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A SUPPORT SYSTEM FOR HIGH-QUALITY URBAN GREEN MANAGEMENT IN TUSCANY

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Abstract

Nowadays, several ongoing processes, ranging from climate change to alien pests spreading, make plants protection and green care more complex, forcing the adoption of stringent management rules and changing traditional operational frameworks. In Tuscany, green maintenance has become extremely challenging for municipal technical departments, professionals, and private companies having the responsibility of High-Quality Urban Green Areas Management, characterized by different types of plants and services. The application of new technologies such as Internet of Things (IoT), geomatics, and automation, could provide concrete assistance for precision gardening, increasing the sustainability of the management practices. This paper describes the general structure and main components of GARANTES, a support system for green maintenance, oriented also to improve the analytical performance of decision-makers and stakeholders in site design and fieldwork programming.

Keywords

Integrated System, Agrometeorological modeling, Precision gardening, Environmental sustainability, Fieldwork scheduling, ICT (Information and Communication Technologies)

1. *Introduction*

Under the pressure of several socio-economic and climatic factors, a change of mindset is required in the design and management of High-Quality Green Areas (HQGAs), looking for more efficient and more effective criteria and procedures, both in the public and private sphere (Demuzere, Orru, Heidrich, Olazabal, Geneletti, Orru, Bhave, Mittal, Feliu, & Faehnle, 2014; Csete & Horvath, 2012; Heymans, Breadsell, Morrison, Byrme, & Eon, 2019).

On the other side, urban greening increases promise to achieve several of the United Nations Sustainable Development Goals, making cities healthier and liveable. Moreover, the protection of ancient trees and precious plants, particularly in historical parks and gardens, requires the recognition and control of a plurality of stress factors, existing in built landscapes (Cavender & Donnelly, 2019).

In the last years, several advanced technological solutions have been proposed for urban plant monitoring and green area control to improve management practices and analytical capability of the involved professionals (Varras, Adreopoullou, Tasoulas, Papadimas, Tsirogiannis, Myriounis, & Koliouska, 2016; Abujubbeh, Al-Turjman, & Fahrioglu, 2019), providing useful information for the contrast of several emerging issues in this specific field of research (Kabisch, Qureshi, & Haase, 2015). Environmental sustainability and resilience in Hight Quality Urban Green Areas Management (HQ-UGAM), on the other side, can be achieved only by promoting "smart green" and multidisciplinary approaches, adopting spatial and temporal geostatistical analysis tools (Tao 2013; Luvisi & Lorenzini, 2014). For this, higher efforts should be made to increase the knowledge on urban forest and green space role in our cities, addressing climate change as a priority issue (Ostoić, Salbitano, Borelli, & Verlič, 2018).

Dedicated support systems, based on solid scientific principles, can make a difference in the introduction of sound sustainable practices and principles at the operational level (Gutiérrez, Htun, Schlenz, Kasimati, & Verbert, 2019), assuring the adoption of good practices for resources exploitation, plant and ecosystem protection against a number of emerging problems (Early, Bradley, Dukes, Lawler, Olden, Blumenthal, Gonzalez, Grosholz, Ibañez, Miller, Sorte, & Tatem, 2016; Moricca, Bracalini, Croci, Corsinovi, Tiberi, Ragazzi, & Panzavolta, 2018), with an array of economic advantages (Rossi, Giosuè & Caffi, 2010; Kabisch et al., 2015).

Under this framework, to provide concrete operational support to professional green managers, the realization of a prototypical system was envisaged under the Rural Development Program of the Tuscany Region - Sector for Innovation Promotion and Knowledge Systems"(PSR 2007-2013). The project, called GARANTES (Green Area contRol And management tools: New Techniques for Environmental Sustainability), involved the evaluation of different HW/SW solutions for urban green area monitoring and analysis (Raschi, Conese & Battista, 2016). Several web-oriented GIS applications were implemented under a multi-purpose IT environment (Rall, Hansen, & Pauleit, 2019; Lv, Li, Zhang, Wang, Zhu, Hu, & Feng S., 2016), ensuring an effective operational co-working and data exchange among the professional involved figures (Decision Makers, Landscape Designers and Greenkeepers) and the Support tools. Model outputs and advice are aimed to increase the efficiency of the urban green and garden management practices, acquiring also expertise for a more careful and sustainable design of these multifunctional spaces (Zhu, Lang, Tao, Feng, & Liu, 2019).

This article describes the structure, procedures, and components of the GARANTES support system, discussing the relevance of its outputs through the analysis of operational cases, extracted from some events recorded in the five years of support activity, on four private High-Quality Green Areas located in different parts of Tuscany.

2. *GARANTES rationale*

From an operational point of view, the Support System development was organized into three main phases:

a) selection of convenient HW/SW devices (cost/performance ratio) for green area monitoring and control;
b) integration of the most promising tools and realization of a Support System prototype;
c) evaluation of the operational benefits derived from the use of project solutions.

During the project, economic and practical considerations have often prevailed on original customized solutions, suggesting the design of a more versatile modular system, open to commercial equipment and components.

Web-oriented GIS functions were then implemented, under a user-friendly open-source framework, able to manage data collected by different sources and oriented to provide scalable multipurpose solutions (Rocchi, De Filippis, & Magno, 2010; Trubina, Nikolaeva, & Mullayarova, 2019; Li, Uyttenhove, & Vaneetvelde, 2020). Available forms and functions allowed a wide range of personalization, both for HW/SW and operational items, including site characterization, plant selection, and management criteria definition. After opportune periods of on-site calibration and evaluation, required to achieve functional reliability of the system on each new green area, GARANTES was able to provide operational advice to approach different relevant issues for green area management, based on the integrated use of agrometeorological models, electronic devices and advanced integrated technologies. For five years, the system has operationally supported a team of experts in HQ-UGAM of four representative private green areas in Tuscany, complying with service standards and end-user directives.

The outputs of indices and models were analyzed at different spatial and temporal scales by means of statistical and geostatistical procedures, using detailed Digital Elevation Model and Remote Sensing Images, obtaining thematic variability maps of interesting factors, such as plant health, biomass, phenology, and evapotranspiration (Battista, Chiesi, Rapi, Romani, Cantini, Giovannelli, Cocozza, Tognetti, & Maselli, 2016; Battista, Chiesi, Fibbi, Gardin, Rapi, Romanelli, Romani, Sabatini, Salerni, Perini, & Maselli, 2018). Full reports, synthetic advices, and forecasts were used by experts for short, medium- and long-term evaluations on green area conditions, local hazards, and management scheduling.

3. *Test Sites*

To accurately assess modeling performance, before their implementation into the Support System, an experimental garden was expressly designed and realized at the CREA Research Centre for Vegetables and Ornamental Crops of Pescia (PT), while for operational testing three private green areas were used, considered representative for vegetation and climate of the Tuscany realities:

- P1 – Pescia (Lat. N.43°52'8.0", Long. E.10°40'53.66") – Experimental garden, with more than 30 Mediterranean plant species, growing in two twin areas used to compare innovative vs traditional practices.
- P2 – Pistoia (Lat. N.43°55'16.3", Long. E.10°55'07.16") – Representative garden, located in the main plant nursery district in Tuscany, hosting very diversified plant species and managed by Mati Plant group to show the most interesting technical solutions to customers.
- P3 – Forte dei Marmi (Lat. N.43°57'34.26", Long. E.10°10'49.41") – Private fine garden, placed along the seacoast, with valuable vegetation and some exotic species.
- P4 – Castiglion del Bosco (Lat. N.43°04'59.30", Long. E.11°25'16.73") – Park of a luxury resort, situated in the hilly region of the Chianti wine-production area, with trees, bushes, and odorous plants.

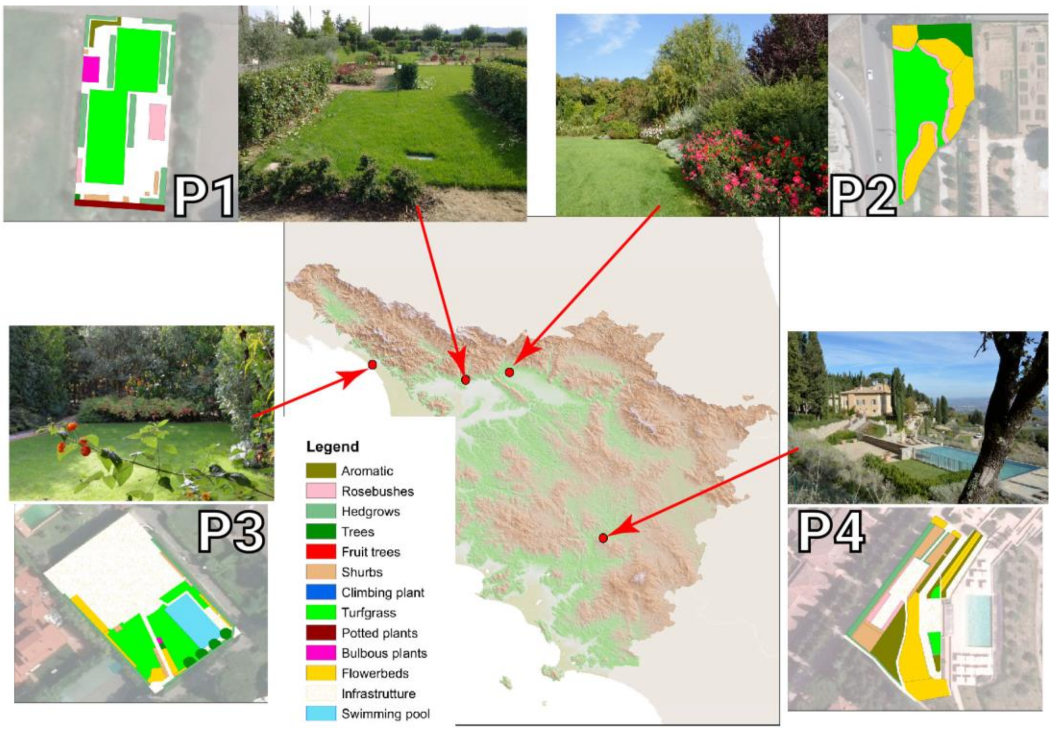

Fig. 1: Main features of the four GARANTES Pilot sites.

The pilot sites (Fig. 1) were selected for their representativeness of typical operational scenarios at the regional level, presenting different environmental, climatic, and socio-economic contexts.

In order to rationalize the system outputs and simplify the evaluation procedures, each pilot site was divided into "homogeneous zones" of variable dimensions, corresponding to surfaces that could be managed according to the same criteria (i.e. action planning, irrigation, treatments, etc.). The evaluation protocol included the comparison between innovative and traditional methods, with direct surveys and measures aiming at quantifying the possible advantages in terms of fieldwork rationalization, resources use optimization, and/or environmental impact reduction. P1 garden is always active and has been included among the WIRE Project sites of the European Innovation Partnership on Water (EIP), (https://www.eip-water.eu).

4. DSS structure

Professional management of the complex relationships between natural and anthropic factors, in urban green areas, requires the analysis of several elements and the adoption of specific solutions. Starting from inhomogeneous platforms, required components must be integrated, assuring a strict informative consistency of the delivered information. The modular form of GARANTES incorporates components using different standard and non-standard formats, integrated by means of dedicated tools (Fig. 2).

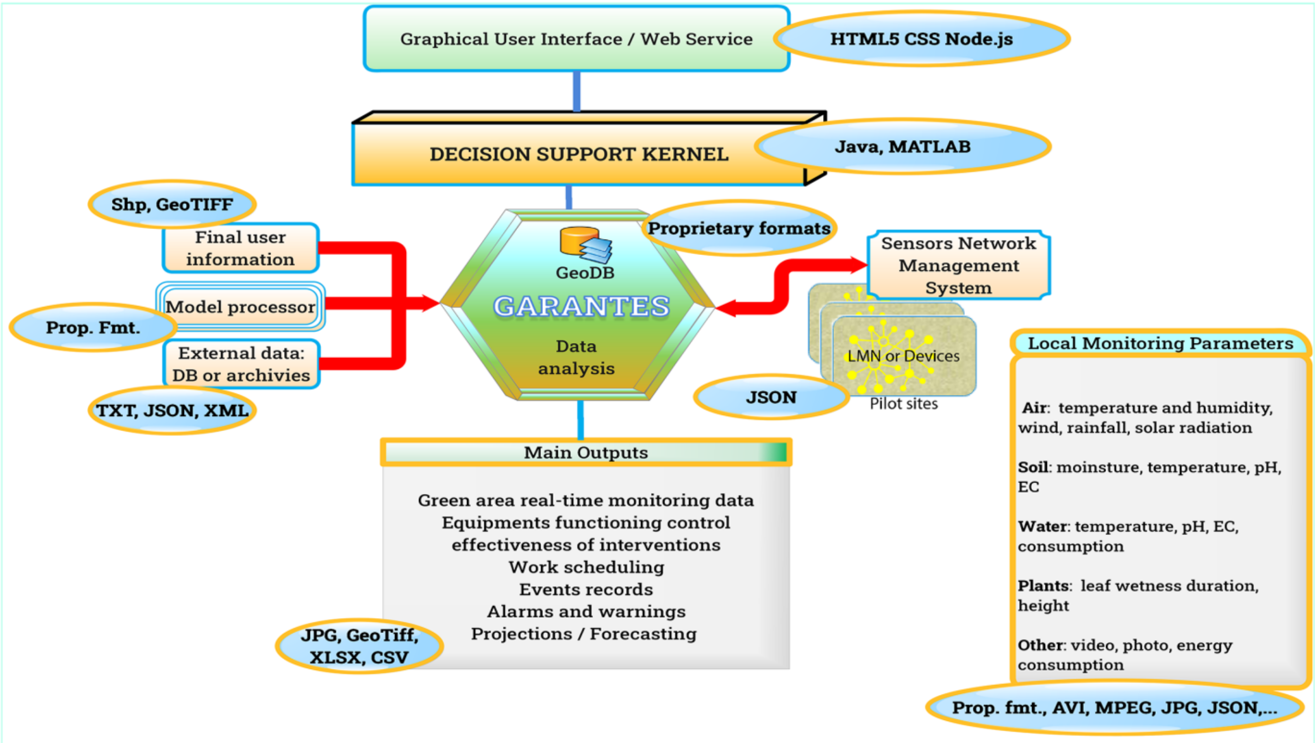

Fig. 2: Summary diagram of the main GARANTES HW/SW components, gathered for functional classes, and principal dataflow roads (arrows), with the indication of the main data formats (blue ovals) used for internal exchange (ovals shapes).

The core of the system is represented by a geographic database (GEO-DB), developed in PostgreSQL with PostGIS extension for spatial data management and GIS operations, where data are stored and made available for processing.

The respect of SOA (Service Oriented Architecture) paradigms assures the intrinsic interoperability between GARANTES components and external platforms. Dataflow reflects the procedures required to activate the system functions and the logic steps for its use throughout four functional classes: 1. Data collection; 2. Data analysis and management; 3. Modeling; 4. Final User Interface.

Data required for environmental and agrometeorological modeling are gathered into five dedicated sections of the DataBase (DB), corresponding to the main elements of the HQ-UGAM: a) Green Areas; b) Botanical Section; c) Plant and Pests; d) Monitoring Network, and e) Models Section.

4.1 Data collection

GARANTES accepts data from three different information sources: i) final user data-entry (in any available format); ii) external databases or archives (through ETL - Extract, Transform, Load - procedures); iii) dedicated local network or subsystems (by specific integration process).

4.1.1 Final user data entry

During the Set-Up phase, internal basic references and procedures can be selected or changed, importing external files (shp, GeoTIFF, etc.) or interacting directly with the database through dedicated tables and forms.

Typically, the introduction of a new green area requires the completion of several passages related to critical functional components, like the following:

- Green area characteristics (position, dimensions, structures, components, functions);
  - Garden list, tables, and tasks set;
    - Shape, dimension, and geographic features (PostGIS tables);
- Homogeneous areas (contours, plants, systems, criteria);
  - Association of models and analytical procedures to any homogeneous section;
    - Shape and table (PostGIS tables);
- Soils and substrate;
  - Identification and characterization (structure, field capacity, wilting point);
- Plants (type, species, number, position, dimension, exigences);
  - Identification of exigencies and detection of interrelationships (requirements, tolerance);
- Pests and diseases (species, name, common id, environmental thresholds, fight systems);
  - Guide parameters for plant enemies (insects, mites, and fungi);
- Indices and models (selection, parameterization, setting);
  - Association of system tools to areas/plants/works/functions/outputs.

4.1.2 External database and archives

The use of environmental data collected by public or private networks is recommended for the very first GeoDB population and preliminary environmental characterization of the areas, finalized at the determination of reference values and guide parameters for selected models and indices. Affecting many system functions, external data needs careful evaluation before its introduction and adoption into the GARANTES DB. Typical data quality control procedures include an accurate validity and reliability check, the analysis of the spatial and temporal representativeness, and a complete evaluation of the dataset consistency.

These operations are required to assure an adequate level of reliability of the basic information derived by external data sources, used by the system in several critical passages, such as the creation of the following basic information-layers:

- Digital Elevation Model (altitude, exposition, slope);
- Soil Map (texture, field capacity, wilting point);
- Land use Map (area classification: urban, green, forestry, agriculture, etc.);
- Technical Cartography (coordinates, contextualization, special themes);
- Orthophoto images by WMS service (10k and 2k spatial analysis)
- Environmental Dataset (Meteorological, agrometeorological and hydrological data - at least 10 years of daily/hourly temperature, humidity, rainfall, wind and solar radiation data, of representative stations);
- Technical Datasheets (regional environmental and green management regulations, integrated pest management plan; natural resource critical issues, local plant pests; etc.).

4.1.3 Local Monitoring Network (LMN)

One of the new paradigms of ICT is represented by the increasing autonomy of sensor-equipped devices, operating locally, and interconnected with several smart components (MEMS - *Micro Electro-Mechanical Systems*, IoT, IoE - *Internet of Everything*, M2M - *Machine to Machine*, etc.). In HQ-UGAM the potential of these tools is huge and ranges from simple monitoring functions to full control of some apparatus, with a similar expectation of the home automation sector. The adoption of electronic and structural components increases the number and effectiveness of green solutions, providing new opportunities for environmental analysis. At the same time, efficient control of their representativeness respect to interesting factors needs for professional application, to prevent inconsistency or misuse of collected data. For this reason, commercial and proprietary subsystems, or equipment were placed under the control of the GARANTES central server, where *ad hoc* solutions are implemented (Fig. 3).

The first version of the GARANTED LMN was realized using proprietary technologies and maintained a basic logic structure for the successive upgrades. During the years, the most interesting compatible solutions available on the market were tested and adapted to the specific exigencies of the support system.

In the last version, each component carries out specific tasks, associated with one or most green areas and involved in several dedicated functions, selected on the base of site characteristics, operational needs, and final user requirements.

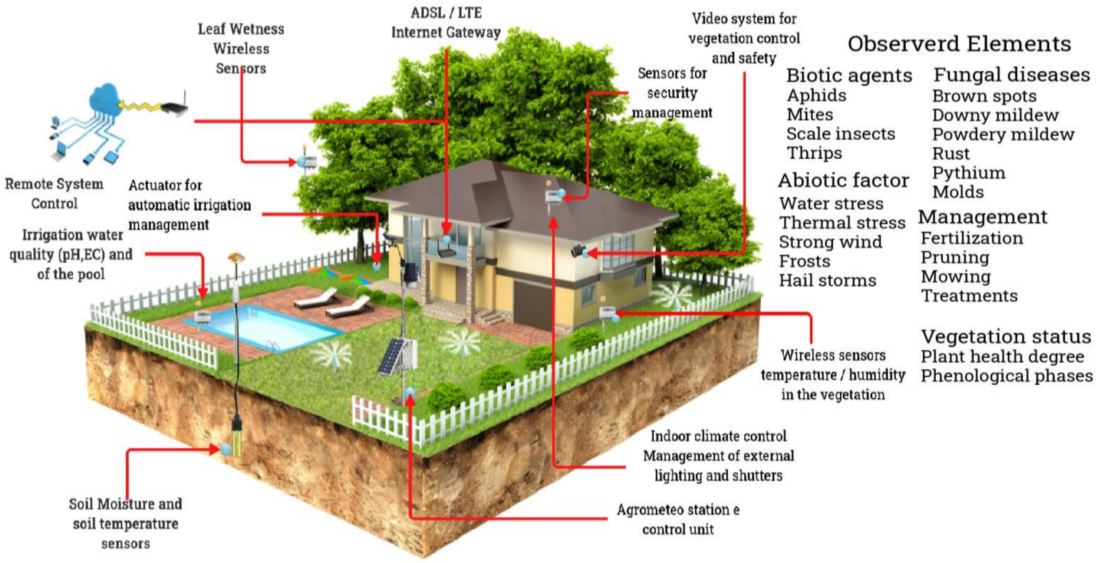

Fig 3: Local Monitoring network and related functional components of the GARANTES system, including biotic and abiotic elements kept under observation during the project's activity.

For a single GARANTES LMN, several services can be activated within a radius of about 2 km, depending on local factors, such as variability and landscape characteristics. In this way, also small size green areas can be supported without additional costs, exploiting the procedures implemented for spatial and temporal analysis. The use of "virtual sensors" (VS), for example, allows us the estimation of interesting physical greatness (e.g., temperature or humidity) or variables in different places, starting from predetermined algorithms or equations (Sánchez, Rodríguez, Guzmán, & Arahal, 2012).

In principle, for each element of interest, a series of functions and criteria can be utilized to improve the spatial and temporal analytical capability of the system.

4.2 Data analysis

To provide reliable spatial information, each dataset must be updated and integrated on a geographical basis, georeferencing any related component (by assigning UTM, Universal Transverse of Mercator, coordinates) and properly filling the prearranged "Field-features" tables. Starting from these datasets, the GARANTES inner procedures are used to create basic layers or complete the IT framework required by the specific analytical modules.

All valuable data and information obtained by the different procedures are stored into the GeoDB under the required formats, ready for their use and integration into other internal or external computational modules. Iterative processes are used to define operational scenarios and evaluate the impact of different management strategies, for an effective rationalization of practices and treatments. Default or updated references are used, based on settled criteria and timing, for preliminary comparisons of scenarios and/or the evaluation of optimal/suboptimal conditions. Since a value change affects simulation in different ways, procedural simplicity and step by step analysis are recommended to allow a full understanding of the analytical summaries produced by the system.

Statistic and logic analysis were used to improve the knowledge of the processes, orienting also parametrization and factors refining, for progressive enhancement of the procedures and improvement of their operational reliability. More complex automatic and semi-automatic procedures are applied to perform descriptive and inferential statistics, data mining, and analytics, on significant series of data, mainly for forecasting and scenario comparison, starting from available agrometeorological models.

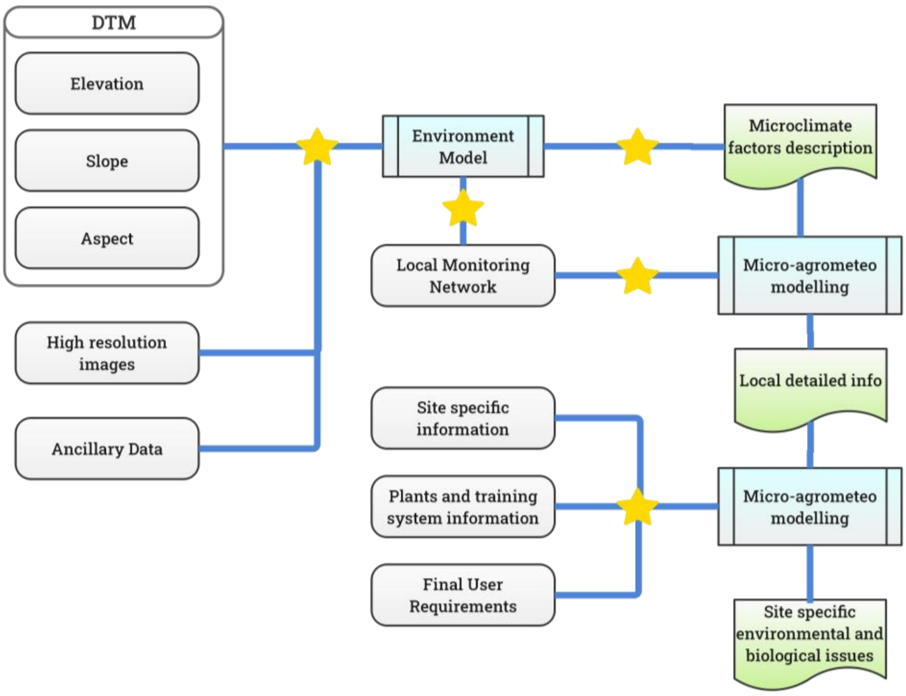

Fig. 4: Simplified GARANTES Modelling data flow, with an indication of basic input (blue boxes), I/O exchanging points to GeoDB (Stars), System processes (Light blue – with default processing) and Outputs (Green – Final documents).

Geo-statistical procedures are also adopted to create represent the spatial trend of significant greatness or parameters on the interesting areas, at different scales, using specific thematic maps.

4.3 Agrometeorological modeling

Several descriptive indices and more than 30 agrometeorological models were adapted and implemented into GARANTES, to support biotic and abiotic risk evaluation inside green areas. Implemented procedures represent a first step towards the construction of a complete set of near-real-time and forecasting information tools for HQ-UGAM, which final users have only partially operationally tested during the project. Routinely support procedures, such as irrigation, pest, and disease control, are subject to frequent checks for real field condition fitting, while model integration and implementation represent only occasional tasks.

In absence of commercial automatic irrigation control systems, GARANTES provided an integrated method (Bacci, Battista, & Rapi, 2008), implemented into a proprietary electronic control unit connected with the remote central server. This tool used soil moisture sensors and weather-based methods to evaluate plant water requirements and to determine irrigation volumes and related scheduling. Plant nutrient uptake could be estimated utilizing predetermined tables or, for some plants, as the percentage of biomass production, supporting fertilizing practices. These procedures were related to several management criteria, following site-specific nutritional programs, and needed adequate feedbacks from local experts (Bacci, Battista, Cardarelli, Carmassi, Rouphael, Incrocci, Malorgio, Pardossi, Rapi, & Colla, 2011).

The changes made on the model parameters or set during each session (Java API for RESTful Web Services) affect only a specific area of competence, determined based on logical, technical, and/or operational criteria. When the model runs, a cascade approach assures an effective interconnection among sections and modules of the system, providing very specific simulations for each homogenous area (Fig. 4)

On the base of system modeling data flow, several modules (exchanging points) are arranged to perform intermediate analysis, evaluating the validity and accuracy of the intermediate outputs. The main goal of the simulation was to provide advices on abiotic and biotic issues, but the improvement of knowledge on strengths and weaknesses points of the operating system to support field activities was also important.

4.4 Final User Interface

Open-source principles and technologies were adopted for the development of a dedicated WEB interface, from which assuring access to project documents, system forms and technical reports. From the "restricted area", authorized personnel could interact with system functions, by using dedicated applications, and sets parameters of interest and/or outputs (Fig. 5).

The System Manager provides a series of authorization to each level of the final user, determining the possibility to change criteria, frequency, and/or priorities of the analysis, based on preliminary agreements. The interface has been developed using J2EE technologies with Java Services Faces (JSF) framework and, to follow the SOA paradigm, all components can communicate through services implemented by JAX-RS.

Logging to the private web pages, final users access to three different sessions, which provide a complete picture of the field realities:

a) Setting – it contains the available and consolidated knowledge on green and environmental components of the interesting area and represents the base for any further speculation on future improvements;
b) Site Monitoring – provide an update visualization of actual field conditions, starting mainly with the data provided by LMNs operating in each site;
c) Report – represent an archive of advice, datasheets, and information, obtained from an integrated analysis of all available datasets.

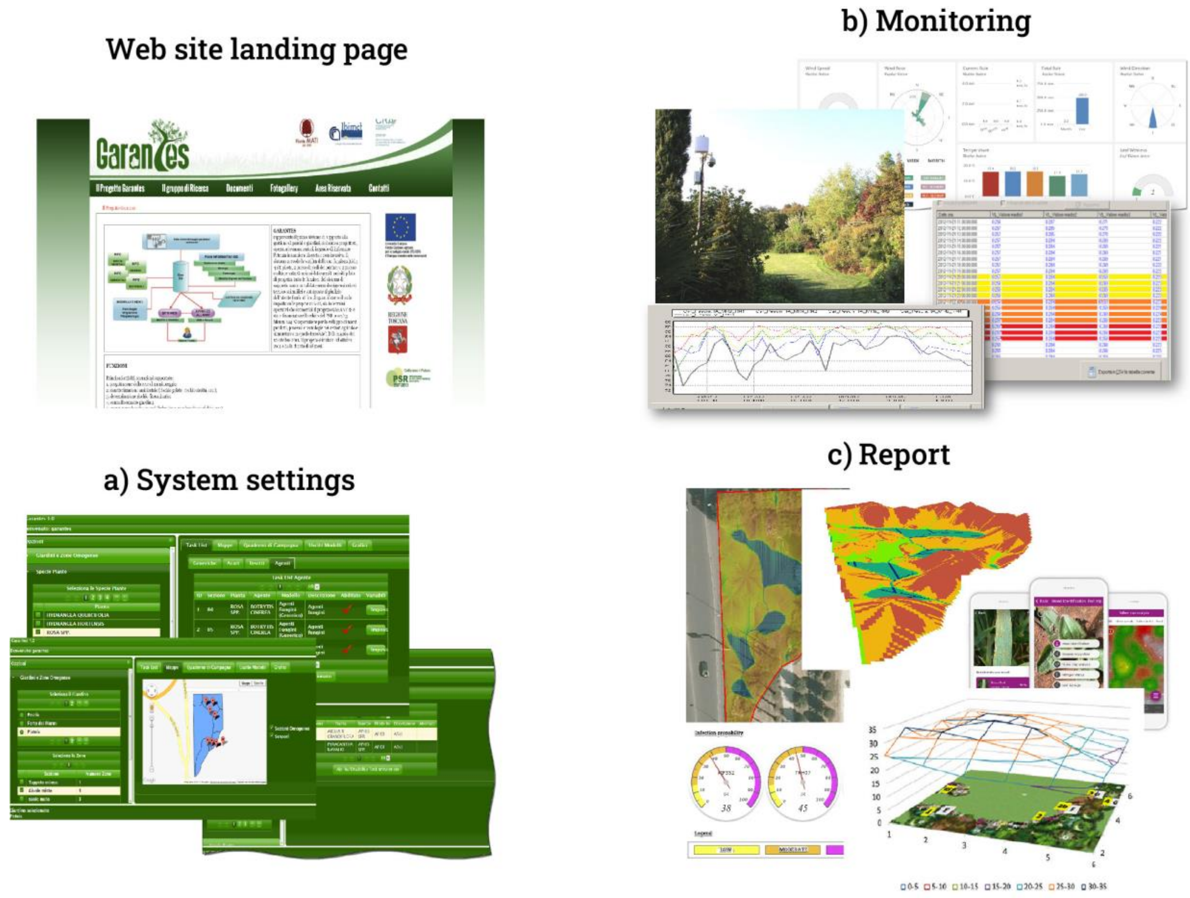

Fig. 5: Screenshots of GARANTES web interfaces and visual representations of some key components: Main page and general project information, system procedures and links; a) System Setting Form, for simulation and tools; b) Monitoring areas, images for visual check and near-real-time data trend representations; c) Report and graphical dataset analysis

4.4.1 System setting

From an informatics point of view, a high level of flexibility is required to the system, because the interest of a given element (plant, pathogen, or environment) changes during the year as a function of several factors, related to biological cycles, meteorological conditions, and technical choices (Fig. 5a). These factors also affect the frequency of system setting, which changes from once or twice a year to many times for a month.

The main forms available in this section are:

- Plant/Pest/Insect/model selection;
- Model adaptation or tuning;
- Task activation (Near Real-Time information, Forecasting, Advice, etc.);
- Criteria modification (thresholds, updating frequencies, etc.);
- Field Book – input of data on green area conditions, events, field works, intervention, and treatments.

During the five-year of the project, due to the importance of these operations for system functioning and reliability, setting parameters were controlled by local experts, supervising input/output representativeness and accuracy in different operational situations.

4.4.2 Site monitoring and field notes

After the completion of the previous tables, depending on available tools, GARANTES system functions are activated to control green areas in many ways and under different points of view, like:

- analyzing near-real-time data and collecting images (or frames) from on-site cameras;
- evaluating recent events and local trends (plant growth, water/nutrient uptake, pathogen, etc.);
- visualizing and updating field interventions (date, operator, kind, effect);
- verifying device functioning and sending alert messages.

This information is made available for a quick check and can be used to organize green care interventions based on real field conditions. From this section, final users can also evaluate the impact on plants of relevant events, simply observing the values or the trend of sensitive parameters (Fig. 5b). These functions are important for decision-makers, who can rely on the constant presence of an "impartial observer" in each green area, able to describe recent and actual environmental conditions and suggest maintenance needs.

4.4.3 Report

Based on the site-specific information-layers, reference values, and LAN data, *ad hoc* reports are created to show actual condition vs theoretical (optimal/suboptimal) ones. These procedures support the analysis of local trends and the assessment of the potential effects of some technical choices, during the time or under different scenarios. For example, spatial or temporal variability of given physical greatness (e.g. solar radiation, air temperature, etc.) can be evaluated on the base of local features (e.g. the presence of green infrastructures), to estimate the related effects on plant, pests, and diseases. After each run, the final user can get from the system the statistics and documents containing detailed information about the interesting variables. Graphical and textual outputs are saved as reports and made available for further analysis (Fig. 5c). These tools are also used for preliminary evaluation of strategic technical choices about local environmental issues or under future climate conditions, for example changing temperature, CO_2 concentration, or water availability.

5. Result and discussion

Some of the most representative results obtained during system testing are given in the following paragraphs, discussing the operational effectiveness of data and information made available to decision-makers. Collected data and operational evidence, testified the advantages resulting from the adoption of the proposed solutions.

5.1 Improvement of rationality and coherence of the Decision Making

The proper interpretation of near real-time meteorological and agrometeorological data can be decisive to make the right operational choices, programming field interventions form reliable objective elements. On-time information is better understood when correctly contextualized and placed in relationships to reference periods or conditions (e.g., optimal vs. suboptimal). In several cases, graphical representations of recent data sequences, correctly contextualized, can be sufficient to determine management exigencies or detect unusual conditions.

For each item, environmental parameter or spatial variations, decision-maker can arrange different strategies:

a) Air Temperature: frost/heat interventions (plastic films, nebulization, etc.);
b) Radiation regime: shading nets and plants location;
c) Soil Temperature: pathogen control and soil ecosystem evaluation;
d) Rainfall and Soil Moisture: field works and watering programming;
e) Air Relative Humidity: pruning or cutting needs;
f) Meteorological and climatic hazard: protection plan;
g) Spatial analysis: precision gardening.

Observing the situation of each site, HQ-UGAM experts can reprogram field visits, determining local exigencies and priorities. During the project, the use of this information leads to the discovery of plant sufferance reasons, explaining the shift in phenological timing or different level of phytosanitary hazard into apparently homogenous zones and despite the presumed similar growth conditions. In highly heterogeneous gardens, the integration of geospatial and remote sensing procedures (i.e – multispectral cameras, drones, satellites, etc.) can be required to describe existing variability, evidencing very local differences and to apply precision management principles.

The analysis based on near-real-time data provide information used mainly at a short temporal scale, leaving to the experts much of the interpretative work. Based on the information provided by the local devices, like the irrigation units, quantifying the differences among the zones or delivering specific advice, technicians and managers can program field works and set more precise interventions.

At the same time, more sophisticated geostatistical analysis can be performed at the server level, and reference maps can be produced for the most interesting factors.

As indicated by the Wetness Index, water, and nutrient distribution, for example, are affected by the micro-morphology of the terrain, resting mainly in the steady-state areas of the field. Moreover, the quantity and quality of water and residuals can be estimated only with the support of other specific models, considering together 3D water and nutrient displacement, irrigation, evapotranspiration, and plant uptake.

The impact of this information is highly variable, depending on awfully specific human and environmental factors, but several indicators are coherent with the operational advantage of the adoption of monitoring and support technologies for HQ-UGAM. For instance, taking into account the performance of the irrigation control systems implemented in GARANTES in the main green area settlements of the P1 pilot site (i.e., turfgrass, rose, hedge shrubs, bulbs and aromatics, trees and potted plants), irrigation efficiency was significantly improved in the experimental trials carried out during the project (Tab. 1).

For five years, the assistance on the irrigation practices allowed a water-saving in comparison to the areas managed by local experts, assuring the satisfaction of plant requirements and providing the right quantity of water at the right time. It is interesting to observe that the percentage of saved water was also related to the total rainfall of each year (R^2=0.865, considering the irrigation period). Expert evaluation, based on a priori ten years average water balance plus a certain amount of water for plant protection from stress, fails in non-standard situations, like that of a heavy rainy season.

5.2 Field activities planning

The use of specific indices allows the attribution of weights to characterize the main site features. From their values, several elements can be derived, evidencing interesting strengths and weak points related to a series of factors affecting plant growth and green area management. The average values of some of those, are given for the four pilot sites in Tab. 2, with a simple annotation of their primary use. Micro-meteorological average condition, corresponding to the specific situation of each homogeneous area in the garden, is closely related to the real local abiotic and biotic risks, with significant impacts on treatments and fieldworks.

Tab. 1: Elements of comparison between Timer (periodically settled) and GARANTES irrigation management controls systems, in term of quantity of water provided from the beginning to the end of the working season for the experimental garden of P1 (all sectors: Turfgrass, Hedges, Rose and Potted Plants).

Year	Irrigation season start	Irrigation season end	Number of days	GARANTES (m^3)	TIMER (m^3)	Saved water (%)	Rainfall (mm)
2014	20/05/14	11/11/14	175	60.9	89.2	31.7	416.6
2015	18/05/15	10/15/15	176	72.0	107.0	32.7	313.4
2016	25/05/16	03/11/16	162	77.5	101.4	23.6	265.0
2017	10/05/17	06/10/17	149	74.6	87.5	14.7	146.0
2018	04/07/18	15/11/18	134	59.1	69.2	14.6	162,0

Tab. 2: Representative values of the main agrometeorological indices used for the characterization of the four pilot sites from climatic, environmental, vegetational, and pests and phytopathological point of view.

Index	P1	P2	P3	P4	Primary Use
Meteo-climatic					
Tmin (°C) Absolute	-7.3	-7.7	-2.6	-5.3	Plant tolerance
Tmax – (°C) Absolute	38.5	41.5	35.1	38.8	Plant tolerance
Frost – n. days (Max)	7	10.0	1	8	Protection plan
Chilling Hours (<7 °C)	1380	1368	862	1537	Plant needs
Gams Continentality Index	6.6	2.4	0.3	13.7	Green design
Average annual rainfall (mm)	870	1195	919	691	Water availability
Rainfall days	63.5	83.1	88	87.3	Water distribution
Environmental					
Windy Day (> 3 m h^{-1})	112.76	72.3	344	135.1	Plant protection
YT (DayAvaSum; T>7°C)	154	168	339	152	Phenology
ETo (Cumulative)	684.1	756	523	811	Plant water needs
SWC (Day at F.C.)	175.7	228.2	254.3	130.8	Edaphic regime
Drought index	0.3	0.4	0.2	0.7	Climatic regime
Plant growth					
Season Start (DOY)	108	112	102	115	Work scheduling
Season End (DOY)	301	300	315	290	Work scheduling
Winter T<5 °C (hours)	819	877	489	652	Vernalization
Active T>7 °C; T<35 °C (hours)	3694	4023	3916	3652	Growth potential
Potential Yearly Growth	0.48	0.46	0.53	0.46	Biomass product.
Climatic Water Balance (mm)	+186	+436	-87.2	-152	Grass Water needs
Pests and Pathogens					
Insect (n. days Alert)	13.2	23.5	6.4	3.9	Insect risk
Moulds/Rot fungi (hours)	4.0	4.3	92.1	37	Moulds risk
Fungi (hours)	60.9	52	301	162	Fungi risk

A direct comparison carried out at different spatial and temporal scales, allows a preliminary evaluation of the site's management requirements, supporting also strategic choices, like garden design and plant species adoption.

Each index, in fact, is an expression of the area potentialities or risks, with respect to a given factor, and provides an objective indication of the commitment required to keep them under control. The results of a similar analysis, unfortunately, is not a simple addition of the considered factors.

Even if P1 (Pescia) and P2 (Pistoia) are recognized suited areas for valuable plant nurseries and gardening, with higher water availability and low moulds and fungi risks, other critical aspects emerge, such that of frost or insects. According to climate change evidence, some consideration can be made also on the relative economic sustainability of the same landscape assets based on environmental trends (Sarkar, Butcher, Johnson, & Clark, 2018).

Green areas maintenance program includes several operations, ranging from soil tillage to plants hedging and pruning, from pest and disease control to fertilization scheduling and weed contrast. For each element, the decision-maker needs a complete picture of the current situation and reliable forecasting of the next operational requirements (at 7 and 15 days) to organize field activities, not always available. The solution adopted by GARANTES consists in the provision of information both relative and absolute terms, leaving to the decision-maker the choice of which to use.

After any significant event affecting the green area, the evaluation of the field condition needs adequate feedback by the experts to re-align the system model at the field reality, according to the classical adaptative process. Aiming to provide the elements for the interpretation of the existing dynamics and a more aware evaluation of the field-work requirements, an adequate period of co-working and experience exchanges is required.

This approach allows an evaluation of GARANTES efficiency by applying specific indicators, and a preliminary detection of some management anomalies, leading to more effective interventions and resource-saving.

The results obtained during the experimental period appear encouraging, confirming significant improvements in comparison to traditional practices:

- Water Use Efficiency was increased from 15 to 35 %;
- Fieldwork Efficiency (hour m^{-2}) was boosted, saving from 5 to 30 % of the time;
- Chemical treatments were reduced in the complex by 10 to 50 %.

About intervention scheduling, for example, considering turfgrass cutting, an adapted version of the Gelernter & Stowell model (2005) was used to estimate grass growth according to the hourly air temperature, applying the following equation:

$$CO = \frac{1}{e^{\left(0.5\left(\frac{(T-Topt)}{C}\right)^2\right)}}$$

Where:

CO = Growth potential (range 0 ÷ 1)
T = Air temperature (°C)
Topt = Growth optimal temperature (20°C for microthermal species)
C = Growth coefficient

The value obtained was transformed into grass height by multiplying the CO parameter for the hourly growth rate (cm), empirically derived. Cutting interventions were planned based on recorded temperatures, setting two thresholds of minimum and maximum height, and assuming no water stress or nutritional limitations.

The model was tested, calibrated, and validated during the GARANTES project in the experimental pilot site P1 (Pescia), to study irrigation strategies and scheduling field interventions (Fig. 6). The number of cutting passages was reduced up to 20 % with respect to traditional practices, just considering seasonal behavior and managing the lawn in convenient ways.

Camera or satellite visual check, when available, can be used to complete turfgrass information at the spatial level, evidencing the general condition of the grass and the presence of worrying spots. During the years, in case of a significant discrepancy between estimated and observed plant growth or lawn condition, some field checks were made for plant care or model parameters resetting

5.3 Further development

Several models and procedures are under evaluation for the straightening of Garantes support functions. Interest was shown by HQ-UGAM experts in the introduction of tools base on Integrated Pest Management principles (Strand, 2000; Peshin, Bandral, Zhang, Wilson, & Dhawan, 2009).

Advanced technologies (ICT, IoT, AI, Big Data, etc.) offer extraordinary opportunities to achieve real sustainability in green-area and resource management in face of Climate Change challenges. Direct observation of plant health is often expensive and time-consuming, but most of all it is not effective in the rationalization of field interventions. Monitoring and modeling can avoid unnecessary or late treatments, increasing environmental and human health (Strand, 2000).

This is particularly the case of new plant pests and pathogens, still little known, but extremely dangerous for the most valuable plants. Cydalima perspectalis (Walker, 1859), for example, is a Lepidopter damaging Boxwood (Buxus spp.), one of the most precious slow-growing plants used in formal Italian gardens for hedges and topiary art.

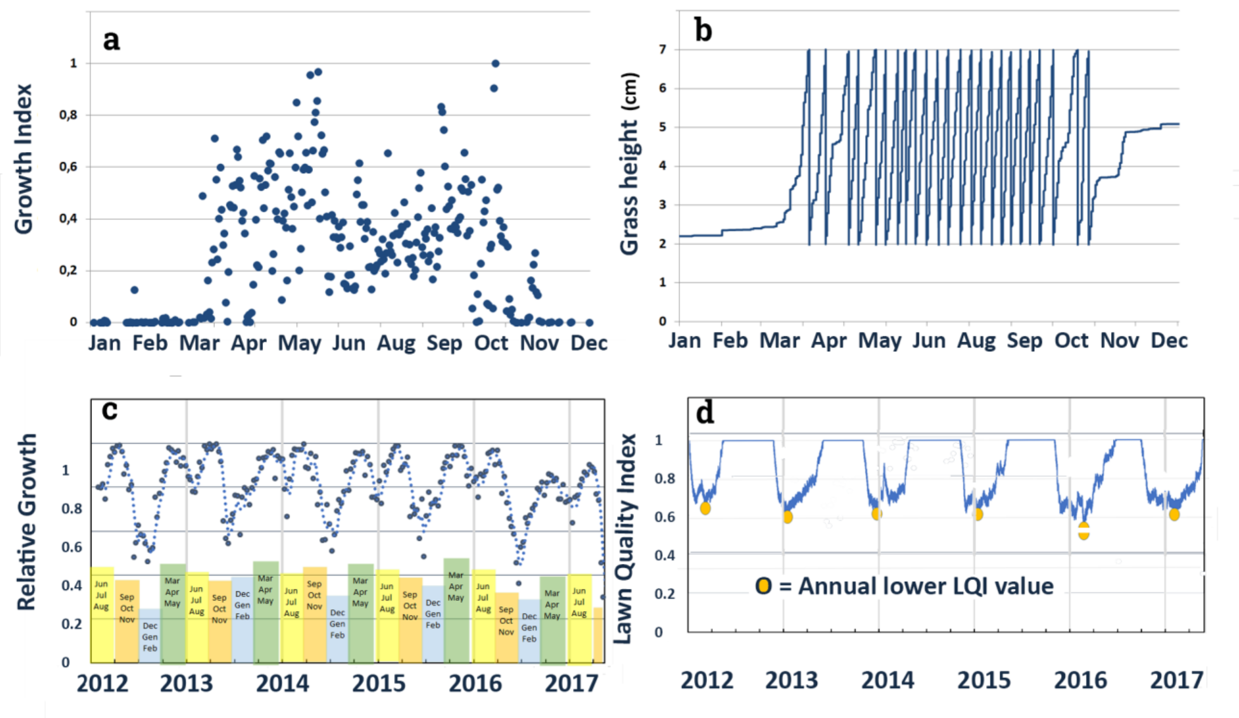

Fig. 6: Example of turfgrass model output for site P1 (Pescia): a) grass daily growth index in function of temperature for 2016; b) simulated cutting interventions for 2016 (growth range from 2 to 7 cm); c) trend of grass daily growth index during the years of the trial (2012-2017), with direct comparison of the seasonal average growth (bars); d) Turfgrass Quality Index during the period 2012-2017.

The phytophagous arrived in Europe in 2007 from Asia, is well acclimated in Mediterranean regions, where attain until three cycles per year (Nacambo, Leuthardt, Wan, Li, Haye, Baur, Weiss, & Kenis, 2014).

Some preliminary simulations, performed using a single sine degree day model sensitive to the radiative regime, suggest that insect development could be affected by very local micrometeorological conditions.

Detailed studies are however required to confirm this and other indications, increasing the number of test sites and improving model sensitivity.

An adequate spatial and temporal resolutions in detecting urban environment and elements could be provided by diffuse IoT networks, making it possible to follow any element of interest, adequately supported by dedicate virtual-sensor and analytical tools.

For this reason, GARANTES is a candidate to become a fully operational framework, based on an advanced digital platform, able to acquire and manage collected data from several different platforms, bringing gardens and urban green areas into a new technological dimension.

6. *Conclusion*

The adoption of decision support system procedures into the emerging field of HQ-UGAM introduces elements of rationality and coherence in the decision-making process, bringing significant advantages in terms of efficiency of several practices, reducing resource wasting and chemical treatments, with consequent economic and environmental benefits.

Water consumption and plant nutrition can be generally optimized by adopting integrated systems (sensors and models), assuring better plant growth and health, in comparison with traditional management procedures or criteria, such as in our experimental trials.

Professionals and decision-makers can take direct benefits from the availability of updated and representative data on the target areas and/or on biotic and abiotic related elements, adapting or improving their management strategies based on reliable and verifiable data.

After 5-year of experimental evidence, many of the proposed tools and procedures can be considered sufficiently robust to be used at the operational level, at least after a period of calibration and tuning of models and practices on each new site. In some cases, during the characterization phase of the green area, preliminary studies should include the installation of additional sensors, working alongside those of the operational local monitoring network, just for the time required to characterize the areas and determine local relationships for virtual sensing completing the dataset in the function of the local variability of the interesting factors.

At this level of development, the adoption of similar DSS by green professionals requires the involvement of outsourcing services, assuring a constant control of the system and device functioning. In the next future, the creation of a Service Center, able to collect and integrate information from different sources, could ensure a significant improvement of system output reliability and a greater impact on their capacity to provide positive answers to economic and environmental issues.

Finally, the availability of reliable agrometeorological monitoring networks and tools (models, indices, and others), creates the condition for the extension of support services over large urban areas, giving an increasing contribution to smart city evolutions.

These considerations are in-line with the provisions of many initiatives carried out in different countries and by the European Commission, already requiring the adoption of DSS for the sustainable management of urban green areas and the increase of final user's awareness, both essential to face the next critical challenges of this composite multifunctional sector.

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