On the integration of nature-based solutions with digital innovation for health and wellbeing in cities

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Abstract -In an increasingly urbanised world, local governments and international institutions strive to increase the productivity and efficiency of cities, recognised as economic growth hubs and ensuring a better quality of life and living conditions for citizens The scope of this research paper is to examine a city case study in Chania, Crete, Greece and to present the potential of Nature-based Solutions enriched with digital techniques (IoT, Mixed Reality, ICT) integrated into a future city. The city use case adopts an innovative cross-sectoral approach by combining urban digital transformation and nature-based actions. The city of Chania implements innovative solutions consistent with increasing citizens' awareness, respect for public spaces and integrating green spaces into everyday life. Developing a healthy green mindset for citizens and improving economic opportunities through green-digital strategies drives the implementation of additional actions, towards becoming a more sustainable, equitable, and liveable city.

Keywords—Nature-based solutions, innovation, IoT, Health, wellbeing, smart cities

I. INTRODUCTION

Sustainable urban development and smart cities are two notable examples that represent cities' drive to be more aligned with citizens' needs, offering conditions that promote wellbeing and strengthen competitiveness in an increasingly globalised environment.[1]. The main challenge of smart cities of the future is to improve environmental and economic performance through data collection, data analysis and evidence-based policy-making,incorporating smart information communication technologies (ICT) into the urban landscape[2].

Past research focuses on improving urban residents' lives through the systematic application of technologies such as wearable health monitors as well as on creating open data platforms in order to analyse health parameters, enhancing virtual communication between patients and health professionals [3]–[5]. Citizens' behaviour and life choices can be monitored through real-time data provided by smart devices, as health and wellbeing (H&WB) increasingly provides opportunities for digital innovation. The critical challenge of such technologies is to contribute to the improvement of wellbeing and urban livelihoods through the application of smart technologies[6]. Nowadays, governments are willing to leverage ICT to improve the health of citizens and upgrade the effectiveness of health-related services. In this way, the costs of public health care expenditure is decreased [7].

According to the European Commission, Nature-based solutions (NBS) have been defined as "*solutions to societal challenges that are inspired and supported by nature, which are cost-effective, provide simultaneously environmental, social and economic benefits, and help build resilience"* [8]. Nature-based solutions and interventions aim at becoming an underlying customisable fabric of an entire ecosystem of fully connected intelligent sensors and devices, capable of delivering several co-benefits, transforming the daily lives of European citizens.[9] Through the integration of smart information, ICT can offer the following to the urban landscape:

- Nature-based solutions contributing to the shaping of future cities and citizens' wellbeing.
- Specific ICT prototypes monitoring and assessing the sustainability and the impact of interventions through advanced (Key Performance Indicators) KPIs for health and wellbeing.

The Internet of Things (IoT) enables the development of a smart environment driving the connection of citizens with intelligent services in order to increase their quality of life. One of the most widely exploited disruptive technologies within IoT is Mixed Reality, which focuses on human-computer interaction within virtual worlds in the case of Virtual Reality (VR) or interaction with digital enhancement of real-world surroundings in the case of Augmented Reality (AR). AR-enabled IoT services often aim to create game-rich experiences to raise awareness for significant societal and environmental issues [7]. AR is combined with data gathered from IoT environmental monitoring services for smart city planning. The role of technologies in real-time simulation and visualisation is often put forward. Urban planners, stakeholders, and communities study the impact of planning policies for creating smart cities from the very early design stage, based on visualisation technologies [8]. Past research examines the challenges of creating and visualising smart cities through material modeling and light simulation in a VR environment [8]. A fascinating application is proposed in [10]. Chemical particles are visualised in mobile AR displayed on an Android smartphone. The New York Times employed AR to visualise the concentration of PM2.5, through the NYTimes iOS app [26], showcasing four different scenarios: good quality, user's location air quality, California Camp Fire being unhealthy, New Delhi being extremely unhealthy. Smartphone are supported integrating only chemical air particles provided by public weather stations. In [27] an interesting visualization approach is presented. Gaseous contaminants of air pollution are visualised as molecules and other pollution particles as solid items.

The main goal of this research paper is to present the potential of Nature-based Solutions enriched digital techniques (IoT, Mixed Reality, ICT) to be integrated into a future city. Developing green-digital strategies raises citizens' awareness about the importance of several environmental issues and the relevant consequences in citizens' H&WB.

II. Material and Methods

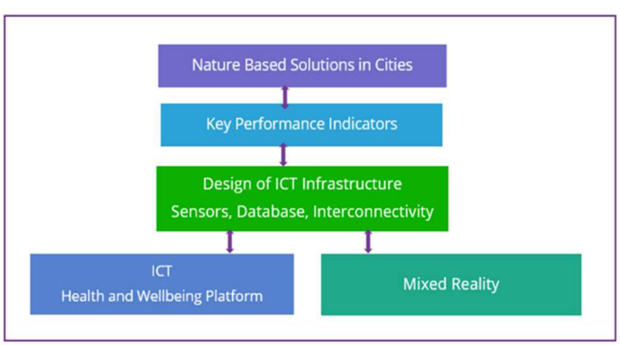

Figure 1. Methodology of the study

Nature-Based Solutions (parks, urban parks, forests, and upgraded ecosystems) in the city Chania in Crete, Greece are introduced, incorporating innovative ICT infrastructure. A network of sensors is established and linked with a cloud-based ICT H&WB platform that is developed. Data from sensors is visualised on standard displays but also on mobile platforms. The collected data are also fed and displayed on the H&WB platform.

A local data platform is implemented in order to establish a framework for data management. A REST API releases data derived from the local data platform to the H&WB visualisation platform. Mixed reality (MR) applications are employed to engage with citizens and increase environmental awareness.

In terms of the development of a monitoring and evaluation framework, as this is not the main subject of this study, a list of Key Performance Indicators (KPIs) is briefly described, presenting the gathered data and link them with the H&WB visualisation platform.

III. Nature-Based Solutions in Cities

A. *Case Study Area*

The city of Chania is at the crossroad of Western and Eastern civilisations, of natural beauty, unique traditions, and architecture. The city occupies an area of 11 sq. km with a population of just over 50.000 inhabitants, establishing Chania as the second largest city in Crete. The city has the typical Mediterranean climate, e.g., warm and dry in the summer and mild in winter. The European Commission's Strategy for Adaptation to Climate Change[11] encourages and supports local authorities to take steps to mitigate and adapt to climate change. Adhering to this strategy, the Municipality of Chania is willing to reduce CO_2 emissions by at least 40% by 2030.

B. *Description of solutions*

A mobile urban living room (MULR) is a convertible construction that can travel to various public spaces creating events so that they are socially revitalised. Educational and social awareness activities and pop-up cultural events will take place in and around the MULR, addressing all ages, designed, and implemented to be fully accessible. Through sensors installed in the MULR to monitor air pollution, noise exposure, microclimate conditions, etc., data are gathered from diverse urban neighbourhoods. The MULR encourages the citizens to provide self-perceived health & wellbeing data by filling out questionnaires/surveys and by hosting local events. Interaction between citizens and green spaces is also encouraged through applications and games.

Sensors are installed on public bikes and bike stations in Chania to collect environmental and health data, while such data are transferred to the H&WB platform. Sensors' data are combined with weather station data and prediction models as well as bike-sharing usage data, citizens' answers to questionnaires, apps, and data from statistical services, offering an overview of real-time environmental monitoring to citizens aiming that such awareness will improve their H&WB by individual and group actions. This knowledge will increase citizens' and visitors' environmental awareness and encourage them to use bicycles in the city on specific days and time slots based on environmental and other data.

Any NBS directed towards a given challenge is associated with a set of objectives and actions, which in turn are associated with expected impacts. In particular, for Chania, to monitor and assess sustainability, a list of Key Performance Indicators (KPIs) was created (TABLE I).

TABLE I. LIST OF CHANIA'S KPIS

KPI	EXPECTED IMPACT/OUTCOME	Units
Recreational or cultural value of green spaces	Increased recreational or cultural value of green spaces	No. of visitors' year-1 / No. of recreational activities year-1
Green-related social service provided to population	increased Green-related social service provided to population	N/A
Physical air quality indicators: temperature, humidity, etc.	Data gathering of local climatic conditions, Citizens ' awareness	°C or % relative humidity
Chemical air quality indicators	Air pollution data gathering, Citizens ' awareness	µg/m^3
Access of residents/employees by foot to open space: sports center, recreation area, or green space	increased accessibility of sport and recreation facilities	km / min
Access of residents to cultural facilities on foot	increased accessibility of cultural facilities	km / min
Perceptions of citizens on urban nature	increased awareness of urban ecosystems	N/A
Citizen participation in and co-creation of the design, implementation and evaluation of project interventions	Increased and improved participation	No. of people / year
Number of individuals that is aware of the project's objectives, content and processes	Increased and improved participation	No. of people / year
Personal and social background of people who participated in the project's activities	Fair participation to project activities	No. of people / year
Exposure to noise pollution	Noise pollution data gathering, Citizens ' awareness	dB(A)
Number / share of people being physically active	Increased outdoor physical activity	No of people / %
Increase in walking and cycling in and around areas of interventions	increased outdoor physical activity	No of people / %
Smoke cessation due to sports activities in green areas	Reduced smoking	No of people / year
No. of jobs created; gross value added	increased job opportunities	No. of jobs created; euro
Definition of parameters for (re)-designing of green public spaces based on the wellbeing of users	definition of parameters for (re)designing green public spaces based on the wellbeing of users	n * Z [(nº jobs) (€/m^2)
Replication of solutions	Replication of solutions	N/A
Saved healthcare spending	Savings in healthcare spending	Euros per year / %
Public Private Investments after 5 years	increased public, private investments	Euros

To calculate these indicators, we use different approaches to gather the relevant data. Specifically, sensors are employed to monitor air quality, microclimate conditions, noise levels as well as the number of visitors in public green spaces. Existing databases and satellite/GIS maps are also used. Moreover, questionnaires /surveys and interviews are used to collect self-perceived health and lifestyle data from citizens and record their perception of urban nature.

IV. ICT INFRASTRUCTURE FOR CHANIA CASE STUDY

A core component of smart cities is a robust ICT infrastructure collecting, storing, analysing, and visualising data derived from the city, making them available to citizens. A robust ICT infrastructure uses open standards to communicate between various components. Based on open standards, the system is interoperable and expandable so that it includes new functionalities scalable to added modules and types of data.

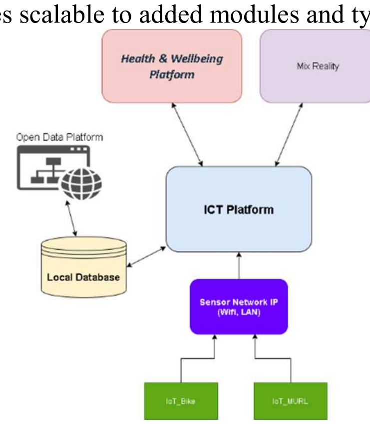

Figure 2. ICT infrastructure diagram

The core component of our implementation of the ICT infrastructure for Chania is the ICT platform. Its main functionality is the interconnection of the Internet of Things (IoT) sensors with the local database and the Health & Well Being (H&WB) platform. Additionally, the platform provides interfaces to enable the interconnection of Mixed Reality applications, Open Data Platforms and third-party applications, e.g., citizens' observatories and data brokers. IoT sensors are installed inside the MULR as well as the bikes to capture and quantify all aspects of health and wellbeing in the urban environment. Several KPIs have been identified and require periodic input measurements from the IoT sensors. Local databases providing an intuitive interface to access data based on the open-source open data portal CKAN [12] is envisioned as part of the ICT infrastructure.

c. INTERACTION WITH USERS

1) ICT Platform

The developed ICT platform is based on the microservice architectural philosophy. Every component has its specific functionality and role in building and operating the ICT platform. The components have loose coupling with each other to reduce dependencies and complexities. Another decision point for following the microservice architecture was that the ICT platform is cloud-based. Microservices are commonly used in cloud-native applications. The ICT platform is built upon four major components:

- Context Broker
- Identity Management
- IoT Agents
- Big data analytics

The ICT platform is based on an open standard, e.g., Next Generation Service Interfaces – Linked Data (NGSI-LD)[13]. The NGSI-LD specification is an API and information model for publishing, querying, and subscribing to Context Information. The European Telecommunications Standardization Institute has standardised the NGSI-LD through the Context Information Management Industry Specification Group. Context Information is represented as entities with properties and relationships to other entities. A unique Internationalized Resource Identifier (IRI)[14] is assigned to every entity and relationship reference as an identifier, making the corresponding data exportable as Linked data datasets. A Context Information Management (commonly named Context Broker) is a platform or a system that utilises the NGSI-LD API to provide the functionality for publishing, querying, and subscribing to Context Information. The Orion Context Broker-Linked Data (LD)[15] is selected to be used as part of the ICT platform. Orion-LD allows context consumers and producers to interact. A Context Producer can be from a single sensor to a complex system pushing context to the Context Broker. A Context Consumer, who wants to receive the producers' published data, has to subscribe to the specific producer. When the Context Producer publishes context to the Broker, the Broker pushes the context to all subscribed Consumers.

Protection of personal data and data security is a cornerstone of modern smart cities' platforms. Components and actors interacting with the ICT platform are securely accessed and managed using a central Identity Management and several Policy Enforcement Points (PEP)[16]. The central Identity Management provides user, organisation, application and role management capabilities, defining authorisation policies. A Policy Decision Point (PDP)[17] evaluates and issues authorisation decisions. Policy Enforcement Points (PEP) are being utilised to provide access control to the ICT platform. PEPs are positioned between the component that requires access control and the actor who uses the particular component.

The IoT agent translates the data generated by the IoT sensors to a suitable format for the ICT platform. Moreover, the IoT agent enables the interconnection of a variety of open protocols such as LoRaWAN[18], MQTT[19], Lightweight M2M[20] with the platform. Additional protocols can be added by extending the already existing IoT agents.

Data generated by sensors are prone to error either because of the sensor itself, its electronic components, or the measurements' transfer to their final destination. A module has been developed using the flow-based tool, Node-Red[21]. It enables the platform to examine data generated by the sensors and ensure that verified data are propagated and stored in the platform.

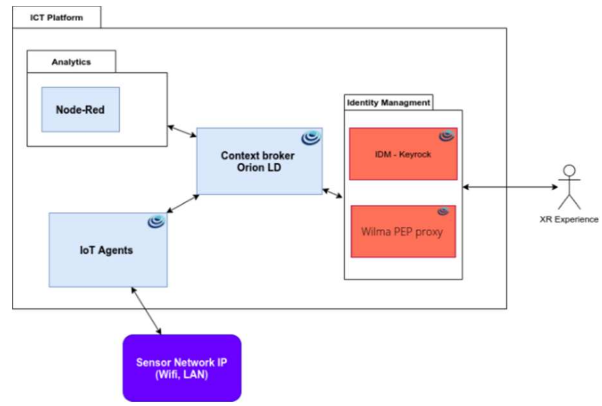

Figure 3. ICT platform components

2) *Sensors in Chania*

A variety of sensors are utilised to gather environmental data to assess the city. Two different sets of sensors are developed on bikes as tabulated in Table II. The first set installed on the bike measures temperature, relative humidity, Particular Matter (PM), and noise. A GPS receiver (2.5m horizontal position accuracy) accompanies the sensor to record the location of the measurements. The above combination better records the resolution of the environmental parameter.

Moreover, the health data of the bike user, i.e., heart rate and oxygen saturation level, are measured. In the second set, an extended set of environmental measurements are gathered as tabulated in Table II (stationary). The extended set of sensors is installed at four locations across the city, specifically at the bike-sharing stations and one sensor on the MULR. The MURL can visit urban and rural areas, providing excellent opportunities to investigate the environment's differences. With the help of the ICT platform, the sensors measurements are used to calculate specific KPIs, as described in Section C.

TABLE II. CHANIA'S SENSORS

	Measurement	**Measurement Range**	**Accuracy**
on Bikes	Temperature	-40°C to 125°C	±0.3%
	Relative Humidity	0 to 100%	±2%
	$PM_{1.0, 2.5, 10}$	0 - 1000μg/m³	±10 %
	Noise	40-100 dBA	±5 dB
Stationary	NO	0 - 250 ppm	±3 ppm
	NO_2	0 – 20 ppm	±0.1 ppm
	SO_2	0 – 20 ppm	±0.1 ppm
	O_3	0 – 20 ppm	±0.5 ppm
	CL_2	0 - 10 ppm	< ±2%
	NH_3	0 - 100 ppm	±10%
	CO_2	0 – 10000 ppm	±100ppm@400ppm
	VOC Index	0.3 – 30 ppm	<±5 ppm

3) Mixed Reality

Smart cities and Mixed Reality visualisation technologies can open new windows in citizens' lives, bringing them closer to phenomena and environmental conditions that appear distinct and often disregarded. Mixed Reality (MR/XR/AR/VR) applications enrich the real-world environment with a certain amount of synthetic information, ideally just enough to overcome the limitations of the real world for a specific application[22]. Here, we focus on deploying XR technologies to engage and sensitise citizen communities around environmental monitoring issues, utilising the sensor network infrastructure and Key Performance Indicators (KPIs) such as physical/chemical air pollution and noise (Fig 4.).

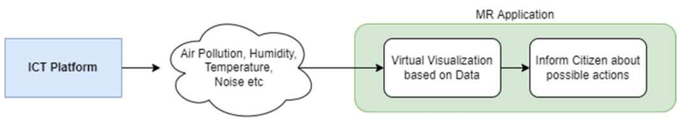

Figure 4. MR Application Data Flow

Our purpose is to design and develop XR experiences that leverage a user's location and physical surroundings alongside real-time KPIs data related to the user's environmental condition to provide empathic experiences related to the increase of noise and chemical particles of the air (e.g. PM2.5, PM10, etc.) (Fig. 5). MR technologies powerfully visualise such attributes, promoting awareness and therefore, public action. MR applications for environmental awareness should:

- Provide a memorable interactive visualisation experience of air pollutants and noise through Mixed Reality, emotionally engaging citizens [23].
- Provide citizens with the understanding of relevant data while being able to draw conclusions about the impact of environmental attributes on their health and well being.
- Provide citizens environmental knowledge and awareness and encourage them to adopt pro-environmental behavior[24].

The MR experience to be developed will take place in public spaces, in Chania, Crete, Greece in the form of a gamified narrative. An interesting approach is described in [25] where air quality and other atmospheric conditions are visualized through a virtual avatar in real time. We will follow a user-oriented approach, where the ordinary citizen is at the center of the action. Using an AR head-worn display, the citizens will be guided through an interactive experience while located in a public space. In the beginning of the procedure there will be an authentication proccess using OAuth2 authorization protocol between the MR app and ICT Platform. After the authorization process, the app will be capable to request KPIs data (Air Quality, Noise Exposure) using a REST API. The whole communication will be encrypted under TLS.

The interactive experience will be geo-located and will comprise of several points of interest in a large, public outdoors space. The user is going to start the experience located at one of the designated points. The experience will take the form of a gamified, environmentally-informed narrative including a treasure hunt. Digital objects may be collected and clues are going to be communicated in conjunction with the real-world surroundings as the user physically walks from one point of interest to the next. The user's position is going to be tracked and the narrative will progress based on the user's actions. Environmental messages, based on the relevant KPIs for each space are going to be entangled with the narrative, elicing environmental awareness related to each specific location. For example, in order to visualise the Air Quality KPIs, the users' Field of View (FoV) will be occluded by virtual pollution particles that float around them. The higher the values from the air quality sensor, the denser those particles will become. A narrator will ask the user to conduct specific tasks; the denser their FOV gets in relation to pollution, the harder it will be to conduct those tasks. Users are going to be engaged and it is going to become evident that air quality affects their daily routine by affecting their health.

In order to introduce the Noise Exposure KPI into the experience, the city's noise levels will affect the audio transmitted to users during the experience. The lower the values, the calmer the music and sound effects. When the noise reaches higher values, the sound effects and music will become harsher. While providing users with a disturbing experience when higher noise values are reached for the air and noise pollution, we aim for each citizen to become aware of the implications of such indicators for their health and wellbeing.

Figure 5 Concept Image: Visualization of Particles in AR

The experience will be transferred into a virtual world in order to inform the user about possible outcomes and future scenarios. Users will be transferred from their surrounding real-world environment to a new virtual one (Fig. 6). They will witness the positive or negative impact of these indicators when they reach extreme values, so that environmental awareness is achieved. Considering related past research analysed, we extend the static visualisation of environmental data to form an interactive, multimodal digital narrative, integrating gamified elements and engaging scenarios for environmental awareness. The interactive experiences will be consumed via MR Head Mounted Displays (HMDs) such as the Microsoft HoloLens 2. The exact design and scenario of the app is yet to be specified after the feedback from the engaged citizens and municipalities.

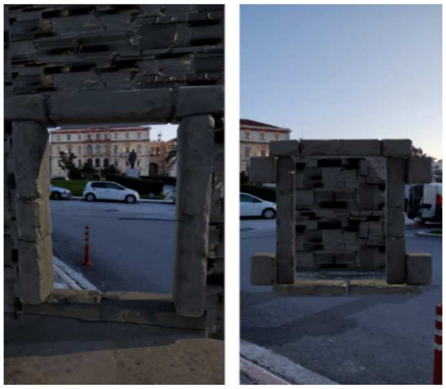

Figure 6 Virtual Portal: From a Virtual Place (left) to Real World (right)

V. Conclusions

This research paper stipulates that visualisation techniques combining data from IoT, processed with ICT and visualised in Mixed Reality, can be integrated to form engaging interactive experiences for environmental awareness, outdoors on-site and on-the-move. The main scope of our work is to demonstrate the capabilities of an ICT Platform which gathers and mines environmental data through visual analytics, enabling the interconnection of interactive Mixed Reality applications, Open Data Platforms, and third-party applications. Mixed Reality technologies provide illustrative, engaging and interactive experiences with the potential of augmenting the real-world with digital information which otherwise wouldn't be visible as well as its consequences for the citizen.

MR interfaces, integrating sensor network infrastructure and Key Performance Indicators (KPIs), enable the citizens of the city of Chania to be engaged in environmental action in relation to air and noise pollution. Both of these indicators represent something that is not visible to citizens. Citizens can only be informed about the levels of such indicators via plots or graphical schemas without direct awareness of their negative implications in their lives. Visualisation and MR technologies increase citizens' and visitors' environmental awareness and motivate them to act accordingly to safe guard their city and individual wellbeing.

Acknowledgment

This work was conducted as part of the VISIONARY NATURE BASED ACTIONS FOR HEATH, WELL-BEING & RESILIENCE IN CITIES (VARCITIES) has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869505. The sensors are provided by Cyclopolis Private Company in terms of their contribution to VARCITIES Project.

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