A web-based application for the spatiotemporal monitoring of the impact of Nature-Based solutions on the urban environment and the well-being of citizens: “The euPOLIS visualization platform”

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ABSTRACT

Nature-Based Solutions (NBS) have become increasingly popular for addressing environmental and societal challenges in urban areas while providing human well-being and biodiversity benefits. A web-based application, to attain the desired optimization and evaluation of such proposed solutions, is of considerable importance. In this work, we introduce the “euPOLIS Visualization Platform”. This platform provides an innovative solution for monitoring the spatiotemporal impact of NBS on the urban environment and the well-being of citizens. The platform facilitates the ability of users to explore, comprehend, and evaluate the proposed solutions, through 2D and 3D views of the city environment, enriched with temporal data provided by the system (e.g., simulations and sensor information analysis). Deployed tools offer a dynamic interface that is adaptable to the user's requirements and possesses the ability to display a range of information, stored within a Data Management System, including measurements from meteorological and air pollution monitoring stations, and advanced analytical, numerical, and time-based data. The results of the platform's analysis will be of great value to stakeholders, such as policymakers and urban planners, interested in understanding the effectiveness of NBS interventions in promoting sustainable urban development and enhancing citizens’ quality of life. The euPOLIS Visualization Platform (eVP) aims to offer complete and easily accessible means of monitoring the effects of NBS on the urban environment and human well-being, by leveraging and combining cutting-edge technologies into one state-of-the-art platform.

Keywords: Nature-Based Solutions (NBS), euPOLIS platform, Visualization platform, Urban environment, Well-being, Physical health, Monitoring

1. INTRODUCTION

In the modern era, multiple adverse effects are observed worldwide, ranging from climate change to biodiversity loss and several natural disasters, which directly impact human well-being. Effects on both people and nature are first experienced in cities, where approximately half of the human population on a global scale can be found. Climate change, urbanization, and the accompanying increases in the size and number of cities are placing a variety of interrelated pressures on ecosystems[1]. These problematic situations need to be addressed decisively, by adopting a holistic approach that considers sustainability’s both social and environmental dimensions.

An emerging and promising strategy is based on the implementation of Nature-Based Solutions (NBS), which value nature’s ability to help overcome these challenges[2]. NBS have emerged within the last decade[3], as international organizations and private companies are exploring ways to mitigate climate change effects, ensuring a sustainable equilibrium between nature, biodiversity, and conventional engineering solutions, recognizing NBS as a framework for their strategy to offset their greenhouse gas emissions and achieve the Paris agreement climate goals[4]. Furthermore, NBS can play a significant role in contributing to the United Nations Sustainable Development Goals (SDGs)[5], especially in the 11^{th} SDG whose main target is to make cities and human settlements inclusive, safe, resilient, and sustainable[6].

Over the past years, NBS have been widely used in European cities[7] as feasible solutions to tackle environmental and societal challenges occurring in urban areas, such as climate change, urban deterioration, and aging infrastructures[8]

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indicatively by using Blue Green Solutions (BG)[9], creating green jobs, improving in place attractiveness, and upgrading health and quality of life[10]. Scientific literature[11], as well as governmental and non-governmental programs[12] increasingly refer to the NBS approach, as an easily-constructed and logical-to-interpret concept. Aiming to achieve an advanced understanding of NBS, the European Commission funded and encouraged research in this area through the Horizon 2020 Research and Innovation program[13]. There are many related projects[13], such as UnaLab[14],CORDIS/CONEXUS[15], and GREEN4GREY[16], which through the implementation of NBS, contribute to the creation of cities that are smarter, more inclusive, more resilient, and increasingly sustainable.

Thematic and interactive maps, provide a thorough understanding of the environmental problem and are simple to comprehend for people outside the scientific field[17]. Since the 1980s, the management of digital geospatial data has advanced significantly, simultaneously changing the environment in which it is projected[18]. For the majority of users, how maps are utilized changed significantly, allowing for database queries to be constructed, and menus or legends, providing access to some fundamental analytical capabilities. These software programs that enabled searches and analysis of geospatial data began to be known as "geographic information systems", widely known by the acronym "GIS". As their functionality developed all fields working with geospatial data incorporated them, allowing GIS to introduce the consumption and integration of geospatial data from different kinds of sources. In the age of digitalization, the continuous demand for information associated with a geographic location to be communicated using visualization tools[19] emerged.

The euPOLIS research project focuses on the regeneration and rehabilitation of urban ecosystems by creating proper urban planning matrices and inclusive and accessible urban spaces. The critical challenges that the demonstration sites face will be outlined during the project's lifetime, by providing integrated solutions, and measuring their impact on the quality of the citizens' lives, in terms of their overall well-being (WB), physical health (PH), mental, as well as emotional health[20]. In this paper the development of a visualization platform is described, aiming at the coordinated customization and integration of existing simulation and planning technologies for NBS-based implementation in the assigned demo sites.

Finding the right visual metaphor to maximize the display's intelligibility and engagement is a crucial issue in this situation. The implementation of this platform, within the framework of EuPOLIS GA 869448[20], enables users to explore, understand, and analyze spatiotemporally the optimized euPOLIS solutions, by providing comprehensive 2D and 3D views of the city environment enriched with temporal data provided by the relevant system (e.g., modeling and sensors information). The fact that time is taken into account in the aforementioned platform can be assumed as a significant component. The platform is responsible for managing the geospatial data required to depict the digital mock-up of the environment by combining existing datasets.

2. EUPOLIS INTERVENTION AREAS

The outcomes of the euPOLIS project's methodologies will be tested in four Front-Runner (FR) cities and disseminated in four Follower Cities (FC), as it is illustrated in the map, in Figure 1. The FC include the city of Trebinje, the city of Bogota, the city of Limassol, and the city of Palermo. The intervention areas of the four Front-Runner cities are described as follows:

The city of Belgrade (Serbia) is located in the north-central region of the nation at the meeting point of the Danube and Sava waterways. Belgrade has a population of 1,374,000 people, however, only 25% of the population has access to water, greenery, and public spaces. EuPOLIS' interventions will be applied to "Linear park" and "Usce", with the latest representing the biggest urban park located in New Belgrade. Currently, the lack of necessary infrastructures results in air/water/soil pollution, and noise, degrading the citizens' WB and PH. Unemployment and aggressive behavior, related to stress, are also reported[20].

The city of Lodz (Poland), is a historical city center, inhabited by 152,292 people, where there are many buildings in poor technical condition, and a few green and attractive public spaces. In Lodz, two multipurpose parks with green areas, one air pollution abatement/mitigating greenery made up of shrubs and vertical green curtains, and environmentally friendly corridors will be considered to establish quality access to the historic city center[20].

The city of Piraeus (Greece), where the largest port in Greece is located. EuPOLIS will intervene in three mutually interlinked neighboring sites at the main harbor area (Mikrolimano). These sites are the Seaside Promenade Mikrolimano area, the riverine inland area in Akti Dilaveri, and the Ralleion Complex Pilot School (RCPS)[20].

The last city is the Municipality of Gladsaxe (Denmark), located in the northwestern suburb of Copenhagen. Scientific analyses showed that Gladsaxe Municipality is a city district with low social development. The main attention is focused on the housing development, called "Pilenparken", which hosts a total of approximately 1,700 inhabitants[20].

Figure 1. Demonstration sites of the euPOLIS project

3. EUPOLIS DATA FOR CONSUMPTION

For the creation of this highly detailed environment for visualization, various data sources incorporated within the euPOLIS project were adjusted and visualized, as it is depicted in Figure 2. There are multiple data channels either explicitly or implicitly induced, as secondary but beneficial data sources. First, the primary data sources or providers are "EuPOLIS by Bioassist, "myFeel" platform by Sentio and FR cities through NTUA's data provision and analysis tools and some already installed permanent sensors. Secondly, the middleware service includes a DMS, which is a tested proprietary solution that is parameterized appropriately and is suitable for storing and presenting all related data flow for the project[21]. All this data are consumed by the visualization toolbox, the eVP platform, which provides a dynamic interface adjustable to the user's needs and capable of illustrating various information, stored in the DMS, including 3D models, advanced analytics, figures, and time-series data. These technologies are not producing measurements but rather consuming data and information in general.

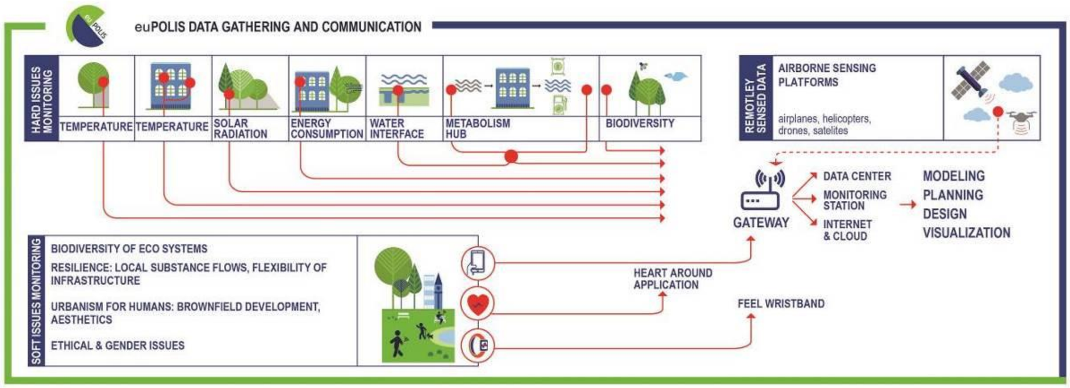

Figure 2. Illustration of the data gathering and communication workflow among the several data sources

3.1 Environmental data

NBS interventions, depending on the scale, may have an impact on micro-climate environmental conditions. To demonstrate and validate the positive impact of the NBS interventions, it is crucial to monitor the affected parameters, so several sensors will be installed in the demo areas of the FR cities, collect real-time data, and through the euPOLIS gateway, this data will be fetched into the DMS. The euPOLIS gateway is an IoT solution for data handling & transmission, introducing the euPOLIS communication gateway, that incorporates the communications and data harvesting from the various environmental sensors deployed in the 4 FR EU cities and leading the task of data acquisition and handling. The deployment of permanent sensor networks in the pilot sites will allow dense and smart monitoring and breaking down of results providing the required level of climatic, social, and other data, which will be used in several applications, including knowledge generation, model calibration, planning, and design, as well as NBS performance.

For the collection of different kinds of environmental data, such as temperature, humidity, barometer, and gas resistance, a couple of advanced information systems with sensor networks are installed in the intervention areas, to collect data from the surrounding environment. Those sensors are the primary function to detect even the slightest changes, allowing an IoT device to capture relevant data for real-time or post-processing. These data are obtained from the DMS and are refreshed daily. The visualization of weather plots is illustrated in the platform, including data stored in the DMS as well, offering the end user the ability to monitor weather parameters in the intervention areas.

3.2 Open Weather Data

Weather data collection was carried out using freely available data from OpenWeatherMap (OWM). OWM is a team of IT experts and data scientists that have been practicing deep weather data science. For each point on the globe, OpenWeather provides historical, current, and forecasted weather data via light-speed API. Besides the basic Air Quality Index, the API returns data about polluting gases, such as Carbon monoxide (CO), Nitrogen monoxide (NO), Nitrogen dioxide (NO2), Ozone (O3), Sulphur dioxide (SO2), Ammonia (NH3), and particulates (PM2.5 and PM10). Air pollution forecast is available for 4 days with hourly granularity. Historical data is accessible from 27th November 2020. [22]

3.3 Wearable devices and mobile applications

The euPOLIS wearable devices and mobile apps are developed and used to support the online measurement of the effectiveness and to validate the impact of NBS on the PH and the WB of the citizens. The mobile apps are designed to offer an attractive, multilingual, easy-to-use interface, permitting seamless communication more naturally and interactively than traditional applications.

The first mobile application is called, the "euPOLIS by BioAssist" mobile app[23] which is developed to monitor citizens' well-being in areas where NBS have been applied. This app is a deployment of the BioAssist platform[24] to cover the euPOLIS project needs. The mobile application is currently available for Android and iOS devices and is compatible with most smart devices and wearables. The “euPOLIS by BioAssist” application can be used as a health and other data collection tool to investigate citizens’ well-being improvement in areas with NBS. For data collection, the mHealth application[25] is combined with a smartphone and a wearable device (e.g., a smartwatch or smart band). BioAssist’s platform and services include well-defined APIs for data import/export and communication with third-party systems such as the DMS and the proposed visualization platform.

The second mobile application that will be used for the citizens’ data collection in the context of the EuPOLIS project is Sentio’s platform, (myFeel app). The “myFeel application” provides information regarding the significant emotional events that a user experiences. The features of this application include emotion recognition and mental health monitoring based on novel technologies (wearables, mobile app, algorithms) to examine the effect of different NBS in citizens’ WB and PH for the pilot demonstrations. The platform can provide the type of emotion (e.g., happy/sad), the duration, time, and intensity of the event as well as what triggered the user to experience such an event, along with thoughts and physical sensations after the event.

3.4 Metabolism-based NBS planning and simulation

The “euPOLIS NBS Urban Water Metabolism Toolbox”, comprises different elements. The Urban Water Optioneering Tool (UWOT) is the main metabolism model of the Toolbox that simulates the entire urban water cycle (UWC), from source to user, treatment, and disposal or reuse[26]. UWOT uses a metabolic approach and therefore simulates and quantifies the main fluxes related to urban water, such as water, waste, energy, CO_2 emissions, etc. UWOT is a single model to simulate the entire UWC, including supply (e.g., reservoirs, aqueducts), distribution and consumption (end-users), as well sewerage, drainage, WWTPs, and recipient waters[27].

Within the euPOLIS project, UWOT has been customized and extended to simulate different types of NBS interventions and hence be able to evaluate the implementation of different conceptual NBS designs[27].An extremely important feature of UWOT is its ability to simulate various decentralized water technologies, including rainwater harvesting and greywater recycling. This is especially useful in investigating the use of alternative water sources in supporting the NBS’ water irrigation needs and therefore developing environmentally sustainable interventions. Additionally, within the Toolbox UWOT's simulation outputs have been linked to related euPOLIS Performance Indicators (Evaluation and Contextual Indicators) to facilitate the impact assessment of NBS implementation on different aspects of ecosystem services and environmental sustainability related to urban water[27].

The specific toolbox comprises a significant component of the eVP as it can assist in communicating the NBS analysis, design, and even the overall intervention strategy, through the investigation of different NBS scenarios and the assessment of the corresponding potential impacts related to the UWC and the environmental sustainability of the proposed solutions.

3.5 Technical Tools and Methods for Data Analysis

In addition to collecting data from a variety of sources, the euPOLIS project employs various technical tools and methods to analyze and interpret acquired data. Correlation analysis, for example, will be used to identify relationships between variables, such as the link between air quality and physical activity levels. Statistical tests, including t-tests and ANOVA, can be used to determine whether observed differences in data are statistically significant, helping to identify patterns and trends. Inference techniques, such as machine learning algorithms, can be used to predict future outcomes based on historical data. Together, these technical tools and methods enable researchers to extract valuable insights from complex data sets, providing a foundation for evidence-based decision-making in urban planning and environmental policy.

4. BUILDING THE EVP PLATFORM

To develop the proposed visualization environment, several/different technologies and programming languages were used. Building these kinds of visualization platforms can be considered as a fundamental step to study and adjust the processing techniques based on the pre-existing requirements established at the beginning of the project to depict the results of all tools embedded into the system in this single visualization application, the DMS will ensure that the visualization component can communicate with them all. Overall, the proposed visualization platform is consuming data and information, rather than creating new measurements.

4.1 eVP requirements

The eVP establishes an integrated solution, capable of determining, gathering, merging, and examining data collected from multiple sources, allowing end-users to assess the effectiveness and suitableness of the adopted NBS services over the citizen's WB and PH.

This platform was designed and unified based on specific requirements, imposed by the project's needs, allowing the integration of multiple tools, provided by relevant partners, and supported by involved parties, such as urban planners, medical teams, citizens, stakeholders, and policymakers in numerous ways. In this section, a general overview of the requirements will be presented, focusing more on the main, not only technical but also user's and functional/non-functional requirements that were considered the foundation of the eVP.

eVP requirements include:

- Create a platform interface that allows easy display of the NBS impact on the project's demo sites
- Provide various analytics, which can help quantify the impact of the applied NBS
- Application of multiple procedures for anonymizing/protecting data in the euPOLIS project
- Create an environment that implements the security framework end-to-end for data (from source to output visualization), including authentication of devices, confidentiality, and integrity of data
- The system needs to be modular. It will offer the possibility to be extended with further sensors. wearables, and larger system deployments
- Availability of the application's menu in the local language or the provision of an extensive manual in the local language
- The visualization solution should be able to deliver all available data on the unified common coordinate system
- Provide a web service to visualize the interventions
- Ability to store different data objects, such as text files, photos, maps, etc.
- eVP to be built over block components
- eVP should be able to process incoming data and check for corrupted instances or failures in transmission
- euPOLIS services should comply with the pilot's country's legislation on data protection and privacy

4.2 eVP architectural design

The eVP is a platform aiming to provide a tool to visualize the intervention results, establishing a User Interface (UI) capable to demonstrate the impact of the NBS on a local level. In this context, the architecture was designed in such a way as to respond to the project's requirements as introduced in section 4.1. The visualization tool offers an enhanced 3D GIS environment with more dimensions including time (4D) providing the possibility for the end-users to define the time parameter in their queries. In Figure 4, the overall architecture of the eVP is depicted, separating three different entities of the processing chain, i.e., the Front-end, the Back-end, and the DMS. For the overall implementation of the platform, only free and open-source libraries/tools have been utilized.

4.3 eVP development

In recent years, tools like web-based applications, centralized computing systems, or visualization platforms follow the concept of the client-server approach[28]. The client-server system is comprised of two independent entities identified as server and client, which can be subsequently separated into physical (e.g., servers, client devices) and logical components (e.g., web pages, data, programming scripts, protocols). This system provides an upgraded way to evenly distribute the workload. The client process continuously launches a connection to the server, while the server process still expects requests from any client. In Figure 3, the system client-system is illustrated including in each separate entity the technologies and programming languages used to develop the eVP platform.

The core of the eVP is deployed using the Nginx Web Server[29]. Nginx is one of the most widely used Web Servers which can also be used as a reverse proxy and load balancer, distributed as open source under the terms of the 2-clause BSD license. The eVP's back-end is written in the high-level general-purpose programming language Python[30], in combination with the micro web framework Flask[31]. Python is one of the most popular backend programming languages offering high scalability, an extensive standard library, and a wide variety of third-party libraries and frameworks. Flask is a lightweight WSGI (Web Service Gateway Interface) web application framework with little to no dependencies on external libraries (micro-framework), supporting the creation of both small and bigger commercial websites, implemented on Werkzeug and Jinja2, along with a built-in development server and a fast debugger provided, used for developing web applications using python. The back end undertakes the following tasks, serving the front end to the client's browser, communicating with API to receive data, communicating with OpenWeatherMap API[22]to receive data about pollution in a specific area, maintaining some of the above information in the local memory, to limit the number of requests to the APIs, and conveniently, preparing the above data for the front end to visualize.

The eVP's front end makes use of the core languages of the Web, combining additional libraries/technologies to provide the user with enhanced web page navigation. More specifically, the front end is written based on the high-level programming language JavaScript (JS)[32], the Hypertext Markup Language (HTML)[33], and the Cascading Style Sheets (CSS)[34]. A combination of cutting-edge technologies is mandatory to achieve the optimized result. Leaflet[35] is an open-source library for mobile-friendly interactive maps written in JavaScript, supporting various functionalities related to map data, used to embed the map together with interactive functionalities. Bootstrap[36] is a powerful, extensible, and feature-packed frontend toolkit, built and customized with Sass, which utilized a prebuilt grid system and components, and powerful JavaScript plugins.

JavaScript libraries such as Three.js[37] and Chart.js[38] provided useful features improving their interaction capabilities with the UI. Three.js is a cross-browser JavaScript library and application programming interface used to create and display animated 3D computer graphics in a web browser using WebGL.Chart.js another JavaScript library that enables the visualization of data through creating flexible charts online. In the context of eVP, chart.js is being used to provide weather and air pollution plots.

React JS is the best option for incorporating all the aforementioned technologies and tools, as one of the most widely known open-source JavaScript frameworks, providing several benefits regarding development, maintenance, and update. It enables the development of applications by producing reusable parts that can be viewed as independent blocks. These components are individual pieces of a final interface, which, when assembled form the application's entire UI. React framework combines the speed and efficiency of JavaScript with a more effective way of manipulating the DOM to render web pages more quickly and create highly dynamic and responsive web applications by breaking complex user interfaces into reusable components. In more detail, when data change in a traditional JavaScript application, manual DOM manipulation is required for these changes to be incorporated. On the other hand, React utilizes a virtual DOM, which is a copy of the actual DOM, offering immediate reload to reflect any change in the data state and then is compared to the actual DOM to detect what exactly has changed.

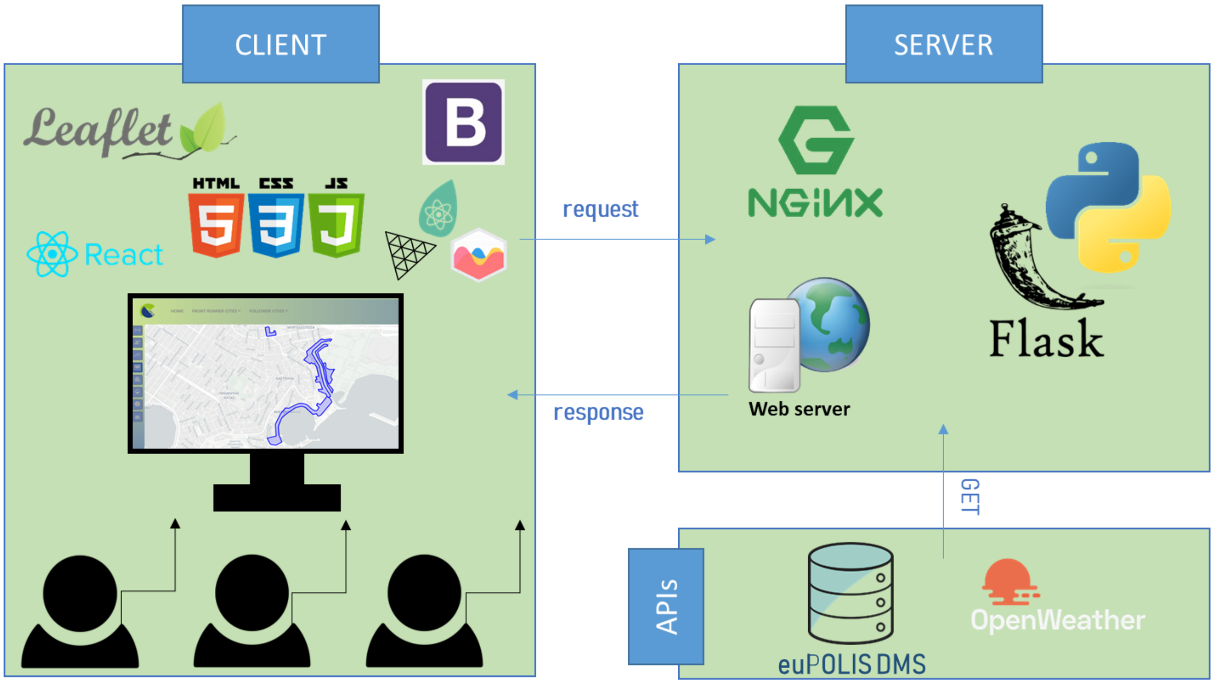

Figure 3. Schematic representation of the programming languages, libraries, and technologies used in the system client-server to develop the eVP platform

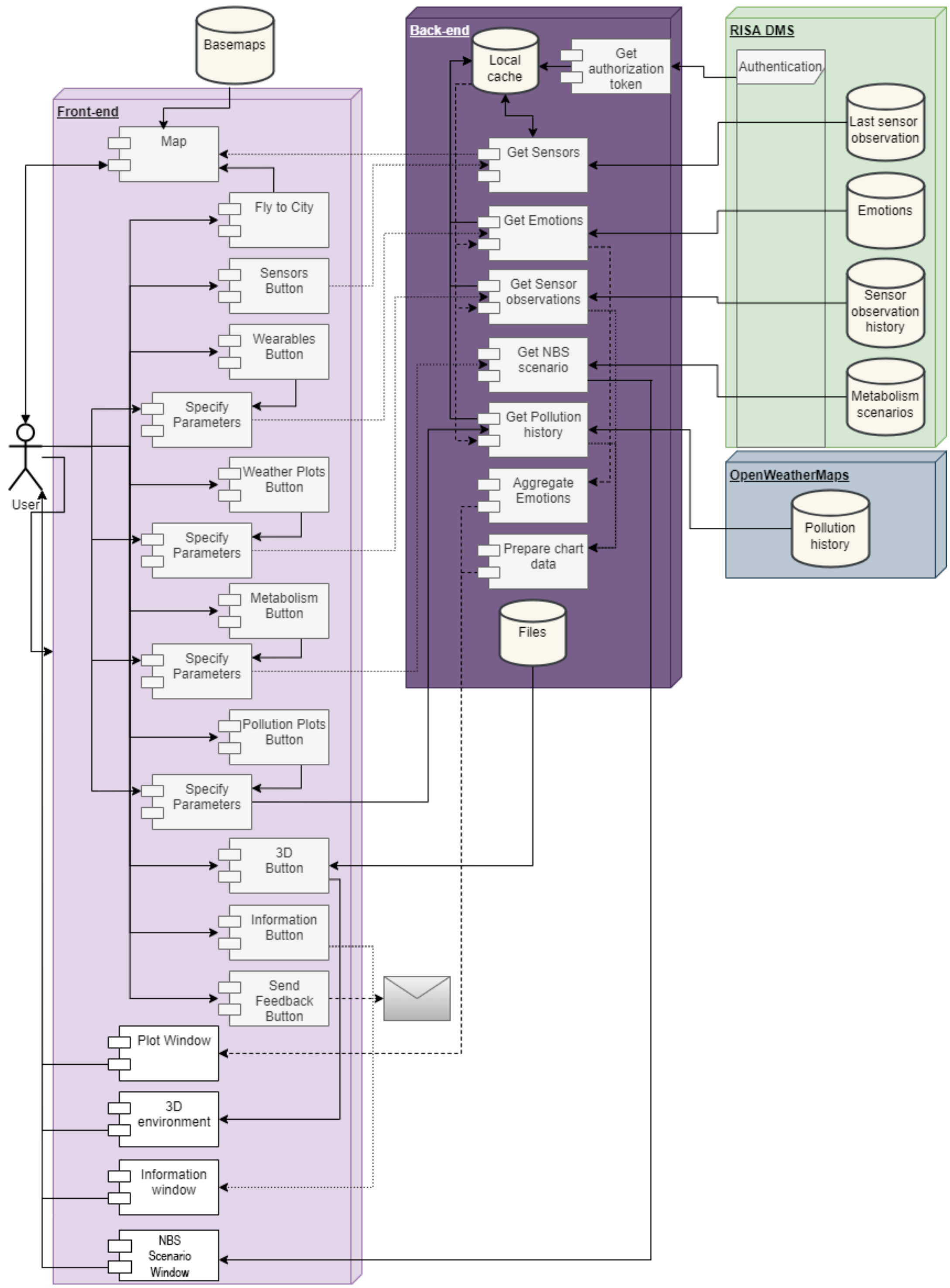

Figure 4. The architecture of the eVP platform.

5. THE EVP USER INTERFACE (UI)

Visualization modules, in general, provide users with the opportunity to translate complex data into a visual context, allowing an easier understanding of the correlation between results and operations, and finding hidden patterns, even when one is outside the specific scientific field. Those computational tools make it possible to link georeferenced databases to digital maps and improve the visualization of the case's study geographical characteristics. The visualization modules frequently incorporate extra features by utilizing data from various sources[39].

The designed interface was created in a way that makes user interaction quick and effective at achieving user objectives. The demonstration starts with the display of a base map, in combination with all the side features comprising this UI, designed based on the euPOLIS colors in accordance with the main website of this project[40]. On the top part of the eVP platform the Main NavigationBar is displayed, allowing the user to interchange between the intervention areas, either FR or FC cities. Additionally, the option for access to people with disabilities is available, similar to the euPOLIS site. Moving to the left, the main navigation tools were built to facilitate users' capabilities and selection among the offered functionalities.

Through these tools, the user can get informed regarding the sensors, the wearable information, the weather and pollution plots, the 3D models, and the Metabolism-based NBS planning and simulation methodology. Each one of the aforementioned data sources (see section 3), corresponds to a particular button in the navigation tools, offering an integrated amount of information for the NBSs. To enchase end-users' interactivity with the map component, on the right side of the platform, the universal navigation tools can be found, such as zoom in, zoom out, and zoom to the full extent to view the map at different scales, allowing users to navigate smoothly and use the layer switcher consisting of various base maps, entailing a better understanding of visualized information. The aforementioned attached tools are all demonstrated in Figure 5.

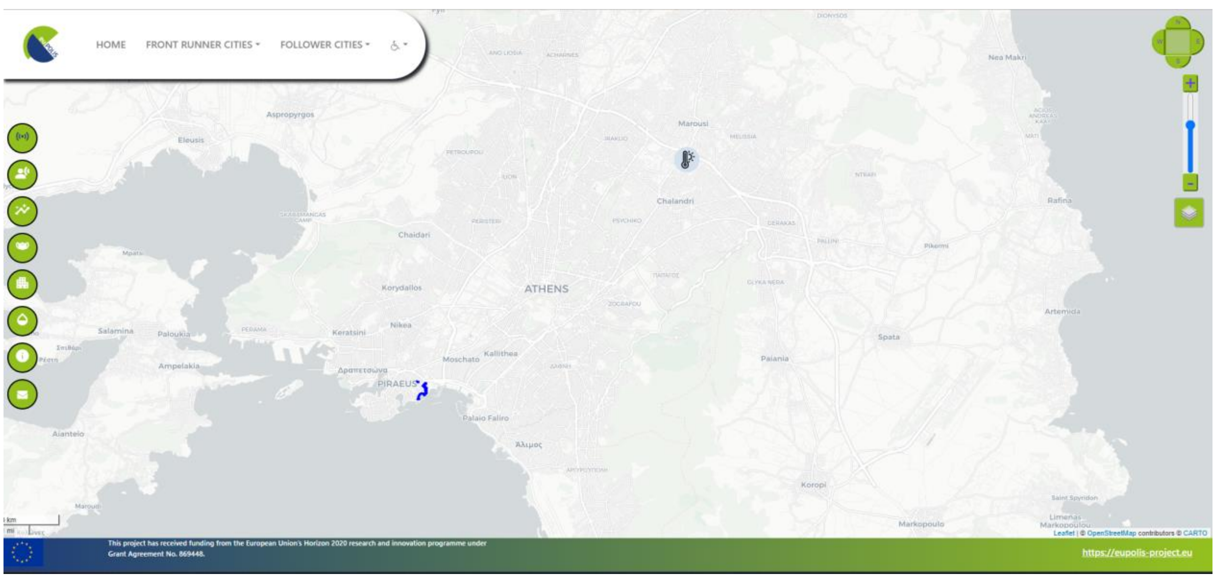

Figure 5. Screenshot of the UI of the eVP platform displaying the base map, the Main NavigationBar, the Navigation Tools, and the Map tools.

As previously mentioned, euPOLIS' interventions will be applied to "Linear park", located on the old side of Belgrade, and "Usce Park" in New Belgrade, to "Ralleion", "Microlimano" and "Akti Dilaveri" located in the City of Piraeus, to "Posaz Anny Rynkowskiej" situated in the City of Lodz and to "Pileparken 6" in Gladsaxe Municipality. In Figure 6, the intervention areas are depicted represented by their polygons (blue highlighted areas). These visualization patterns can provide the user with a more holistic understanding of the overall focus of the project.

Figure 6. Screenshots of the intervention areas of the FR cities. On the left-upper image are the "Linear park" and the "Usce Park" situated in Belgrade, while on the left-down image is "Posaz Anny Rynkowskiej" located in Lodz. On the right-upper image are the "Ralleion", "Microlimano" and "Akti Dilaveri" found in Piraeus, while on the right-down image is "Pileparken 6" located in Gladsaxe Municipality.

The second visualization tool provides aggregated data of the emotions and other measurements (e.g., physical activity) recorded by the wearables, in collaboration with BioAssist's and Sentio's applications (Figure 7). These data comprise a valuable component of the eVP. Having collected these data, each user can be informed either through diagrams or pie charts for the aggregated measured data regarding the intervention area of their interest.

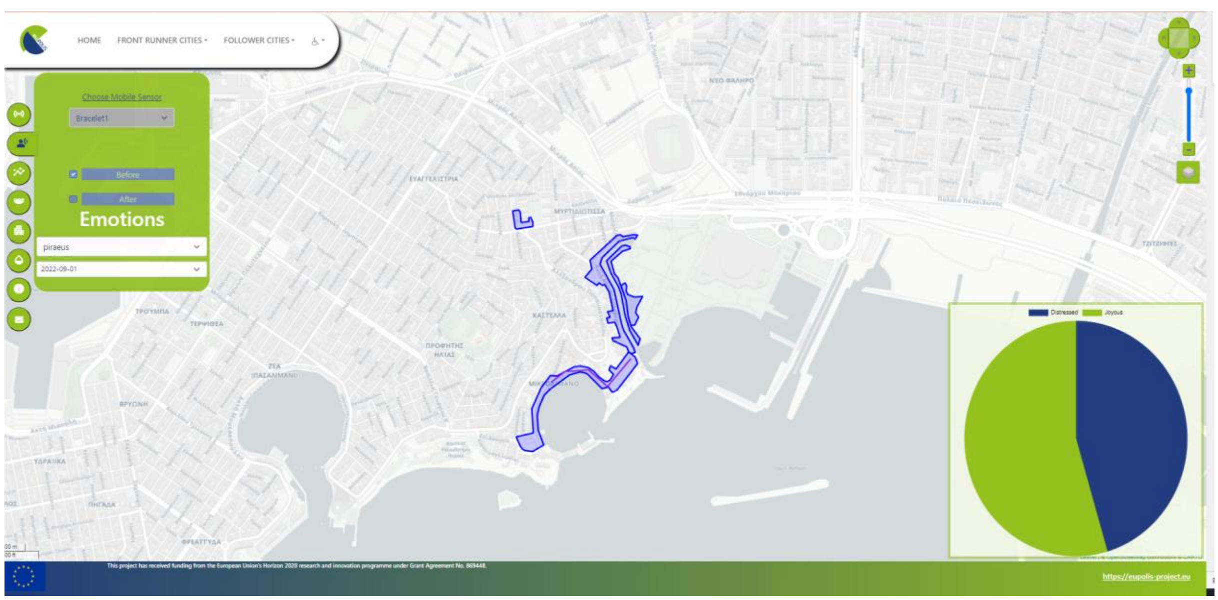

Figure 7. Visualization of the second tool. Aggregated data of the emotions recorded by the wearables.

The third visualization tool provides weather data recorded by the installed sensors. Several sophisticated information systems with sensor networks are placed in the intervention areas for the gathering of various environmental data types, such as temperature, humidity, barometer, and gas resistance. These sensors serve as the main means of spotting even the smallest changes, enabling an IoT device to record pertinent information for processing in real time or later. These statistics come from the DMS and are updated every day. The platform's illustration of weather plots, as shown in Figure 8, includes data from the DMS as well, giving the user the ability to keep track of weather parameters in the intervention regions.

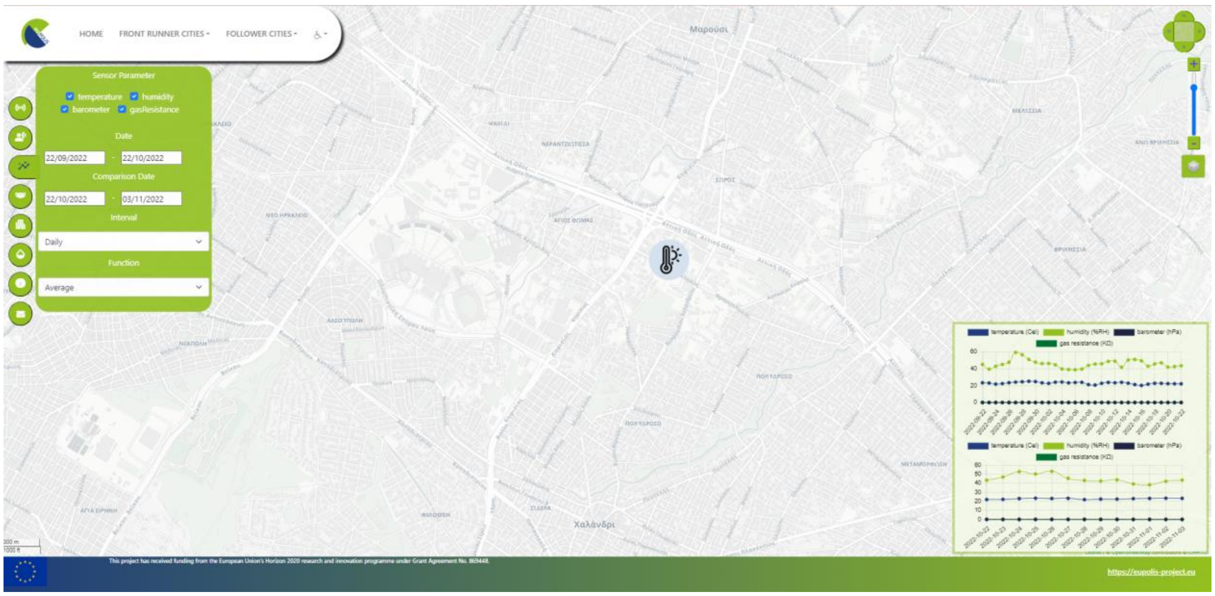

Figure 8. Visualization of the third tool. Weather data recorded by the installed sensors.

The fourth visualization tool provides pollution data collected by OpenWeatherMap (Figure 9). Besides the basic Air Quality Index, the API returns data about polluting gases, such as Carbon monoxide (CO), Nitrogen monoxide (NO), Nitrogen dioxide (NO_2), Ozone (O_3), Sulphur dioxide (SO_2), Ammonia (NH_3), and particulates ($PM_{2.5}$ and PM_{10}), as detailed explained in Table 1.

Table 1. Description of the Air Quality Index levels.

Qualitative name	**Index**	**Pollutant concentration in µg/m3**					
		SO2	**NO2**	**PM10**	**PM2.5**	**O3**	**CO**
Good	1	0-20	0-40	0-20	0-10	0-60	0-4400
Fair	2	20-80	40-70	20-50	10-25	60-100	4400-9400
Moderate	3	80-250	70-150	50-100	25-50	100-140	9400-12400
Poor	4	250-350	150-200	100-200	50-75	140-180	12400-15400
Very Poor	5	>350	>200	>200	>75	>180	>15400

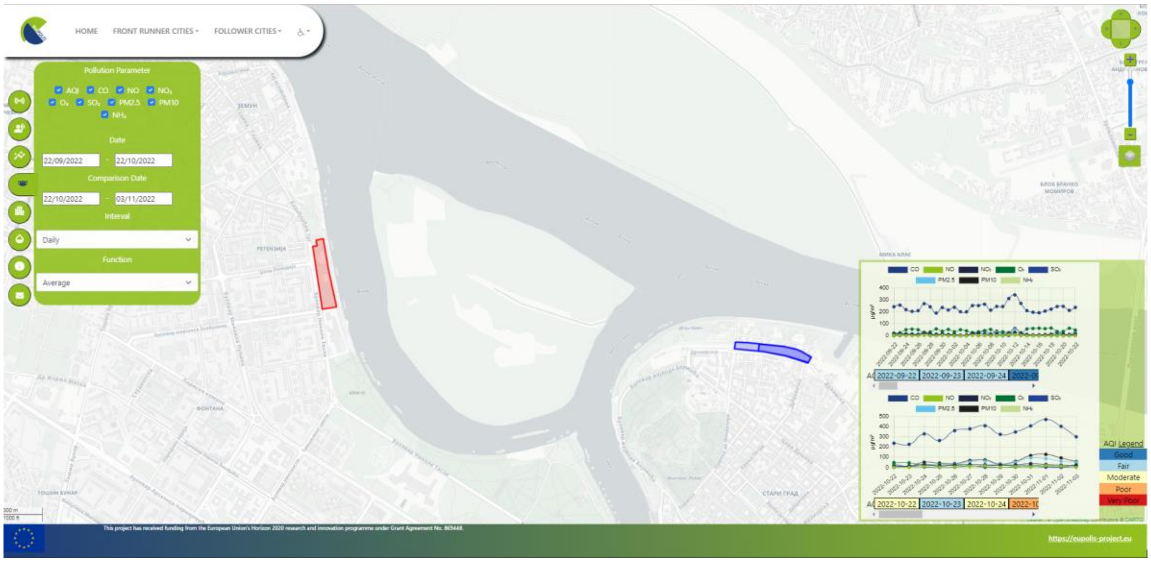

Figure 9. Visualization of the fourth tool. Pollution data collected from the open-source data of the OpenWeatherMap.

The fifth visualization tool provides photo-textured 3D models (in FBX format). Such digital developments require many tools and on-site visits from engineers to gather the necessary information (images, drone views, recordings, etc.)[41] combined with a cutting-edge structure of motion algorithms. Three-dimensional visualization (digital twin) is turning into a necessity since it is easier not only for humans to identify patterns and relationships between objects but also enables planners to make decisions in accordance with those patterns. The 3D visualization additionally offers a shared, interactive, and navigable world, which fosters co-creativity between planners and non-planners. Using 3D virtualization models, interventions can be evaluated in advance without affecting daily activities or post-intervention environmental conditions[41]. These 3D models represent the before and after interventions in each of the demonstration sites. In Figure 10, the “before-situation” of Piraeus is illustrated, indicatively.

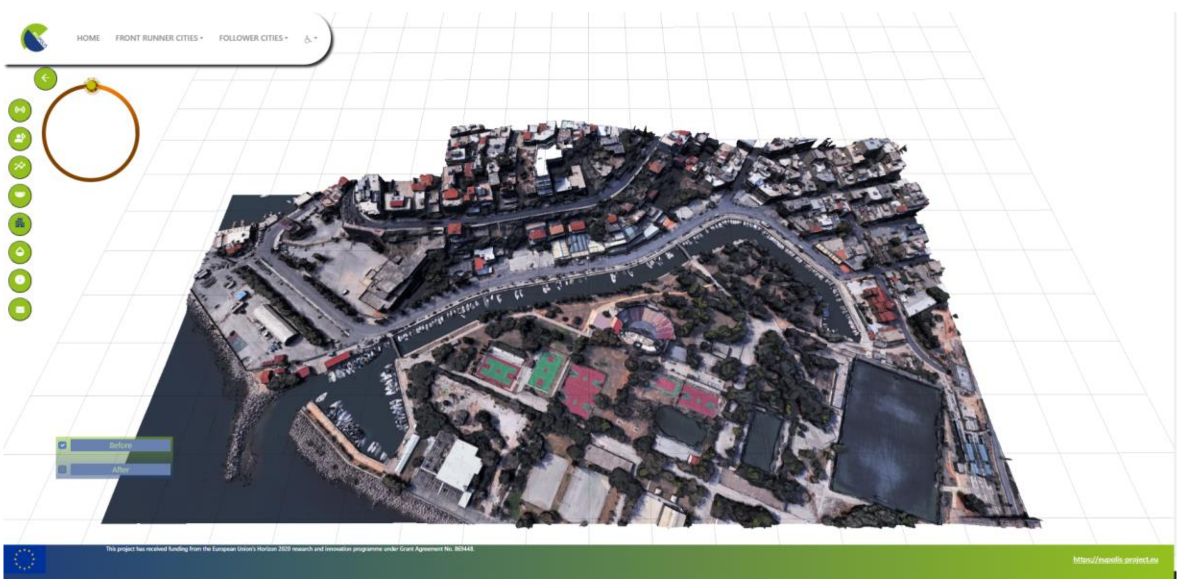

Figure 10. Visualization of the fifth tool. 3D models representing the before and after-situation of the interventions.

The sixth visualization tool presents key information and simulation outputs for different examined NBS scenarios analyzed within the euPOLIS NBS Urban Water Metabolism Toolbox (Figure 11). This type of information can facilitate the effective communication of quantitative comparative analyses and relevant decisions on the choice of the most appropriate technical solutions[27].

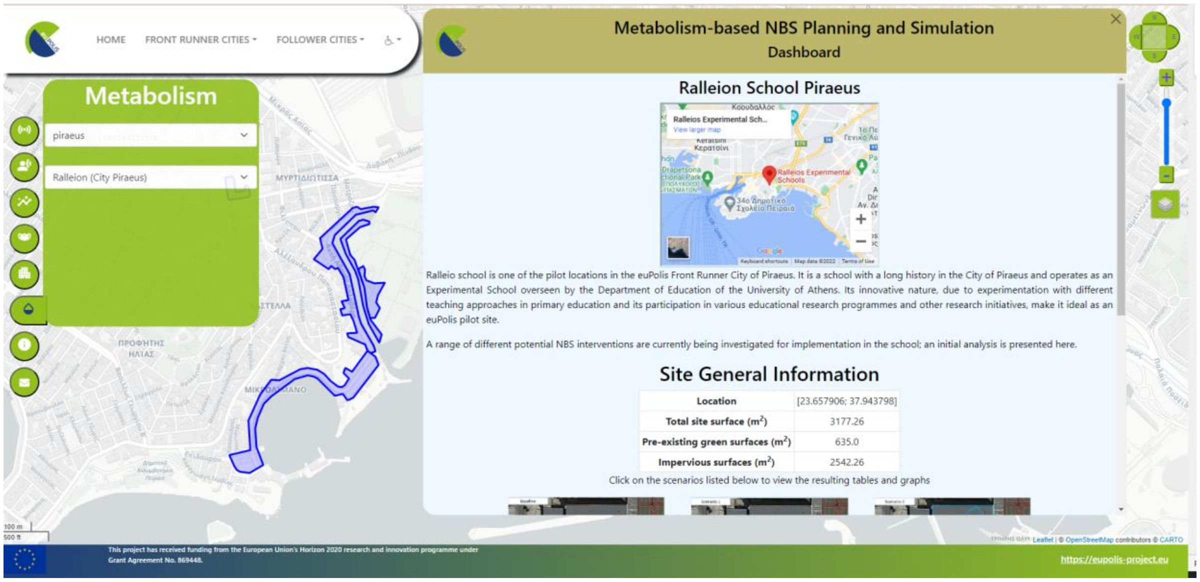

Figure 11. Visualization of the sixth tool. A separate selection containing the methodology of the metabolism-based NBS planning and simulation.

The last Navigation tool is the Project Information button explaining the euPOLIS project, followed by the send feedback option, by which the user can provide valuable information regarding the platform and help with its improvement. A user manual is available through a download link, redirecting the user to a browser tab providing a step-by-step explanation and navigation throughout the eVP as demonstrated in Figure 12.

Figure 12. Visualization of the seventh tool. Information regarding the project and a user manual to facilitate user experience.

6. DISCUSSION

The traditional approach to urban and revitalization planning is mostly driven by financial criteria and regular processes, frequently lacking cutting-edge integrated approaches and concepts that place a strong emphasis on societal, cultural, economic, and environmental factors. As a result, the demands of local communities are either ignored, or underappreciated, and as a result, cities make expensive investments that local populations do not support and are consequently not sustainable. To address these challenges, urban planning approaches built on the euPOLIS NBS services and enhanced with cultural and societal considerations provide the combination of a people-centered approach with the major environmental and economic benefits of BG Solutions. A significant benefit of NBS is the multiple benefits that are offered across different sectors, such as the environment, economy, and society.

One of the most crucial features of any project or any business intelligence solution is data visualization. Visualization modules allow users to translate complex data into a visual context, allowing an easier understanding of the correlation between results and operations, and at the same time the identification of possible hidden patterns, even when one is outside the specific scientific field. Significantly better business decisions can be achieved by giving a more comprehensive picture of each operation.

Taking into consideration that euPOLIS is an ongoing project (2020-2024) and the implementation of the designed interventions has not yet been completed in all study areas, it is expected that additions will need to be implemented to the euPOLIS visualization module. These additions include indicatively establishing new connections through APIs with the euPOLIS DMS to visualize data coming from the newly installed in-situ sensors (weather and air pollution stations) or incorporating some new 3D models of the designed interventions. The design, implementation, and functionalities of the eVM have been thoroughly presented in this publication and future additions will not alter the core of its implementation.

7. CONCLUSIONS

The aim of the euPOLIS Visualisation Module can be summarized in two main elements; the first is providing the end users with a powerful ICT tool for visualizing the designed and implemented urban planning interventions and the second is monitoring the environmental and societal impact. The first objective is fulfilled through the support of visualizing 3D models, while the second objective is achieved through the following features: environmental monitoring by creating weather and air pollution plots and societal monitoring by visualizing aggregated emotions. The fact that time is taken into account in the aforementioned is a crucial component. In more detail, the user can define the period for which he/she wishes to receive this information (e.g., weather plots for a specific demonstration site) enabling this way a comparison of pre-and post-intervention situations.

In conclusion, the euPOLIS visualization platform is a valuable tool that can facilitate the implementation of NBS in urban areas and promote sustainable development. The most significant advantage is the visualization of spatial environmental data, which translates valuable information comprehensible to citizens and policymakers interested in promoting sustainable urban development. Its ability to provide real-time data and visualization of NBS implementation is particularly useful, along with the highlighting of the resulting patterns between the different data sources.

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