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URBAN GARDEN MANAGEMENT THROUGH THE USE OF IOT MONITORING SYSTEMS AND MULTI-CRITERIA APPLICATION

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ABSTRACT. Urban Garden Management Through the Use of IOT Monitoring Systems and Multi-Criteria Application. Modern cities face growing challenges in terms of food, the environment, and quality of life, making the opportunity to transform urban spaces into gardens increasingly relevant. The purpose of this paper is to present and detail the system developed within the U-GARDEN project, focusing on the creation and implementation of a multi-criteria application, including real-time monitoring of environmental conditions through the integration of IoT technology. This aims at efficiently managing various types of urban gardens, facilitating a sustainable approach, and optimizing plant development in these green spaces. The results obtained demonstrate the effectiveness of the developed system, providing users with the ability to identify and efficiently manage suitable locations for creating urban gardens, as well as monitoring real-time parameters relevant to optimizing environmental conditions and plant development. The QGIS-type application, enriched with a multi-criteria formula, proves to be a scalable and adaptable tool, contributing to the promotion of sustainable urban development by involving the community in managing green spaces. The system developed within the U-GARDEN project represents not only an innovative technological solution but also a practical and efficient tool for communities and other stakeholders, offering a sustainable way to transform cities into greener and more productive spaces.

Keywords: IoT system, urban garden, monitoring, multi-criteria, Romania.

1. INTRODUCTION

Urban gardens, in their traditional forms of "community gardens" and city allotments, have long contributed to cities. A new wave of urban gardens has emerged in recent years; these gardens are different from the ones that existed before them in that they are the result of people's motivations related to sustainability. A cursory review of the many case studies on urban gardens that are available in the published scientific literature validates these goals, which include: sustainable eating

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dynamics, sustainable lifestyles, and personal well-being stemming from demands for social inclusion and a sense of community.

Due to its popularity in society and city planning, urban gardening, along with the effects of climate change on cities and their adaptation, is gaining a lot of academic interest. Nevertheless there isn't much scientific research on community gardening as a whole. The majority of this literature offers proof of the social benefits of community gardening, including stress relief and overall well being. Furthermore, little is currently understood about how events related to climate change affect the production of food in cities or how resilient urban gardening and the urban food supply are to harsh weather (Tomatis et. al, 2023).

Urban gardening is a type of urban agriculture (UA), which is the production of livestock and crops inside the limits of a city. UA is common in private and business settings, on rooftops, in public areas, and in backyards. Urban farms, community gardens, allotment gardens, rooftop gardens, school and educational gardens, easement gardens, private gardens, windowsill gardens, guerrilla gardens, family gardens, vertical and hydroponics farming, balcony gardens, indoor farms, and rooftop gardens are just a few of the many varied initiatives that UA has to offer (Ribeiro et al., 2023). Our focus is on urban farms and the monitoring system developed for a better functioning of the garden.

Recognizing their significance beyond food production, the “Promoting capacity building and knowledge for the extension of urban gardens in European cities” (U-GARDEN) project employs interdisciplinary approaches to address needs and opportunities, facilitate stakeholder and citizen involvement, and evaluate social, cultural, and environmental impacts and also is the background of this research. Through Urban Living Labs, U-GARDEN aims to foster innovative business models and establish a multi-criteria framework for informed decision-making in locating urban gardens, contributing to resilient and eco-friendly urban landscapes.

The two primary components of the system used in the U-Garden project are the IoT network for real-time monitoring of important variables for optimizing environmental conditions and plant growth, and the QGIS multi-criteria application for effectively managing locations suitable for the creation of urban gardens. The system's main objective is to manage various urban gardens in an efficient manner while encouraging a sustainable approach and boosting plant development in these green spaces. By means of methodical management, the system guarantees a sustainable methodology, enabling users to identify suitable locations for the development of urban gardens. This developed system is unique in that it is efficient, enabling users to continuously monitor relevant parameters in real-time in addition to identifying ideal locations. The optimization of environmental conditions that are essential for promoting strong plant development in urban garden spaces becomes possible by this real-time monitoring.

This article is structured as follows: related works summarizing research by different authors on IoT technologies, GIS and real-time monitoring of important parameters, implemented in projects based on urban agriculture. It follows the implementation of the system, which addresses multi-criteria applications and real-time monitoring of the urban laboratory implemented in the project. Also, the results obtained are detailed in the next chapter, at the end concluding with some important aspects of the research carried out in the U-Garden project.

2. RELATED WORK

The topic of urban gardening has changed dramatically since the advent of technologies such as Geographic Information Systems (GIS) and the Internet of Things (IoT). Urban gardens can now gather data on soil quality, moisture content and other parameters in real time by utilizing smart sensors and IoT devices. GIS technology is essential in enabling gardeners to assess geographical data and decide the best way to distribute resources. Urban gardening becomes an effective practice thanks to the synergy between IoT and GIS, creating sustainable green spaces in urban environments.

The recognition of the significance of integrating novel technologies into precision agriculture is growing within the literature. A new era of "modern agriculture" has been established with the growth of IoT and information management technologies. The design and implementation of a system using IoT technologies along with a number of sensors is presented in the study by Carrión et al. (2018). Equipped with sensors for CO_2, humidity, luminosity, temperature, and plant detection, the system incorporates a hybrid application for remote monitoring connected to a local area network. The communication process utilized by the system undergoes testing, with a comprehensive evaluation of its performance and reliability. The primary goal of the article is to promote agricultural production within urban areas, using the advantages of IoT technology in the context of urban gardening.

China's fast urbanization in the last few decades has brought attention to the need for greater efforts in urban gardens, which frequently face issues including poor management and expensive operating costs. These difficulties have an impact on both urban growth and the populations' quality of life. Therefore, utilizing state-of-the-art technology, the authors Chang and Tan (2022) of Ankang University in China carried out a study to enhance the digital administration of urban gardens. Their study aims to explore the feasibility of creating a digital management system for plant growth status in urban gardens and its development. This work mentioned above describes the design and implementation of the system, including the hardware and software components, the data acquisition and processing methods, and the system functions. There are also presented experimental results and analysis, which show that the system can effectively collect and display the image data of garden plants.

The study by Thebault et al. (2020) describes a decision-making approach for ranking a group of buildings based on their potential to host solar systems in the urban environment. The study is part of a Franco-Swiss effort focusing on the Greater Geneva area. The authors address the problem using the ELECTRE III outranking approach, which provides an efficient ranking of the various solutions. They take into account a variety of features, including energy, economy, heritage, and roof structure. They apply the strategy to a Geneva district and compare the outcomes to alternative scenarios that just take into account one factor, such as solar irradiation or payback period. They conclude that the suggested multicriteria method incorporates the complexity of the urban environment and delivers more relevant information to urban actors.

Another study by Baker and Smith (2019) made in order to categorise UK urban garden surfaces investigates the methodological implications of combining GIS with an Object Based Image Analysis (OBIA) remote sensing methodology that makes use of extremely high resolution Worldview-2 images. Gardens were categorized with an overall accuracy of about 86%, focusing on a 7 km^2 research area in Leicester, UK. The results demonstrate how GIS and OBIA analysis may be used to map urban garden surfaces in the UK, providing a useful framework for further research. Insights related to urban greenspace analysis in other UK urban regions were revealed by further analyzing the obtained dataset to find connections between garden greenspace percentage and physical garden attributes.

3. SYSTEM IMPLEMENTATION

The system implemented in the U-Garden project is based on two main elements, namely the multi-criteria application to efficiently manage suitable locations for the creation of urban gardens and the IoT network for real-time monitoring of relevant parameters for optimizing environmental conditions and plant growth. In the following we will discuss the functionality of the two key elements of the U-Garden system separately.

3.1. Multi-criteria application

The Multi-criteria application is a web application designed to simplify decision-making for urban garden locations. It serves as an interactive and user-friendly platform, allowing various stakeholders, including public administrations and associations, to input their data. Users can categorize variables, weigh them based on personal criteria, and obtain a visual output. This output helps identify vacant plots suitable for urban gardening, aiming to democratize the location process by empowering users to make informed decisions using their own defined variables and criteria.

After loading the application, users import data and select variables for analysis, which can be in raw form or min-max scaled. Variables can be assigned to dimensions, and users can adjust weightings based on importance through interactive controls. The application calculates a final score, aiding users in identifying optimal plots based on their specified criteria. Visualization options include an interactive map for spatial data and an interactive table for non-spatial data. The application offers flexibility, allowing users to refine their analysis as needed.

Imported data will be in the form of polygons or spatial points, representing the locations of interest. These data include associated attributes, which serve as variables. Users can select and categorize these variables into dimensions such as Spatial, Urban, Environmental, Economic, Political, and Social. Each dimension receives a score, calculated as the arithmetic mean of its assigned variables.

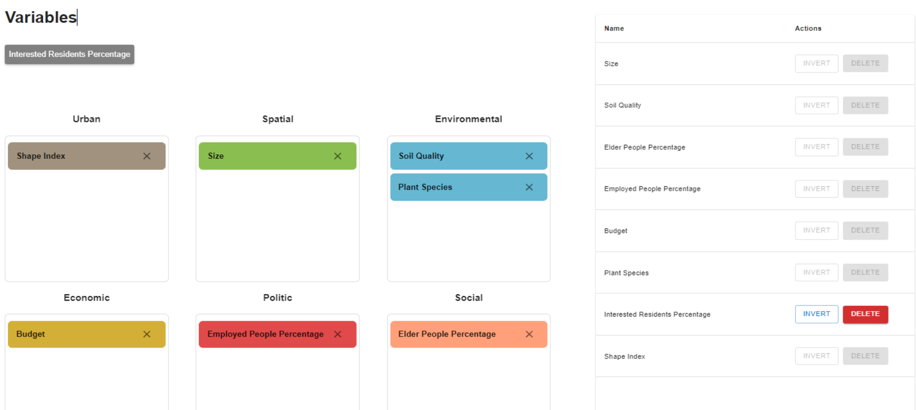


Fig. 1. ***The selection and classification of variables***

The user interface is intuitive, offering tools and visualization options. Users can choose the base map source, apply filters, conduct searches, and adjust settings. The outcome is a clear visual representation, aiding users in identifying suitable plots for urban gardening.

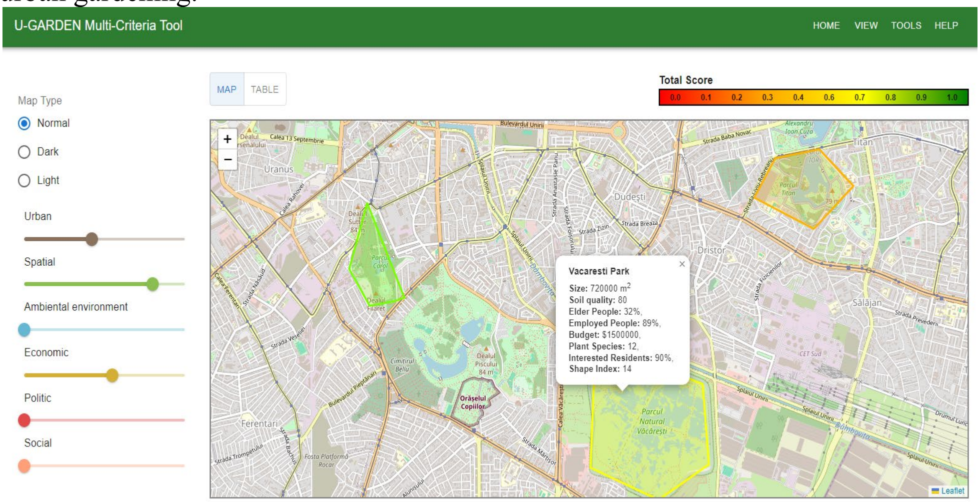


Fig. 2. ***The identification of plots on the map***

Key functionalities include the "Home" menu for general configuration and common tasks, the "View" menu for data display customization, and the "Tools" menu for data analysis and manipulation. The "Help" menu provides guides, answers to common questions, and contact information for assistance.

3.2. Real-time monitoring

The second important element of the system is the IoT real-time monitoring network. The architecture of this network is detailed in Fig. 3.

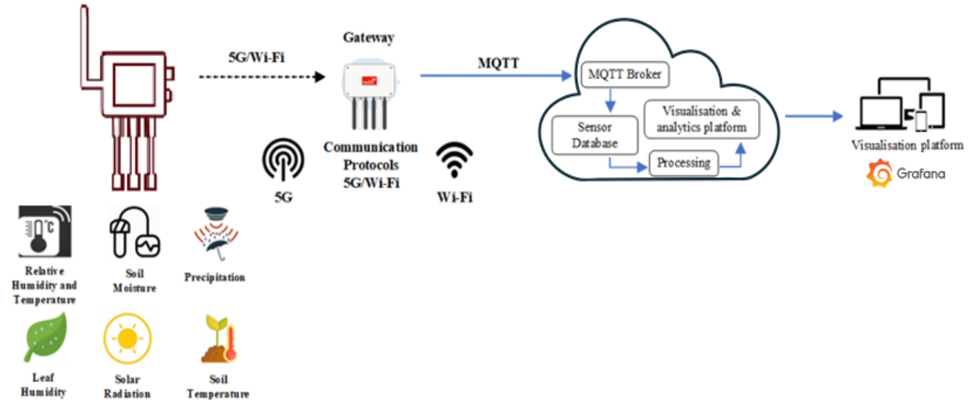


Fig. 3. ***The system architecture***

For the implementation of the IoT monitoring system of the urban laboratory is used the monitoring station, Smart Agriculture PRO, high precision, provided by the manufacturer Libelium. The components of the urban environmental quality monitoring system, in addition to the IoT station and the sensors used for monitoring parameters, are: the Gateway, which collects data in real time and regularly transfers them to applications and databases, and manages the communication protocols of the sensors; the InfluxDB database, which allows real-time recording of parameters from the monitoring station; the Grafana platform used to visualize the parameters monitored by the Libelium station.

The data captured by the sensors is transmitted to a data concentrator via Wi-Fi or 5G and then sent to the cloud via a network protocol called MQTT (Message Queuing Telemetry Transport). Here, this data is stored in a database and processed for further use. The choice of the MQTT protocol is characterised by its efficiency and simplicity of use, allowing data to be transferred without requiring significant resources from the IoT (Internet of Things) platform.

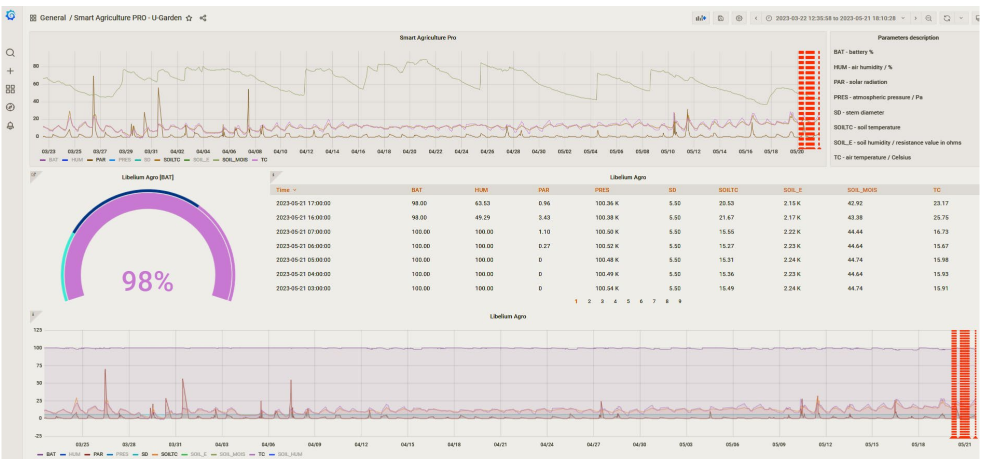


Fig. 4. ***Grafana dashboard visualization***

The database used in the system is InfluxDB, taking into account the numerous advantages it benefits from. This system is specifically optimized for storing time series data, with outstanding performance in both writing and reading information. These features ensure efficient management of data from IoT devices, facilitating successful data development, monitoring and analysis.

The Grafana visualisation platform, allows users to access data in graphical or tabular format, apply mathematical formulas to graphs and set up alerts. Using this platform, data can be extracted from the database and analysed in terms of its evolution over time (Fig. 4).

4. RESULTS

4.1. Multi-criteria application

To explain the functionality of the Multi-criteria application we will prepare a report on which empty plots would be the most suitable for the implementation of an urban garden in the Bucharest metropolitan area. For this we found some vacant plots, obtained their spatial polygons and scored a set of criteria for each one. Some of these criteria include the size (in m2) of the plot, shape index, soil quality, budget, percentage of elderly people in the neighborhood in which it is located, among others. First we open the application and start loading the file containing the polygons of the plots and their characteristics.


```json
{
    "name": "Titan Park",
    "data": {
        "size": 560000,
        "soilQuality": 30,
        "elderPeoplePercentage": 23,
        "employedPeoplePercentage": 39,
        "budget": 150333,
        "plantSpecies": 9,
        "interestedResidentsPercentage": 75,
        "shapeIndex": 14
    },
    "coordinates": [
        ["44.416791", "26.156127"],
        ["44.41964506566907", "26.147857657091734"],
        ["44.42315692826376", "26.15085068640847"],
        ["44.423974878373016", "26.156913097928957"],
        ["44.42065938311134", "26.161646970904645"]
    ]
```


Fig. 5. ***The json input data***

Once the file is loaded, the application recognises the attributes as variables and we start grouping each variable in the corresponding dimension. For example, we group the plot size variable into the spatial dimension. Similarly, we group the percentage of elderly population variable into the social dimension, soil quality in the environmental dimension and the budget into economic dimension.

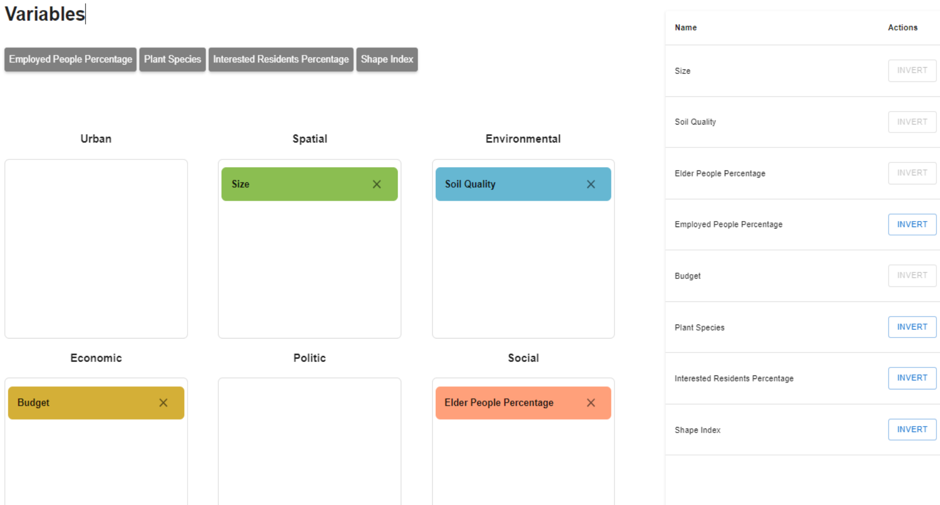


Fig. 6. ***The assignment of variables based on input data***

Initially, the total score of all plots is 0, since by default the weighting of all dimensions is 0. On the contrary, if the weighting were identical between dimensions, the total score would simply be the arithmetic mean.

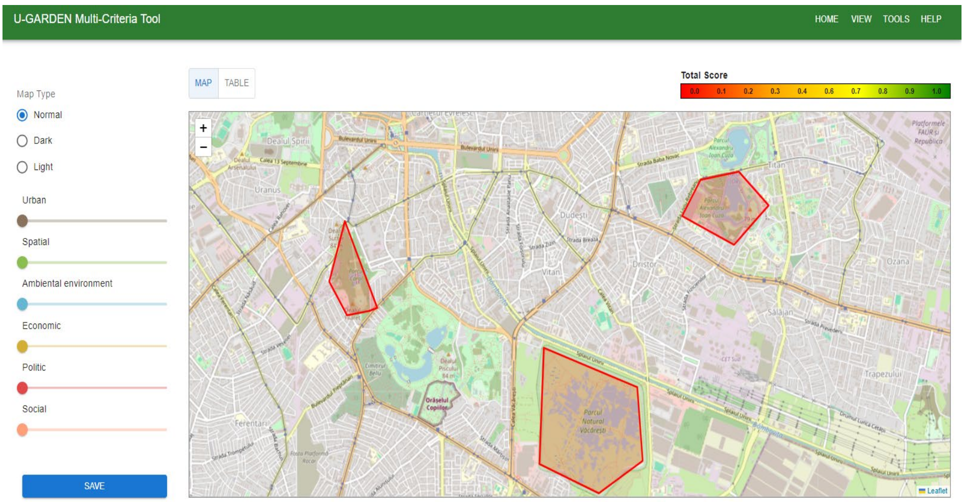


Fig. 7. ***Display plots with score 0***

We decide to weight the dimensions as shown in Fig.8. The color of the plot will change according to the highest score.

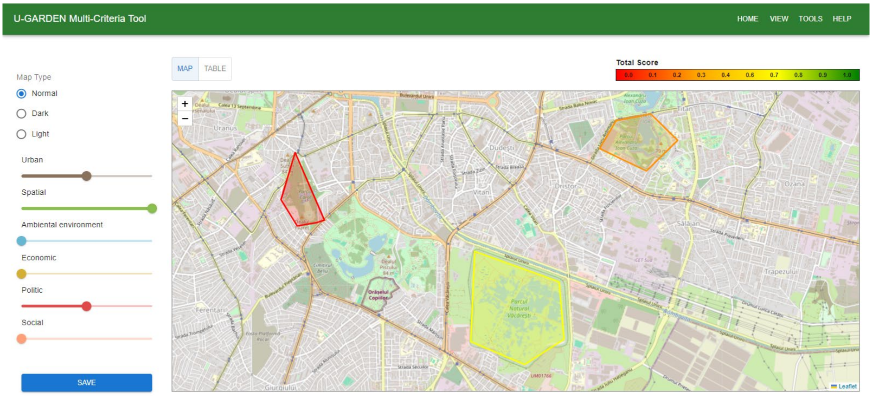
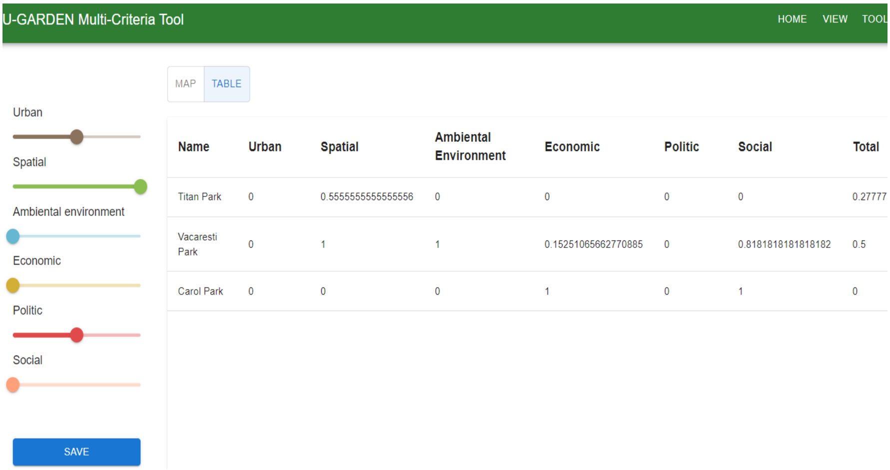


Fig. 8. ***Display of the plots after applying filters***

To see the score of each plot, we switch to the table format, the results are shown in Fig. 9.



Name	Urban	Spatial	Ambiental Environment	Economic	Politic	Social	Total
Titan Park	0	0.5555555555555556	0	0	0	0	0.27777
Vacaresti Park	0	1	1	0.15251065662770885	0	0.8181818181818182	0.5
Carol Park	0	0	0	1	0	1	0

Fig. 9. ***The table format of plots score***

We can see here that Vacaresti Park has the highest score which is 0.5. This value is obtained as follows: Each plot has a normalized value for each category based on how we grouped the variables. For example if we put size in the spatial category then that category value will be decided only based on each plot size alone. If we grouped multiple variables in the same category then we will make the arithmetic mean of all normalized values. In our case, the biggest score (1) for the spatial category will correspond to the biggest plot in size and the smallest score (0) smallest plot. All other intermediate values will be in (0,1) interval.

Following the calculation, the result will be as follows: (50*0 + 100*1 +0*1 + 0*0.15 + 50*0 + 0*0.8) / (50 + 100 + 0 + 0 + 50 + 0) = 100/200 = 0.5.

This value corresponds to yellow based on the total score legend so the plot will be colored accordingly.

4.2. Real-time monitoring

In terms of interpreting the results in terms of real time monitoring in urban gardens, we will continue to analyse the most important parameters monitored in the urban garden over two months, presenting them in individual graphs. In Fig. 10, we can see the variations of solar radiation, which shows an increase during the day and a decrease during the night. It can also be seen that solar radiation gradually decreases as we approach the autumn season.

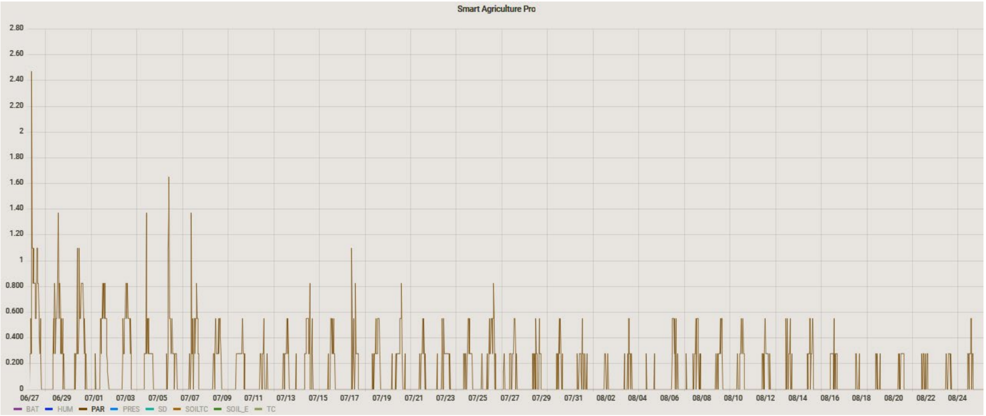


Fig. 10. ***The solar radiation variations***

Fig. 11 and 12 show the variations in air temperature and soil temperature. These two variables are closely correlated, and it can be seen from the graphs that they evolve in a similar way. Thus, thermal changes in the atmosphere can have a significant impact on soil temperature and vice versa, which contributes to a deeper understanding of the thermal dynamics within this urban garden.

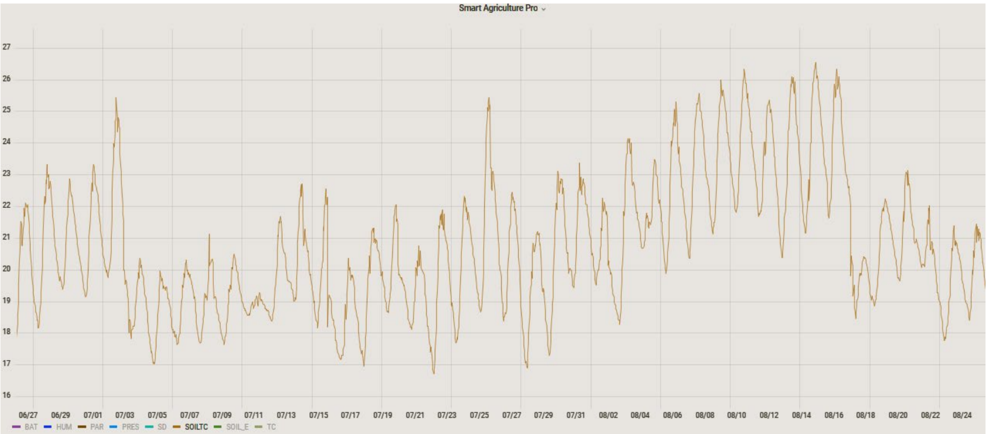


Fig. 11. ***The soil temperature variations***

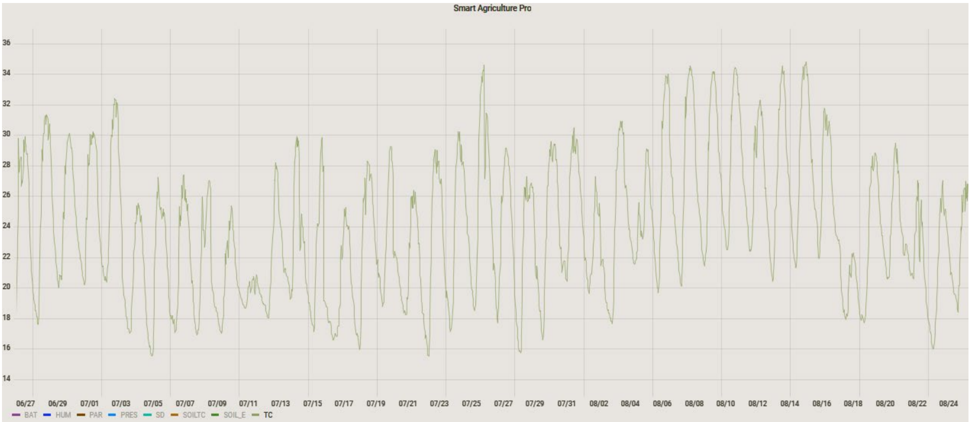


Fig. 12. ***The air temperature variations***

Thus, the modular structure of the U-Garden project proved essential for the analysis and interpretation of the data collected in the urban garden. This approach facilitated the identification of significant correlations, such as the relationship between variations in solar radiation and recorded temperatures, bringing value to the understanding of environmental dynamics and supporting informed decision-making for urban garden optimization.

5. CONCLUSIONS

In conclusion, this paper has successfully addressed the current challenges of modern cities in terms of food sustainability, environmental quality and overall urban living standards. The combination of the Multi-criteria application and the IoT-based real-time monitoring network proved to be a robust and effective system for transforming urban spaces into productive and sustainable gardens.

The Multi-criteria application serves as a powerful decision-making tool, democratizing the process of selecting suitable locations for urban gardens. The app's flexibility and visual outputs contribute to informed decision-making, empowering users to actively participate in the creation and management of urban green spaces.

On the other hand, the real-time monitoring network, based on IoT technology, provides valuable information on environmental conditions in urban gardens. This real-time data facilitates a deeper understanding of the dynamics within the urban garden, highlighting correlations between environmental factors and supporting data-driven decisions for optimal plant development.

In essence, through this work we not only introduce an innovative technological solution, but also establish a practical and effective tool for communities and stakeholders. The success of the U-GARDEN system exemplifies its significant potential in contributing to the future of urban planning and sustainability.

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REFERENCES

1. Baker, Fraser & Smith, Claire. (2019). A GIS and object based image analysis approach to mapping the greenspace composition of domestic gardens in Leicester, UK. Landscape and Urban Planning. 183. 133-146. 10.1016/j.landurbplan.2018.12.002.
2. Carrión, Gabriela & Huerta, Mónica & Barzallo, B.. (2018). Internet of Things (IoT) Applied to an Urban Garden. 155-161. 10.1109/FiCloud.2018.00030.
3. Chang, J., & Tan, Y. (2022). Application of GIS Sensor Technology in Digital Management of Urban Gardens under the Background of Big Data. Journal of Sensors, 2022.
4. Ribeiro, A., Madureira, L., & Carvalho, R. (2023). Evidence on how urban gardens help citizens and cities to enhance sustainable development. Review and bibliometric analysis. *Landscape and Urban Planning*, *236*, 104766
5. Thebault, Martin & Clivillé, Vincent & Berrah, Lamia & Gaillard, Leon & Desthieux, Gilles & Ménézo, Christophe. (2020). Multi-criteria decision aiding for the integration of photovoltaic systems in the urban environment: the case of the Greater Geneva agglomeration. Territorio. 2020. 1. 10.14609/Ti_1_20_1e.
6. Tomatis, F., Egerer, M., Correa-Guimaraes, A., & Navas-Gracia, L. M. (2023). Urban Gardening in a Changing Climate: A Review of Effects, Responses and Adaptation Capacities for Cities. *Agriculture*, *13*(2), 502.