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Article

Advanced solution for urban gardens based on IoT systems, prediction algorithms and multi-criteria application

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Abstract

Faced with the challenges posed by rapid urbanization and climate change, the U-GARDEN project offers an innovative solution for sustainable urban development through the implementation of smart urban gardens. The project utilizes an advanced multi-criteria application that combines real-time environmental monitoring with Internet of Things (IoT) technologies to optimize the management of green spaces and support healthy plant growth. A key component of this system is the implementation of algorithms to predict the risk of disease outbreaks in cultivated plants, based on the analysis of monitored data such as humidity, temperature, and air quality. The QGIS-based application allows for the identification of optimal locations for urban gardens, considering both socio-demographic and environmental factors, thereby facilitating efficient and sustainable management. Through active community involvement and the use of advanced technological tools, U-GARDEN contributes to improving urban quality of life and creating greener, more resilient cities. This article highlights the project's potential to transform urban spaces into productive and healthy environments through scalable and innovative solutions.

Keywords: *urban gardening, sustainable development, IoT technology, prediction algorithms, multi-criteria application*

INTRODUCTION

Urban gardening has emerged as a practical and effective strategy to enhance the green footprint of cities, promote healthier lifestyles, and combat the challenges posed by climate change. Traditionally seen in the form of community gardens and city allotments, urban gardening has evolved into a movement driven by sustainability and social well-being. The U-GARDEN project, which integrates advanced technology into urban gardening, represents a significant step forward in this evolution. By integrating IoT systems, and Geographic Information Systems (GIS), U-GARDEN optimizes the management of urban green spaces, making them more efficient and sustainable. Real-time monitoring of crucial environmental variables such as temperature, humidity, and soil conditions, enabled by IoT technology, is a key aspect of U-GARDEN's methodology. This approach ensures optimal conditions for urban gardens, supporting optimal plant growth. By incorporating predictive analytics alongside active community participation, the project not only advances sustainable food production, but also strengthens social inclusion, ultimately improving the quality of life in urban environments.

This article explores how the U-GARDEN project's combination of IoT-based systems and multi-criteria decision-making tools creates a scalable and sustainable solution to urban gardening. By utilizing real-time environmental data, U-GARDEN provides a framework that promotes environmental health and supports healthier lifestyles, all while addressing the pressing issues of climate change adaptation and urban sustainability. The concept of urban gardening has evolved significantly with the integration of advanced technologies such as GIS and the IoT. Through the use of smart sensors and IoT devices, urban gardens can now collect real-time data on key factors such as soil quality, moisture levels, and other environmental parameters. This approach allows gardeners to make informed decisions that optimize the growth conditions of urban green spaces. GIS technology has an impotrant role in this process by providing valuable geographical data, enabling better resource allocation and strategic site selection for urban gardens.

The synergy between IoT and GIS has made urban gardening more efficient and sustainable, turning these green spaces into dynamic components of urban ecosystems. As highlighted in the literature, the adoption of these technologies marks the advent of "modern agriculture" within urban environments. In the article [1], Carrión demonstrate the practical application of IoT in urban gardening by designing a system equipped with sensors that monitor CO_2, humidity, luminosity, and temperature, alongside plant detection. This system, connected via a local area network, allows for remote monitoring and improves the precision of urban agricultural practices. The study emphasizes how IoT-driven solutions can boost agricultural productivity within cities, demonstrating the critical role technology plays in advancing urban gardening [2].

Urban gardens improve human health and mitigate the environmental impacts of urban land use. As part of broader green infrastructure (GI) initiatives, these gardens enhance the quality of often paved or neglected urban spaces. By transforming impermeable surfaces, urban gardens help reduce flooding risks and counteract the urban heat island effect. Although urban areas cover only 2% of the Earth's surface, they host half of the global population and much of the world's industrial activity, exerting significant pressure on the environment. Rapid urbanization, particularly in developing countries, amplifies these effects. Green infrastructure, including parks and green corridors, improves urban life by supporting ecosystem functions. Urban gardens reduce pollution, sequester carbon, and promote biodiversity, all while helping to combat the urban heat island effect, which increases energy demand [3].

Multi-criteria Decision-Making (MCDM) techniques are vital in urban planning, especially for selecting optimal locations for urban gardens [4, 5]. These methods evaluate various factors such as land slope, elevation, land use, and water accessibility to identify the best sites. GIS further improve this process by providing precise data [6,7]. This approach improves decision-making accuracy, promotes efficient resource use, and minimizes environmental impact, contributing to sustainable urban growth [8÷10].

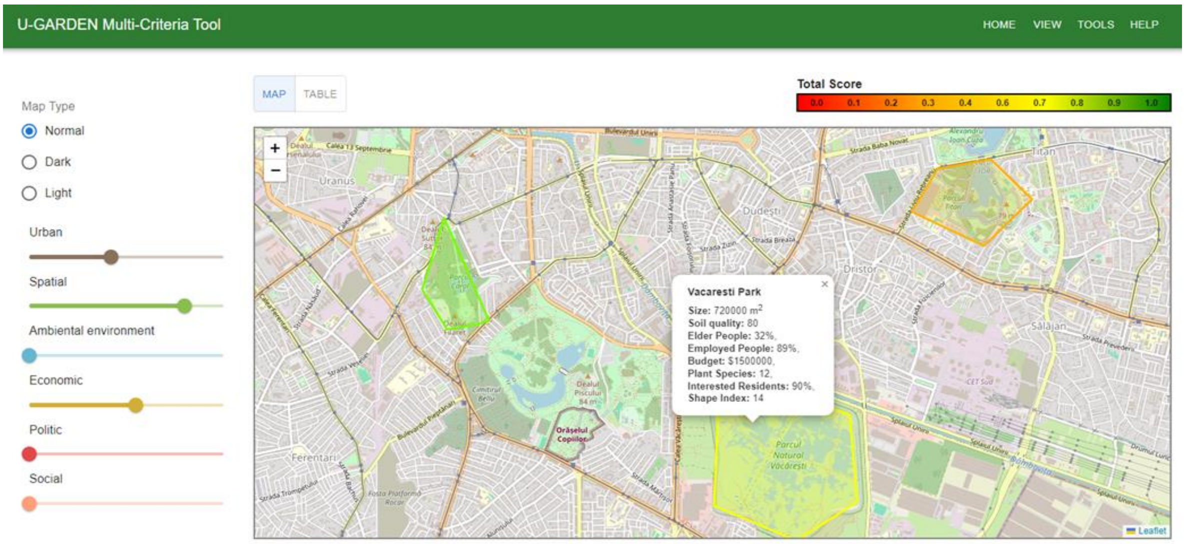
MATERIALS AND METHODS

We implemented the system in the U-Garden project, which is based on two main components: the multi-criteria application designed to manage suitable locations for urban gardens and the IoT network [11] that facilitates real-time monitoring of environmental parameters essential for optimizing plant growth [12, 13]. Below, each of these elements will be described in detail.

The multi-criteria decision support system (MCDSS) [14, 15] serves as a web-based platform developed to streamline decision-making processes related to urban garden site selection. We have developed this application in order to be highly interactive and user-friendly, allowing stakeholders such as urban planners, local governments, and community organizations to input and analyze various data layers. Users have the ability to categorize variables into relevant dimensions—such as spatial, environmental, economic, and social—and assign custom weights to each variable based on its importance in the decision-making process.

The data imported into the system may include spatial polygons or points, representing plots or land parcels, with associated attributes such as soil quality, pollution levels, and proximity to public infrastructure. These data are imported in JSON format, which must be populated with relevant information by users when adding locations to the platform. Upon uploading datasets, the application applies normalization techniques such as min-max scaling to standardize variables, ensuring comparability. This enables users to adjust the weightings of variables in an interactive manner and receive a visual output in the form of both maps and tables.

The interface of the multi-Criteria Tool application is presented in figure 1, illustrating how green areas and parks, are displayed after applying various filters. These areas were used as a demonstration to showcase the system’s capabilities, with the tool computing a final suitability score for each location by aggregating the weighted values across all selected criteria. This functionality provides users with a ranked list of potential urban garden locations in a hypothetical scenario.



Vacaresti Park
Size: 720000 m^2
Soil quality: 80
Elder People: 32%,
Employed People: 89%,
Budget: $1500000,
Plant Species: 12,
Interested Residents: 90%,
Shape Index: 14

Fig. 1. Display of the plots after applying filters

We built the interface of the multi-criteria tool to be intuitive and adaptable, featuring several core functionalities. For example, users can customize the map display by selecting from a range of base maps, adjusting filters, and running spatial queries. The application also includes menus such as "Home" for general configuration, "View" for controlling data display, and "Tools" for applying spatial and statistical analyses. The flexibility of the tool allows users to refine their analyses by iterating the evaluation process, thereby ensuring that the most optimal plots are selected based on evolving criteria and priorities.
The second component of the U-Garden system that we have implemented is the IoT-based real-time monitoring network. This network comprises high-precision sensors that continuously monitor environmental conditions within the urban gardens. We have created the architecture of the system, that is illustrated in Figure 2 and is designed to support efficient data collection and transfer. In illustrated architecture can be found the core of the IoT network, that is the Smart Agriculture PRO station [16] provided by Libelium. This station is equipped with sensors that measure a variety of critical parameters such as soil moisture, temperature, humidity, CO2 levels, and air quality.

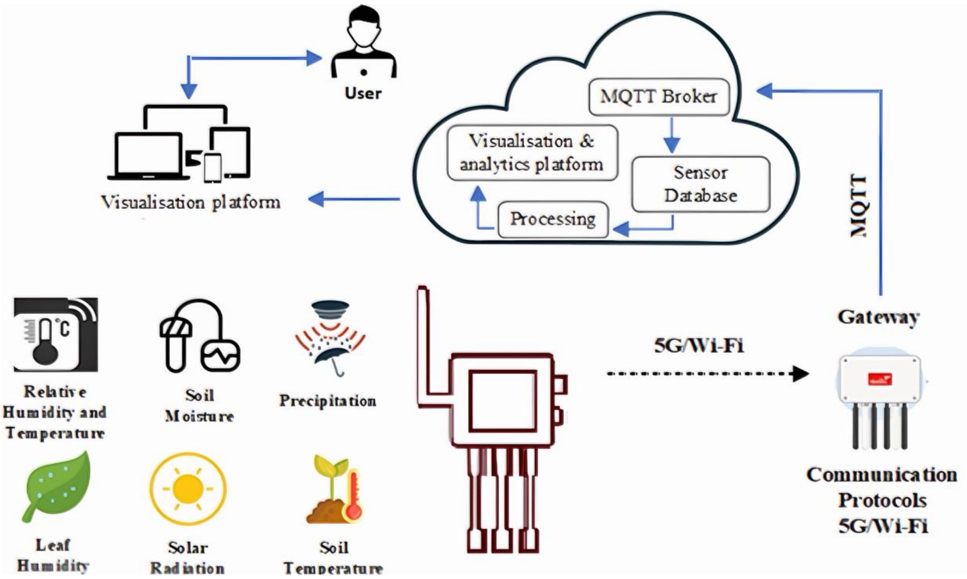
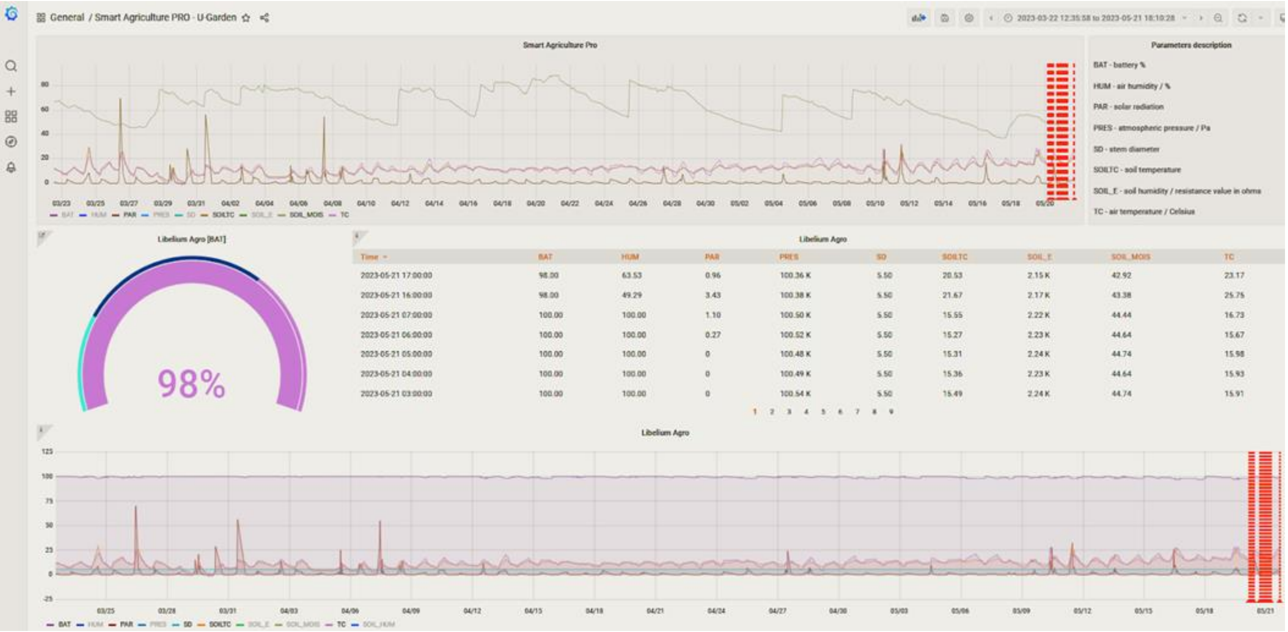


Fig. 2. The system architecture

In addition, the data collected by the sensors is transmitted to a central gateway, which consolidates the information and relays it to cloud-based storage via either Wi-Fi or 5G. The MQTT protocol [17] is used for data transmission due to its efficiency and minimal resource consumption. Once the data is transferred to the Cloud, it is stored in an InfluxDB database [18]. InfluxDB is particularly suited for time-series data, offering exceptional performance in terms of both writing and reading data. The database’s architecture supports horizontal scalability, making it capable of handling big data generated over time. The data stored in InfluxDB is then visualized using the open-source platform, Grafana, which enables users to interact with the data in a flexible and intuitive manner.

As shown in figure 3, Grafana [19] offers customizable dashboards that allow users to display environmental parameters in various formats, such as graphs and tables [20]. Users can also set alerts based on threshold conditions; for instance, an alert can be triggered if soil moisture levels fall below a predefined limit, signalling the need for immediate irrigation. Furthermore, Grafana allows users to apply mathematical transformations to the data, offering advanced options for analysis, such as calculating moving averages or applying filters to smooth data trends over time.



Parameters description

BAT - battery %
HUM - air humidity / %
PAR - solar radiation
PRES - atmospheric pressure / Pa
SD - stem diameter
SOILTC - soil temperature
SOIL_E - soil humidity / resistance value in ohms
TC - air temperature / Celsius

Libelium Agro

Time	BAT	HUM	PAR	PRES	SD	SOILTC	SOIL_E	SOIL_MOIS	TC
2023-05-21 17:00:00	98.00	63.53	0.96	100.36 K	5.50	20.53	2.15 K	42.92	23.17
2023-05-21 16:00:00	98.00	49.29	3.43	100.38 K	5.50	21.67	2.17 K	43.38	25.75
2023-05-21 07:00:00	100.00	100.00	1.10	100.50 K	5.50	15.55	2.22 K	44.44	16.73
2023-05-21 06:00:00	100.00	100.00	0.27	100.52 K	5.50	15.27	2.23 K	44.64	15.67
2023-05-21 05:00:00	100.00	100.00	0	100.48 K	5.50	15.31	2.24 K	44.74	15.98
2023-05-21 04:00:00	100.00	100.00	0	100.49 K	5.50	15.36	2.23 K	44.64	15.93
2023-05-21 03:00:00	100.00	100.00	0	100.54 K	5.50	15.49	2.24 K	44.74	15.91

1 2 3 4 5 6 7 8 9

Fig. 3. Grafana dashboard visualization

Together, these two components implemented by us—the multi-criteria application and the IoT monitoring system—form an integrated solution for managing urban gardens. The system architecture is modular, allowing for easy expansion or modification as additional data sources or sensors are incorporated. This modularity ensures the long-term sustainability of the system, as it can be continuously improved and adapted to meet new challenges in urban agriculture and environmental monitoring. By combining robust data analysis with real-time environmental monitoring, this system provides a complete set of tools for optimizing the selection and management of urban garden plots, thereby promoting sustainability and improving urban food security.

To provide a clear understanding of the system's capabilities, table 1 outlines the main sensors used, along with their technical specifications such as measurement range, accuracy, and measure units.

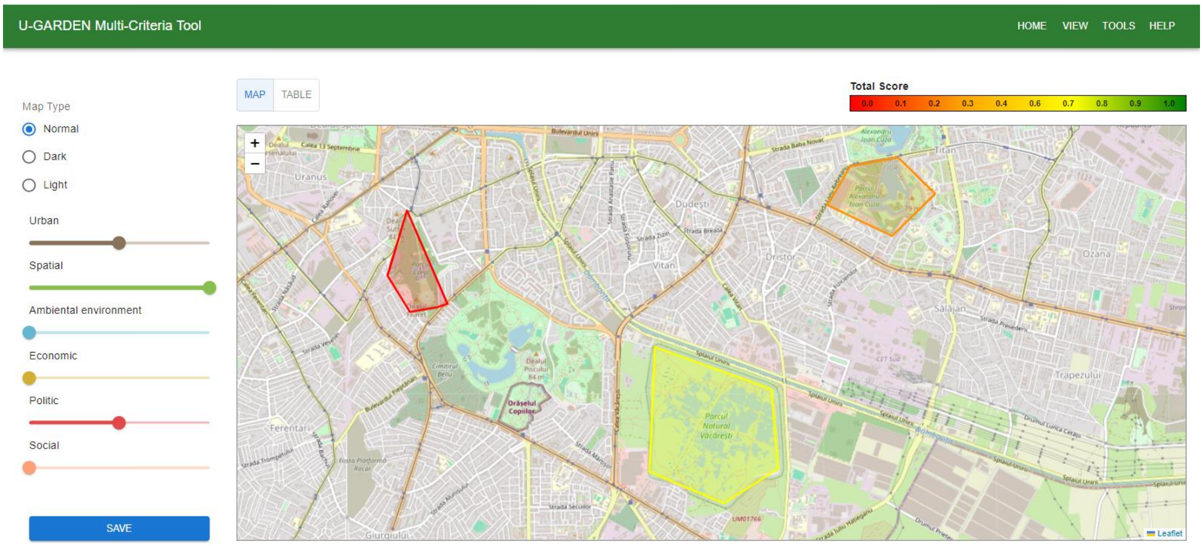
Table 1. Technical specifications of the sensors

Sensors	Specifications	Value/Measurement Range
0	1	2
Soil Temperature	Measurement Range	-50÷300ºC
	Accuracy	±2%
	Resistance (0ºC)	1000 Ω
	Length	40 mm
	Cable	5 m

0	1	2
Soil Moisture	Measurement Range	0÷200 cb
	Frequency Range	50÷10000 Hz
	Diameter	22 mm
	Length	76 mm
Air Humidity	Measurement Range	0÷100% (for temperatures < 0°C and > 60°C)
	Accuracy	< ±3% RH (at 25ºC, range 20÷80%)
	Operating Temperature	-40÷85 ºC
	Response Time	1 second
	Sensitivity	0.200 mV / µmol·m^{-2}·s^{-1}
	Spectral Range	410÷655 nm
Solar Radiation	Accuracy	±5%
	Operating Temperature	-40 ÷70ºC
	Operating Humidity	0÷100% RH
Atmospheric Pressure	Measurement Range	30÷110 kPa
	Accuracy	-40÷+85 ºC
	Response Time	0 ÷ +65ºC
	Absolute Accuracy	±0.1 kPa (0 ÷65ºC)
Air Temperature	Measurement Range	-40 ÷ +125ºC
	Accuracy	±0.2 ºC
	Response Time	2 seconds
Leaf Humidity	Measurement Range	0 ÷100%
	Accuracy	±5%
	Response Time	1 – 2 seconds
	Operating Temperature	-20 ÷60ºC
Precipitation	Measurement Range	0 ÷50 mm/h
	Resolution	0.2 mm
	Accuracy	±2%
	Operating Temperature	-20 – 70ºC
	Operating Humidity	0÷100% RH

RESULTS AND DISCUSSION

To test and demonstrate the functionality of the Multi-criteria application, various green areas and parks within Bucharest, such as Carol Park, were selected as representative examples. These areas were used for illustrative purposes to showcase the application's capabilities, rather than as proposals for actual urban garden conversions. The selected areas were analyzed based on multiple criteria, including their size, shape index, soil quality, available budget, and demographic characteristics of the surrounding neighborhoods, among other factors. This approach ensured a practical and visually compelling demonstration of the application's features (fig. 4).



Map Type: ● Normal ○ Dark ○ Light

Fig. 4. Plots after customization

The results demonstrated that the Multi-criteria decision tool goes beyond simply identifying suitable locations for urban gardens. It provides deeper insights for users, particularly local authorities and community groups, by highlighting the various benefits associated with different plot characteristics. For instance, some plots might offer superior soil quality and larger surface areas, while others may be more accessible or better aligned with community benefits, such as serving areas with a higher concentration of elderly residents. The tool's capacity to adjust the weighting of criteria enabled a qualified analysis, helping users to balance multiple priorities, such as environmental sustainability and social impact. This detailed assessment showcases how the application can support informed decision-making in urban gardening by aligning plot selection with broader goals related to sustainability and community development.

Regarding the interpretation of real-time monitoring data in urban gardens, we concentrated on analyzing key environmental parameters over a two-month period, visualizing them through individual graphs to enhance understanding. Figure 5 illustrates the fluctuations in solar radiation, demonstrating a consistent increase during daylight hours followed by a decrease at night. Additionally, the data reveals a gradual decline in solar radiation as the autumn season approaches, which could affect plant growth and photosynthesis.

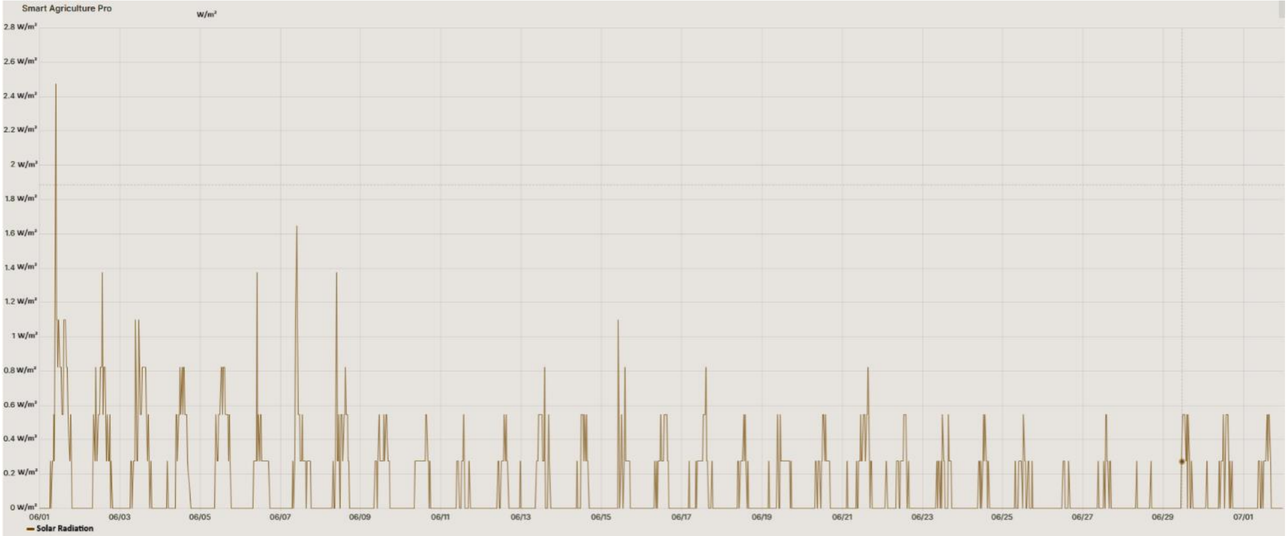


Fig. 5. The variation of solar radiation

Figure 6 showcases the variations in air and soil temperatures. The close correlation between these two parameters is evident, as they both exhibit similar trends over time. This relationship underscores the influence of atmospheric temperature fluctuations on soil temperature, highlighting the interdependence between the two. Such insights are crucial for understanding how temperature dynamics can affect plant health, growth rates, and overall garden productivity.

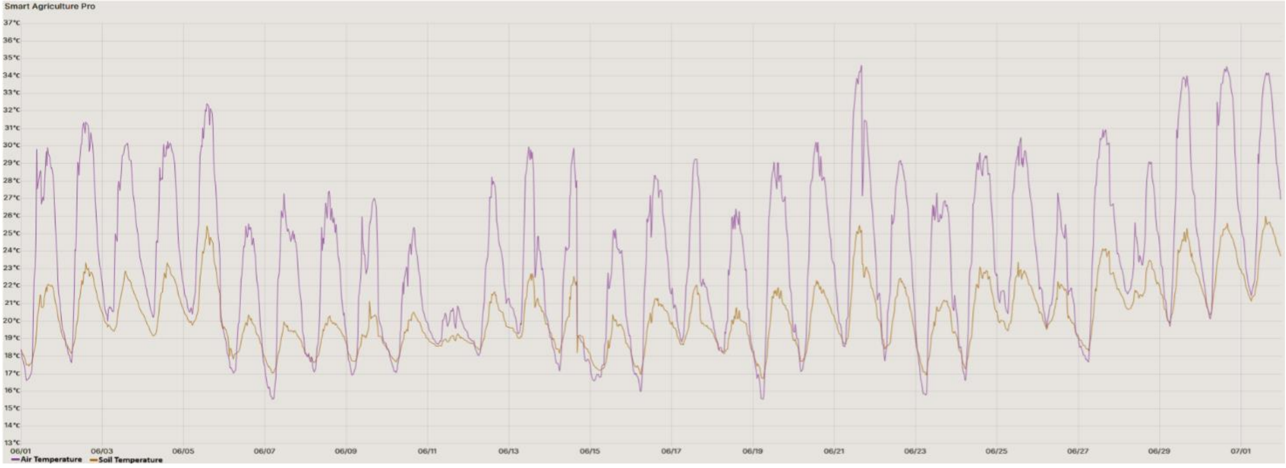


Fig. 6. The variation of air and soil temperature

Furthermore, we also monitored other critical parameters such as humidity and soil moisture levels (fig. 7), which play a vital role in plant growth. The interaction between these factors can significantly impact the microclimate of the urban garden. For example, higher humidity levels during the day can lead to increased evaporation rates, affecting soil moisture and requiring careful water management to ensure optimal conditions for plant development.

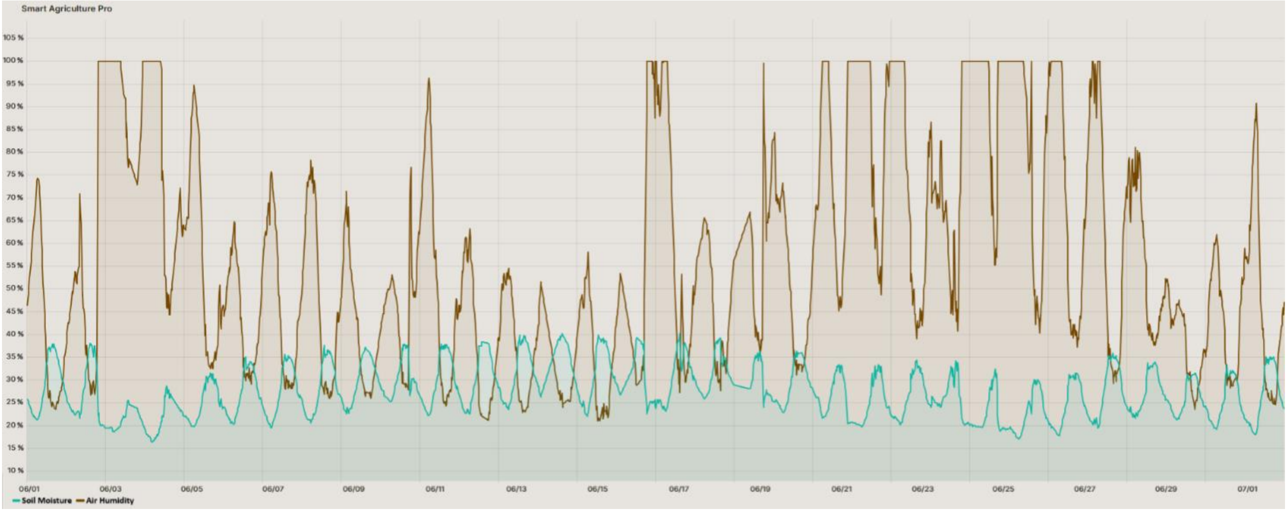


Fig. 7. The variation of air humidity and soil moisture

The results from the real-time monitoring system highlight the importance of integrating advanced monitoring technologies in urban gardening. By continuously assessing environmental conditions, stakeholders can make data-driven decisions to improve plant health, enhance yields, and promote sustainable practices in urban agriculture.

CONCLUSIONS

The U-GARDEN project illustrates how the integration of IoT and GIS technologies can transform urban gardening into a more sustainable and efficient practice. The project optimizes the management of green spaces and supports healthy plant growth, contributing to sustainable urban development. A key component of this approach is a multi-criteria decision-making tool, which evaluates spatial, environmental, social, and economic factors to identify the best locations for urban gardens. This allows users to make informed decisions, balancing environmental sustainability with community benefits.

The use of IoT-based sensors for continuous monitoring of factors such as soil moisture, temperature, and air quality ensure that urban gardens are managed effectively. Data collected from these sensors is visualized through Grafana platform, enabling real-time decision-making, such as triggering irrigation systems when soil moisture drops below a defined limit. U-GARDEN creates a collaborative platform that improves both the environmental quality and social well-being of cities. The project demonstrates how advanced technology can help create greener, healthier, and more resilient urban environments.

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