Twins that are designed to operate as interoperable components connected by shared data structures and continuous information flows. Unlike static or sector-specific representations, this approach frames the city as a dynamic and data-driven ecosystem in which heterogeneous observations can be integrated to support joined-up urban analysis and governance [22–25].

In this perspective, the value of monitoring lies not only in the collection of measurements, but in its capacity to enable cross-domain interpretation. Traffic dynamics, environmental conditions, and urban form are not treated as independent layers; rather, they are read as mutually interacting components whose relationships can only be properly understood within an integrated analytical environment. This is one of the main causes why a Digital Twin oriented approach is particularly relevant to complex urban contexts. It allows raw observations to be changed into operational knowledge and supports the transition from siloed data management to more strategic forms of evidence-based planning [14, 19].

The implementation of this approach in Catania is intended to overpass the gap between high-level conceptual architecture and real-world functional needs. The proposed frame is not restricted to the positioning of sensors but is figured as part of a broader methodological structure in which sensing, data integration, and future resolution support are principally linked. Therefore, the consequent system is intended not just to view urban events, but to make the observational foundation for forecasting modelling, combined interpretation and flexible governance.

2.2 UISH and the Catania Pilot Architecture

Within this notional setting, the city of Catania constitutes the pilot environment in which the UISH framework is carried out. The developed architecture for this case study is planned as a set of interconnected functional layers that allow monitoring, data storage, modelling, and future decision-support activities to be joined within a single operational sequence. In this perspective, the monitoring system is not thought of as a stand-alone network, but as part of a more extensive urban intelligence ecosystem in which environmental and mobility data are foreseen to interact constantly.

At the base of this architecture there are two thematic modules: the Digital Twin of Mobility (DTMob) and the Digital Twin of Air Quality (DTAir). DTMob is created to support the observation, interpretation, and future simulation of vehicular and pedestrian dynamics, while DTAir is created to describe environmental conditions by integrating atmospheric measurements, traffic-related pressure and urban-context data. A core attribute of the framework is the dealings between these components: the environmental layer is created to profit from mobility-related information to better define pollutant

emission sources and traffic-exposed circumstances. This relationship demonstrates a system-of-systems logic, in which mobility and environmental quality are examined not as separate domains, but as mutal units of the same urban system [14–21].

The link between these analytical modules and the physical city is provided by the sensing infrastructure, which supplies as the observational backbone of the UISH ecosystem. To control the diversity and volume of the consequent data flow, the framework contains a concentrated Data Lake and a combining layer planned to assemble, store, and provide mixed information through compatible interfaces. This architecture is important for changing scattered observations into a collective data environment, facilitating the connection among thematic modules and helping future analytical processes in a scalable and assignable way [15, 19].

The functional series ultimately move toward future Decision Support System (DSS) features; thus, the role of monitoring increases well beyond diagnostics.

By providing structured observational input to DTMob, DTAir and the joint data environment, the monitoring architecture develops the enabling layer for hotspot identification, scenario searches, and future mitigation-oriented investigation. This is notably important in a city such as Catania, where traffic-intensive corridors, transport infrastructures, parking areas, and green spaces correspond within a heavy and environmentally vulnerable urban framework. Here, the integration of environmental and mobility observations gets especially useful for interpreting traffic-related environmental pressure and for planning future evaluation of diminution strategies, containing Nature-Based Solutions.

Within the wider UISH sensing ecosystem, the proposed architecture includes an AirQino-based environmental monitoring layer, radar-based traffic sensors, environmental multi-sensor platforms, and portable E2SENS devices.

The work highlights the AirQino-based layer joint with traffic monitoring, while admitting the wider integrated architecture in which this layer is integrated. This choice is inspired by the fact that the AirQino network makes up the main environmental observational backbone of the selected case studies and the most direct link between traffic-related disclosure, air-quality interpretation, and future mitigation-oriented assessment.

The reason behind the selection of the urban contexts considered in the framework is not based only on accessibility or technical convenience. Rather, it searches for catching differentiated conditions that are pertinent to the interaction between traffic and environmental quality: contexts directly uncovered to vehicular flows, contexts associated with public transport operations, contexts where environmental monitoring can be understood in relation to adjacent green infrastructure and contexts where existing municipal sensing systems can support traffic observation. In this way, the urban context of Catania does not perform as a simple spatial background, but as an active component of the monitoring design itself.

2.3 Functional Interaction and Data Interoperability

The interaction among thematic modules of the UISH framework directly shapes the design requirements of the sensing architecture. The monitoring phase is conceived as a structured observational layer able to support cross-domain interpretation. This is particularly relevant in urban interface contexts where traffic pressure, environmental

conditions and mitigation potential of green infrastructures coexist and must be analysed jointly rather than through separate sectoral lenses.

Within this logic, the synergy between DTMob and DTAir becomes especially important. Information associated with mobility is not managed as an external background variable, but as a key input for the environmental assessment of areas revealed to urban traffic. On the other hand, environmental observations provide an empirical basis for understanding how traffic pressure interprets into confined air-quality and microclimatic conditions. This joint relationship braces the idea that the monitoring structure should be planned to capture dynamic interactions rather than isolated variables [14–21].

Therefore, data compatibility is a central necessity of the overall system for hotspot recognition and future scenario-oriented analysis [15, 19]. By counting on a shared Data Lake and an integration layer, the framework enables heterogeneous data streams to be stored, connected, and made accessible within a common environment. This allows fixed and mobile environmental observations, traffic-related sensing outputs and sites' information to converge into an integrated analytical structure.

This aspect is particularly relevant for future Nature-Based Solutions assessment. In urban contexts exposed to high traffic volumes, the possibility of evaluating mitigation-oriented configurations depends on the capacity to relate vehicular pressure, environmental response, and features of nearby green infrastructures within the same observational and analytical environment. Therefore, the role of the monitoring network is foundational because it provides the evidence base required to identify traffic-related environmental hotspots and to support future model-based planning within a coherent Urban Intelligence ecosystem.

3 Study Area and Monitoring Design

3.1 Site Selection Methodology

The monitoring design is developed within the urban context of Catania, where traffic-intensive corridors, parking facilities, green spaces and a dense historical fabric coexist within a Mediterranean environment characterized by significant environmental vulnerability. These conditions make the city particularly suitable for a spatially differentiated observation strategy aimed at capturing the interaction between mobility-related pressure and local environmental response.

Site selection was based on the availability of locations and at the same time on the need to represent different urban conditions relevant to the framework. The selected contexts include areas directly exposed to heavy vehicular flows, nodes associated with public transport operations, and urban interfaces where environmental monitoring can be interpreted in relation to nearby green infrastructure. In this way, the study area is an active component of monitoring design.

The placement of sensing devices is guided by a planned spatial logic grounded in the discretization of urban space into rationally meaningful units. These units are featured through multiple dimensions, including environmental pressure, urban vulnerability, morphological conditions, and microclimatic conduct. This approach makes it possible to decide on monitoring concerns through a multi-criteria process. In addition, the classification of a set of sites is carried on based on clustering-oriented reasoning

and restricted placement principles assistance. Thus, it is not limited to the most critical sites, but it is also capable of representing the diversity of urban circumstances across the study area. Therefore, sensor location is treated as a design problem in which information coverage, characterization and technical feasibility must be balanced.

This methodological approach is especially pertinent in a Digital Twin frame because the objective is to provide a robust observational basis for wider interpretation, integration, and future scenario studies [19, 21].

3.2 The AirQino Network and Monitoring Sites

The environmental element of the proposed frame has its center within the AirQino-based monitoring layer, which includes 11 fixed stations and 1 mobile unit. This element constitutes the main observational backbone of the frame and is planned to catch air-quality and microclimate conditions across selected urban frameworks in Catania. The monitored variables include air temperature, relative humidity, and major atmospheric pollutants, allowing to address both environmental description and the presence of traffic-related pressure in dissimilar settings.

The AirQino layer is placed in a set of infrastructures contexts-related transport- and green chosen for their relevance to the environmental meaning of traffic vulnerability. These include bus-based monitoring, the Famà parking area, the Fontanarossa parking area, and the Falcone-Famà interface. The mobile unit extends the observational logic from fixed-point monitoring to trajectory-based acquisition, thus allowing the frame to capture spatial gradients that would continue in part invisible within only static network. In this sense, bus-based monitoring does not only expand the monitored area, but includes a dynamic dimension to the environmental observation of the city.

The fixed monitoring sites play complementary roles within the overall design. The Famà parking area is notably pertinent because of its nearness to both traffic-exposed spaces and adjacent green elements, making it suitable for examining parking-related vulnerability patterns in a transport-oriented urban context. The Fontanarossa parking area, by contrast, sustains a more specific heat-mitigation-oriented point of view. Here, monitoring architecture is designed to relate environmental conditions to the spatial configuration of green infrastructure and to the potential cooling functions associated with different vegetated settings. In this way, the framework interprets these parking areas not simply as transport nodes, but as functional urban ecosystems in which mobility-related pressure and environmental mitigation opportunities can be jointly observed. Figure 2 illustrates the localization and environmental setting of the Famà and Fontanarossa areas.



Fig. 2. Localization of areas. (a) Famà parking lot; (b) Fontanarossa parking lot

Within the broader UISH sensing ecosystem, the framework also includes two radar-based traffic sensors, two environmental multi-sensor platforms, and five portable E2SENS devices. These components contribute to the wider cross-domain logic of the project, but they are only briefly considered in the present contribution, since the focus here is on the AirQino-based environmental layer and on its role in structuring the observational basis for hotspot-oriented analyses.

3.3 Integrated Traffic Sensing and Traffic Green Interface

Traffic sensing is a core component of the proposed framework, as environmental observations are explicitly linked to mobility conditions and vehicular pressure. In this perspective, the AirQino-based monitoring layer is combined with a traffic-monitoring system that relies both on dedicated sensing devices and on existing municipal infrastructures. This integrated design allows air-quality and microclimatic observations to be analysed together with traffic dynamics, thereby supporting a more robust interpretation of traffic-exposed urban contexts.

A typical characteristic of the Catania pilot is its ability to build upon pre-existing municipal sensing assets, combining video-surveillance infrastructures and radar-based devices with recently stationed environmental sensors. This approach makes the frame both technologically practical and formally realistic, since it influences actual municipal property to supply the mobility-related information required for environmental interpretation. At the same time, the framework contains privacy-aware local video analytics, in which raw video streams are processed in situ and only joint or anonymized outputs are used for analytical purposes. This strategy avoids the circulation of sensitive visual data while still facilitating the extraction of vehicular flow and other information related to traffic which are needed for Digital Twin applications and integrated hotspot evaluations.

This traffic-monitoring logic is particularly important because it permits the combined observation of vehicular pressure and environmental conditions in the same urban settings. Rather than directing traffic as a separate engineering problem, the frame considers it into the environmental interpretation of urban space. This is notably pertinent in traffic-exposed areas, where pollutant concentrations and microclimatic conditions are firmly affected by the intensity and spatial organization of vehicular flows.

This integrated observation logic is especially evident in the selected pilot areas. The Fontanarossa parking area was selected because of the traffic pressure connected with its proximity to the airport, one of the main intermodal transport hubs in the city, and because of the significant presence of different tree species within the site, which makes it especially suitable for heat and vegetation-related environmental examination. Figure 3 shows the site configuration and the spatial distribution of the mapped tree species.

A consistent reasoning highlights the selection of the Falcone-Famà area, which constitutes a strategic traffic–green interface. The Famà parking lot was selected as a representative transport-related setting distinguished by frequent urban traffic pressure, while the nearby Parco Falcone e Borsellino supplies the corresponding green equivalent. In this case, the monitoring design is meant to catch the environmental gradient between a traffic-exposed area and an adjacent vegetated context, thereby assisting future analyses of how mobility-related pressure communicates with local environmental conditions and green-infrastructure-related diminution potential. Figure 4 illustrates the logic of this traffic-green interface and the relative positioning of the main observational contexts.



Fig. 3. Aerial view of the Fontanarossa parking lot with a zoom representing the distribution of different tree species.



Fig. 4. Aerial view of the Famà parking lot with a zoom representing Falcone Park

4 Sensor Placement

4.1 Multi-source Environmental Sensing Architecture

The technical architecture of the proposed frame is a multi-source sensing layer intended to support high-frequency environmental and mobility-related data acquisition within the broader UISH ecosystem. It lies the AirQino-based monitoring network, which forms the main environmental observational backbone of the framework. This layer includes 11 fixed stations and 1 mobile unit, set up to catch both air-quality and microclimatic states across chosen urban contexts in Catania. The observed variables include O_3, NO_2, CO, CO_2, $PM_{2.5}$, PM_{10}, air temperature, and relative humidity, thus enabling the combined observation of pollutant dynamics and local atmospheric conditions.

From a technical point of view, the coincidence of stationery and mobile AirQino units permits the framework to address the typical trade-off between temporal continuity and spatial granularity. While the fixed stations guarantee constant observations at representative locations, the unit placement on the bus presents a trajectory-based

monitoring logic able to catch spatial gradients and limited vulnerability patterns that would remain only in part visible within a simple static network. In this sense, the mobile sensor actions as a dynamic observational investigation that enhances the fixed network and expands its interpretative reach. Examples of mobile monitoring unit installation on the public transport bus are shown in Fig. 5.

Within the broader UISH sensing ecosystem, this environmental layer is matched by additional sensing components, including two radar-based traffic sensors, two environmental multi-sensor platforms, and five portable E2SENS devices. These elements contribute to the overall cross-domain architecture by broadening the range of environmental and mobility-related observations.

To complete the environmental observations, the overall architecture also includes a mobility-sensing component based on radar devices and privacy-aware video analytics, as discussed in the next sub-section. This setup allows raw vehicular movement to be transformed into aggregated and obscured traffic metadata, which can then be synchronized with the environmental streams. At the level of the broader digital ecosystem, this integration is necessary for concerning local air-quality patterns to vehicular pressure and for supporting the interaction between the mobility and environmental components of the UISH framework.



Fig. 5. Examples of the mobile monitoring unit installation on the public transport bu

4.2 Traffic Video Analytics Integration

Traffic-related information is a key component of monitoring architecture, as environmental observations are explicitly linked to vehicular pressure. Within the planned framework, traffic data are expected to be obtained from both dedicated radar sensing devices and existing municipal infrastructures, including radar-based systems and fixed urban surveillance cameras (see Fig. 6). In this point of view, traffic monitoring contributes directly to the identification and interpretation of traffic-related environmental hotspots.

A distinctive element of the framework lies in the use of urban video-surveillance cameras as part of the operational sensing infrastructure of the city. These devices are used as continuous observation sources for critical nodes and corridors. Through an AI-based processing conduit, video streams are locally processed in order to discover, track,

and count vehicles and to restore movement-related information across the observed scene. This permits raw visual data to be progressively transformed into structured traffic variables, such as directional flows and movement patterns, which can then be coordinated and assessed with the environmental observations collected by the AirQino network.

This approach makes it possible to change existing urban video resources into analysis of complete traffic information without depending only on invasive field campaigns. In addition, it allows traffic observations to be related to dynamic vehicular conditions rather than static measurements. In practical terms, radar data and locally processed video flows help reconstruct traffic pressure in selected areas and therefore support the environmental interpretation of the AirQino-based monitoring layer.

At the same time, the use of video-derived information requires privacy-aware processing schemes based on local analysis and on the generation of aggregated or anonymized outputs, so that traffic observation remains compatible with a responsible and operationally realistic data-governance approach. Within the broader UISH ecosystem, the resulting traffic descriptors can support both the environmental reading of sites exposed to high traffic volumes and the future integration of empirical observations into modelling and Digital Twin analytical workflows.

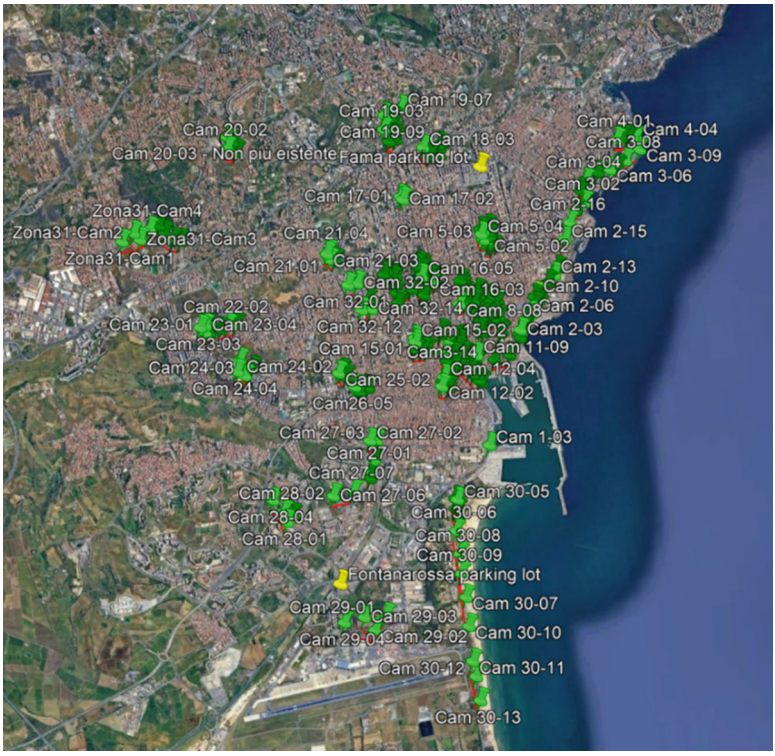


Fig. 6. Geolocation of fixed urban surveillance cameras installed in the city of Catania

4.3 Hybrid Infrastructure and Mitigation-Oriented Monitoring

To complement traffic and environmental sensing, the broader UISH architecture incorporates a specialized ecological monitoring layer designed to observe the response of green infrastructure to urban stress. This component extends the framework beyond conventional air-quality monitoring by including instruments specifically intended at catching the thermal and physiological behaviour of urban vegetation. In particular, the ecological sensing layer includes thermometric range and plant-level devices, such as Bioristor-based solutions for in vivo monitoring, which provide detailed information on the condition and feedback of vegetation under different environmental pressures. An example of the installation of environmental sensing units for plant-level monitoring is shown in Fig. 7. The use of this layer must satisfy the same feasibility needs that apply to the rest of the monitoring architecture. Power supply, installation height, accessibility for maintenance, protection against vandalism, and compatibility with the physical characteristics of the monitored vegetation all influence the realistic implementation of the system.

Within the overall framework, the role of this layer is to support a broader mitigation-oriented interpretation of urban environments. By combining environmental observations, traffic-related pressure and plant-response indicators within the same analytical ecosystem, the framework establishes a common interpretative basis through which ecological response can be related to mobility-related stress.

This ecological sensing layer is particularly relevant for future Nature-Based Solutions assessment within the UISH urban intelligence ecosystem. The inclusion of plant-level and thermal monitoring devices provides the observational basis needed for future analyses of how urban vegetation responds to localized traffic pressure, heat stress, and environmental exposure.

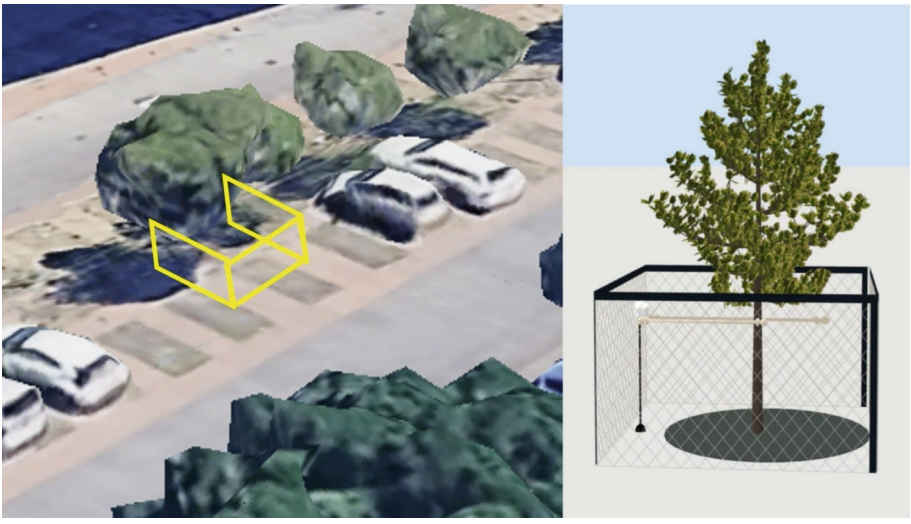


Fig. 7. Installation of environmental sensing units for plant-level monitoring

5 Environmental Hotspots and Nature-Based Solutions

In the proposed framework, traffic is treated as a major source of environmental pressure able to affect local air quality and, more broadly, the environmental conditions experienced in urban space. The purpose of monitoring expands from the estimation of vehicular counts and flow conditions to the identification of urban situations in which emissions, exposure, urban morphology, and environmental sensitivity interact in especially relevant ways.

Within this perspective, traffic-related environmental hotspots are interpreted as priority urban contexts in which integrated monitoring may provide the observational basis for future mitigation-oriented investigations.

By identifying traffic-exposed contexts and structuring monitoring around air quality, mobility conditions, and features of green infrastructures, the framework enables future analyses of weather and how specific urban configurations may support mitigation. Therefore, the proposed approach turns fragmented observation into a more structured basis for future hotspot-oriented and Nature-Based-Solutions-oriented urban analysis [26–29]. This interpretative logic is particularly relevant in dense urban settings, where the effects of vehicular activity cannot be separated from the characteristics of local morphology, land use, and environmental sensitivity.

The Catania pilot illustrates this logic through the selection of urban contexts in which mobility pressure and mitigation-related urban elements spatially coexist. This perspective is related to the selected case studies. Falcone-Famà provides a representative example of a traffic-green interface suitable for future pollutant-mitigation-oriented analyses, while Fontanarossa offers a context more directly related to heat-mitigation-oriented configurations.

6 Discussion and Conclusions

The paper formalizes a coherent sensing architecture within the broader UISH Digital-Twin-oriented environment, providing a methodological and operational reference for integrated urban monitoring in Catania.

The main value of the proposed framework lies in its attempt to bridge the gap between conceptual Urban Digital Twin architecture and the concrete design of real urban monitoring systems. While much of the debate on Digital Twins focuses on modelling environments, simulation, and data integration, the observational layer is often treated as secondary or assumed to be already available. This paper takes the opposite path by placing the monitoring architecture at the center of the discussion. It highlights that the quality of future modelling and decision-support activities relies on how sensing is structured, spatially dispersed and integrated before empirical results become accessible.

A second contribution is the integration of urban domains that are often managed independently. By jointly considering traffic observation, AirQino-based environmental sensing and green-infrastructure urban contexts, the framework helps a more systemic interpretation of traffic-related environmental pressure. This is notably relevant in urban areas where vehicular flows, public-space disclosure, parking-related functions, and

green elements correspond within short spatial ranges. In such situations, isolated observations are often not enough to support meaningful explanation or mitigation-oriented planning.

In addition, the integration of different observational layers within the wider UISH ecosystem makes up an additional value of our planned frame. The interaction between DTMob, DTAir, the shared Data Lake, and future DSS-oriented features gives the monitoring network a role that goes beyond simple diagnostics. Within this architecture, environmental sensing, traffic metadata, and ecological observations are progressively organized into a common interpretative environment, thereby supporting future cross-domain analyses and model-based decision-making.

Nevertheless, the real-world complexity of building integrated monitoring systems may evolve some implementation details according to institutional timing, site accessibility and technical adjustments. In this sense, the framework provides both a concrete basis for the next empirical phase and a transferable reference for forthcoming assessments of urban climate resilience and sustainable mobility in complex urban settings.

Once monitoring data becomes available, next research steps will focus on subsequent phases of data integration, calibration and scenario analysis. It will allow the comparison of traffic-related environmental hotspots, the interpretation of localized environmental responses and the assessment of Nature-Based Solutions in contexts where vehicular pressure and ecological opportunities spatially intersect. In addition, further validation across multiple case studies could be considered as a promising direction for future research, to strengthen the generalizability and robustness of the proposed framework.

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