PhD THESIS

Development of a Planning Methodology for Sustainable Irrigation of Green Spaces

(SUMMARY OF THE DOCTORAL THESES)

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Introduction

The Florence Charter (ICOMOS/IFLA 1981) defines a historic garden as a landscaped green space with architectural composition whose components are primarily vegetal. Naturally, in such green spaces, any modification of the physical environment that endangers the ecological balance is prohibited. Thus, the research project that is the basis of this doctoral thesis proposes a methodology for planning irrigation systems in various existing green spaces by applying the following steps:

(a) Inventorying the vegetation,

(b) Estimating the water needs of plants in correlation with

(c) Climatic data, soil characteristics, and land topography,

(d) Providing a set of norms regarding *when, where, and how* irrigation should be carried out in accordance with international guidelines for the conservation of green spaces.

In the context of climate change and urbanization, water deficit, soil drought, and extreme weather events are increasingly frequent and widespread globally. In this context, the European Union (EU) has developed a series of policies, programs, and strategies for sustainable development. To enhance the sustainability of EU cities, among other, the implementation of sustainable urban planning policies and the conservation of urban biodiversity is envisaged.

To determine whether and when irrigation is necessary in historic gardens and existing green spaces, we proposed, as a first step, conducting a detailed study of the vegetation composition. For this purpose, four sites located in different climatic zones (Cluj County, Mureș County, Bucharest) were studied. Of the four sites chosen for this research, three are urban public green spaces (Simion Bărnuțiu Central Park in Cluj-Napoca, Cișmigiu Garden and Grozăvești Park in Bucharest), and one is a private green space (Teleki Castle Garden in Gornești, Mureș County).

Structure of the Doctoral Thesis

The doctoral thesis entitled "Development of a Planning Methodology for Sustainable Irrigation of Green Spaces" was prepared in accordance with the drafting and writing norms in force at the Doctoral School. The thesis is structured into two parts, consisting of 10 chapters, and contains 41 tables, 31 figures and graphs, as well as 108 bibliographic references.

Part I - CURRENT STATE OF KNOWLEDGE

Chapter 1. General characterization regarding water management in green spaces and urban vegetation inventory

This chapter lays the foundation for the necessity of a methodology for sustainable irrigation planning in green spaces. Internationally, water management is important due to climate change and population growth, affecting urban landscapes and community needs. In Europe, challenges related to water deficit and drought have led to strategies for the sustainable use of water resources, green infrastructure, and the reuse of treated water. In Romania, national legislation and sustainable development

strategy emphasize the importance of managing green spaces and water resources, although there are difficulties in implementing green registers and other tools. Sustainable water management in the urban environment requires clear policies for efficient irrigation, ecosystem protection, and maintaining quality of life.

Chapter 2. Benefits and classification of woody vegetation

This chapter classifies the vegetation used in green spaces. Urban vegetation is essential for creating a suitable living environment, influencing temperatures, air quality, and noise levels. In the urban environment, vegetation must withstand difficult conditions such as degraded soil, lack of nutrients, water, light, and necessary space, soil impermeability, and pollution**.**

Chapter 3. Sustainable and efficient use of water in green areas

In the planning, design, and maintenance of green spaces, it is important to adopt sustainable practices for efficient water management. Choosing plants adapted to the local climate and drought-resistant, improving the soil, and implementing efficient irrigation systems are essential strategies. Rainwater harvesting and the reuse of wastewater for irrigation complement these efforts, reducing dependence on drinking water.

Chapter 4. Water management in green spaces

This chapter studied water management starting from the water management plan, environmental risks, and technical risks regarding irrigation systems to managing the irrigated space in the future. In the context of climate change and the need to conserve resources, adopting innovative technologies and water management strategies is essential for ensuring sustainable and resilient green spaces.

Part II - PERSONAL CONTRIBUTION

Chapter 5. Objectives details the main objectives proposed in the doctoral thesis.

Chapter 6. Characterization of the natural environment details the three areas (Cluj, Mureș, Bucharest) from which the four studied green spaces (Central Park in Cluj-Napoca, Teleki Castle Garden in Gornești, Cișmigiu Garden and Grozăvești Park in Bucharest) are part.

Chapter 7. Materials and method presents for each site the data collection and processing methodology. This chapter also presents innovative technologies such as TreePlotter software, Lidar, AutoCAD, Revit, and Lumion used in data processing, analysis, and presentation of results.

Chapter 8. Results and discussions presents the inventories of woody plants carried out in the four studied green spaces: Central Park in Cluj-Napoca, Teleki Castle Garden in Gornești, Cișmigiu Garden, and Grozăvești Park in Bucharest. It also presents the analysis of existing vegetation in the four sites based on water requirements in the soil and drought resistance, determination of water consumption for existing vegetation in the studied green spaces, and the proposal for revitalization for Grozăvești Park using strategies for sustainable irrigation.

Chapter 9. Conclusions and recommendations presents the conclusions and recommendations made following the research for the doctoral thesis.

Chapter 10. Originality and innovative contributions of the thesis details the importance and novelty brought to the field by the present doctoral thesis.

Objectives

This research aims to establish and implement sustainable approaches to planning and managing the irrigation of green spaces:

Inventorying woody vegetation in four sites in Romania using modern green space inventory and management technologies.

- Inventorying trees in Central Park in Cluj-Napoca, Teleki Castle Garden in Gornești, Cișmigiu Garden, and Grozăvești Park in Bucharest.
- Using modern technologies in mapping, inventory, and management of green spaces such as TreePlotter software and Lidar scans.

Creating databases according to tree water requirements, resulting in different categories of vegetation used in Romanian green spaces.

- Analyzing and classifying existing species in the four sites based on soil water requirements and drought resistance to establish irrigation priorities.

Developing the proposal for the rehabilitation of green spaces based on the different categories of vegetation resulting from the green space analysis and identifying sustainable irrigation methods for Grozăvești Park (Bucharest, Romania).

- Using software for 2D design in AutoCAD, 3D in Revit, and renderings in Lumion for graphical representation of the proposal.

Materials and Method

Inventory of the existing vegetation in the four locations

Data collection from the field

Central Park in Cluj-Napoca

Field data were collected for the creation of the green register. The data were provided for research purposes by the Green Spaces Service - Urban Ecology and Green Spaces Department of the Cluj-Napoca City Hall.

Teleki Castle Garden in Gornești

Field data were collected in the summer of 2019 over approximately three working days by a team of seven professionals and students from domains such as landscape architecture, arboriculture, architecture, and history.

Cișmigiu Garden in Bucharest

Field data were collected in August and September 2019 by a team of about 60 volunteers led by five professionals in landscape architecture.

Grozăvești Park in Bucharest

The study was conducted by three landscape architects with the help of five urban planning and landscape students for a total of four field study days. Tree data were collected from the field in two periods: February 2024 (identification of tree genera) and April 2024 (inventory of tree species and other characteristics). In February, due to winter conditions, some species could not be determined, so a new verification inventory was conducted in April. Data collected for the tree inventory: species, DBH at 1.3 meters, and viability. A general visual and aesthetic analysis was also conducted in October 2023.

Fig. 7.5. Site location of trees, zoning and data collection (original)

Fig. 7.6. Field workflow (original)

Field data analysis and processing performed with TreePlotter software. To create the inventory of the existing vegetation, field data were processed and analyzed using TreePlotter software. Each tree was analyzed, and the information entered into TreePlotter included: location, species, tree characteristics, trunk diameter at 1 meter height according to nursery standards (DBH) because ornamental trees are analyzed, not forest trees.

TreePlotter is a tree inventory software that fully functions for mapping and managing urban forests (new and established trees) and the maintenance work history on public and private property, built by certified arborists and foresters (HANOU 2014; TreePlotter 2019).

Field data analysis and processing. All field data were then exported to Microsoft Excel spreadsheets for data file construction and analysis.

Analysis of vegetation according to soil water requirements. The existing species in the four sites were classified based on soil water requirements according to data found in several sources (BRUNS 2023; ZAHARIA *et al.* 2008; STĂNESCU 1979): dry soil species, moist soil species, wet soil species, and species with ecological amplitude regarding moisture.

Analysis of vegetation according to drought resistance. The species present in the four sites were classified according to drought resistance based on data from several sources (BRUNS 2023; ZAHARIA *et al.*, 2008; DUMITRAȘ *et al.*, 2008; STĂNESCU, 1979) as follows: drought resistant species, temporarily drought resistant species, and drought sensitive species.

Technologies Used for Design. The proposal for the landscaping concept of Grozăvești Park was based on the CAD file resulting from the topographic study and vegetation study. The 2D plan was created, after which it was modeled in 3D using Revit, and presentation renderings were made in Lumion.

Results and Discussions

The study was conducted in four locations: Central Park in Cluj-Napoca, the Teleki Castle Garden in Gorneşti, Cişmigiu Garden in Bucharest, and Grozăveşti Park in Bucharest. For each site, existing vegetation was inventoried, water requirements were analyzed, and drought resistance was assessed.

Inventory of the existing vegetation in the four locations

The 7,717 specimens of woody plants inventoried across the four studied sites (Fig. 8.1., Fig. 8.3., Fig. 8.5., Fig. 8.8.) represent 168 plant species and 79 genera (Table 8.9).

Tabel / Table 8.9.

Synthesis of vegetation inventories in the 4 locations (original)

Site	Area (ha)	Total Inventoried Specimens (nr.)	Species	Genera
Central Park, Cluj-Napoca	13	2,914	97	57
Teleki Castle Garden, Gorneşti	3	582	42	28
Cişmigiu Garden, Bucharest	16	3,742	119	62
Grozăveşti Park, Bucharest	3	479	31	24

Based on the summary of data obtained from the four studied sites, the following observations can be made:

- 13 genera (*Acer, Fraxinus, Tilia, Aesculus, Thuja, Prunus, Buxus, Celtis, Taxus, Pinus, Populus, Robinia, Ulmus*) out of the 79 identified represent 70% of the total inventoried vegetation.
- 13 species (*Fraxinus excelsior, Aesculus hippocastanum, Acer platanoides, Thuja orientalis, Buxus sempervirens, Tilia cordata, Tilia tomentosa, Tilia platyphyllos, Taxus baccata, Celtis australis, Acer pseudoplatanus, Robinia pseudacacia, Gleditsia triacanthos*) out of the 168 identified represent 51% of the total inventoried vegetation.

Synthesis of data on soil water requirements of plants in the studied sites

In the four studied sites, a total of 7,717 specimens were inventoried. Based on their soil water requirements, the summary of the inventoried vegetation is as follows (Table 8.16):

- 2,630 specimens from 51 species (34.08%) are dry soil species.
- 1,982 specimens from 67 species (25.68%) are moist soil species.
- 2,481 specimens from 33 species (32.15%) are wet to moist soil species.
- 624 specimens from 17 species (8.09%) are species with ecological amplitude regarding moisture.

Vegetation analysis according to plant resistance to drought in the fours studied sites

Regarding the grouping of inventoried vegetation in all four analyzed sites (a total of 7,717 specimens), the summarized results based on plant drought resistance are as follows (Table 8.21):

- 113 drought-resistant species (6,016 specimens - 77.96%)
- 17 temporarily drought-resistant species (598 specimens - 7.75%)
- 38 drought-sensitive species (1,103 specimens - 14.29%)

From the data presented above, it can be observed that, in terms of drought resistance, the predominant species in all four analyzed sites are drought-resistant.

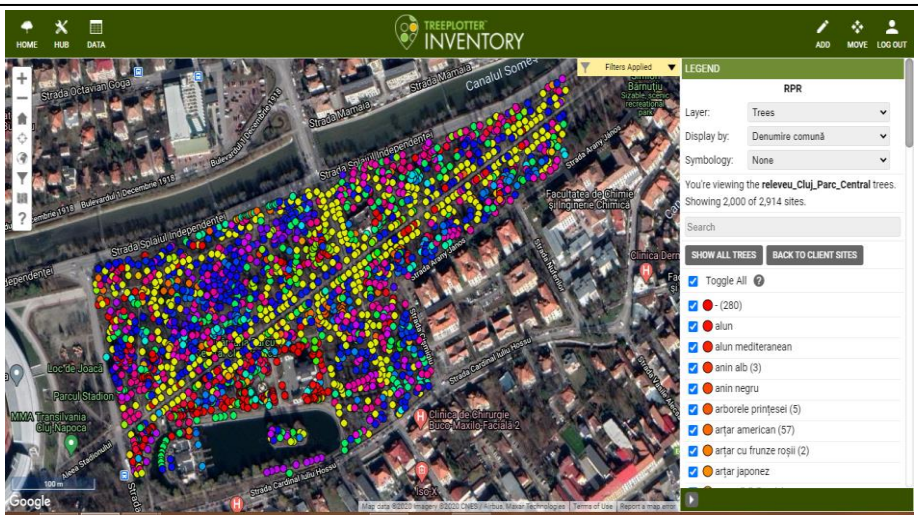

Fig. 8.1. Digital inventory of woody plants in Cluj-Napoca Central Park (original)

Fig. 8.3. Digital inventory of woody plants in Teleki Castle Garden in Gornești (original)

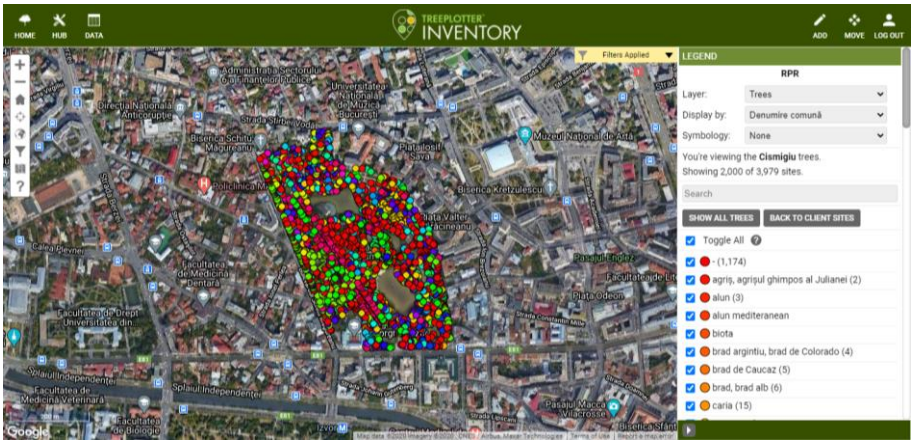

Fig. 8.5. Digital inventory of woody plants in Cișmigiu Garden in Bucharest (original)

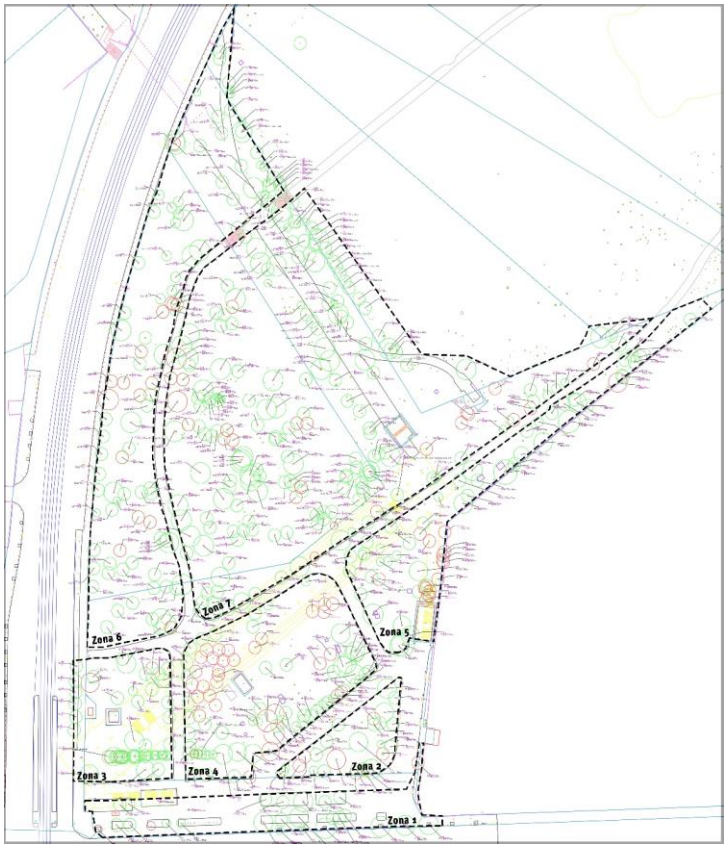

Fig. 8.8. Inventory map in CAD by zone in Grozăvesti Park in Bucharest (original)

Tabel / Table 8.16.

Synthesis of data on soil water requirements of plants in the 4 studied sites (original)

Analyzed Site	No. of Inventoried Specimens	Species			
		Dry Soil	Moist Soil	Wet to Moist Soil	Ecological Amplitude for Moisture
Central Park, Cluj-Napoca	2,914	894	580	1,332	108
Teleki Castle Garden, Gornești	582	176	44	313	49
Cișmigiu Garden, Bucharest	3,742	1,343	1,274	781	344
Grozăvești Park, Bucharest	479	217	84	55	123
TOTAL	**7,717**	**2,630**	**1,982**	**2,481**	**624**

Tabel / Table 8.21.

Synthesis of data on plant resistance to drought in the 4 studied sites (original)

Analyzed Site	No. of Inventoried Specimens	Species		
		Drought Resistant	Temporarily Drought Resistant	Drought Sensitive
Central Park, Cluj-Napoca	2,914	2,211	219	484
Teleki Castle Garden, Gornești	582	426	89	67
Cișmigiu Garden, Bucharest	3,742	2,934	277	531
Grozăvești Park, Bucharest	479	445	13	21
TOTAL	**7,717**	**6,016**	**598**	**1.103**

Proposal for Revitalizing Grozăveşti Park Using Sustainable Irrigation Strategies. The landscaping proposal took into account the specific characteristics of the site, including the metro system with water usage restrictions and the hydrozones resulting from the analysis of existing woody plant species (Figure 8.14).

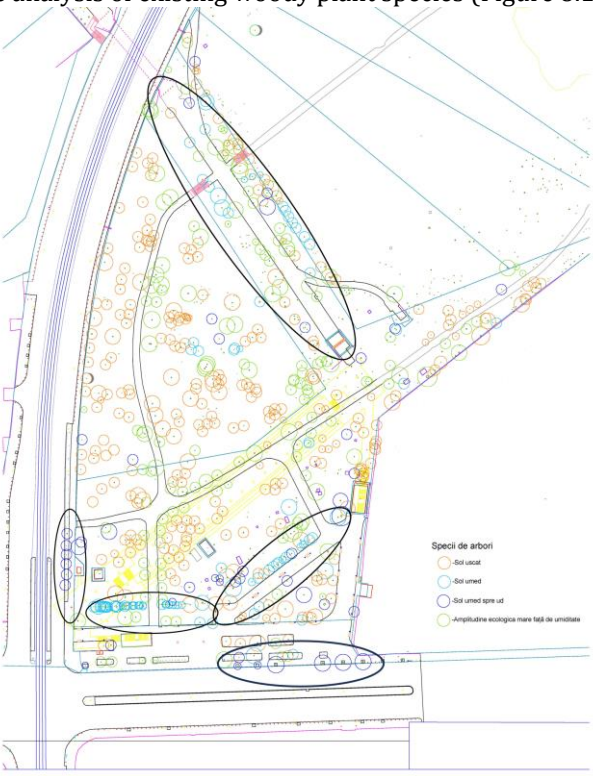

Fig. 8.14. Existing hydrozones in Grozăveşti Park (original)

Given that the majority of species on the site are either dry soil species or species with ecological amplitude for moisture, and most are drought-resistant, a drought-resistant approach has been chosen. This approach uses irrigation systems only where necessary, and hydrants for tanks/hoses must be provided during critical times. The irrigation system will be implemented as follows:

- New areas with perennials, ornamental grasses, shrubs, and trees will benefit from drip irrigation.
- Sprinklers will be used only in parts of the park that are not above the metro, specifically in some lawn areas near children's playgrounds.
- Other areas of the park, which mainly feature mature drought-resistant trees, will only be irrigated as needed and according to a park management plan developed from the implemented project. These areas will be landscaped with flowering meadows, avoiding disturbance to the trees' root systems.
- In areas with trees that require wet/ wet to moist soil, such as alignments, localized drip irrigation or water bags with controlled release are recommended.
- Implementation of drains where necessary.

Installation of rain sensors, soil moisture sensors, etc. (Figure 8.15).

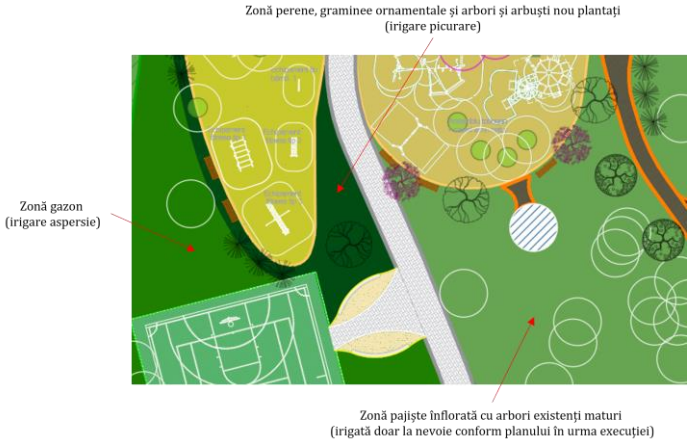

Fig. 8.15. Detail of proposed irrigation (original)

The new park will integrate the existing green area and mature trees, creating a harmonious, secure space with an attractive overall appearance. The tree species and plants used will mainly consist of local or naturalized species adapted to the climate of the area, requiring minimal maintenance, including both deciduous and coniferous trees. Additionally, the proposed shrub species, mostly indigenous, will be suited to the urban environment and the dry soil conditions, besides their ornamental value. For color, dynamism, and diversity, areas with perennials and ornamental grasses will also be arranged. Only a few areas with lawn will be created near the playgrounds, while the rest of the lawns will feature flowering meadows. All chosen plant species will ensure decor throughout all seasons.

Proposed tree species: *Abies concolor*, *Acer campestre*, *Acer platanoides*, *Prunus cerasifera* 'Pissardii', *Prunus serrulata* 'Kanzan', *Picea pungens*, *Robinia pseudoacacia* 'Casque Rouge', *Quercus robur*, *Sorbus aucuparia*, *Tilia tomentosa*, *Ulmus minor*, etc.

Proposed shrub species: *Cornus mas*, *Cornus sanguinea*, *Crataegus monogyna*, *Juniperus horizontalis*, *Philadelphus coronarius*, *Syringa* sp., *Tamarix* sp., *Viburnum lantana*, etc.

Proposed perennial plants and ornamental grasses: *Achillea millefolium*, *Festuca ovina*, *Festuca valesiaca*, *Salvia nemorosa*, *Stipa calamagrostis*, *Stipa pennata*, *Thymus vulgaris*, *Thymus praecox*, etc. (Fig. 8.16.).

Fig. 8.16. Grozăvești Park proposal - perennial landscaping and local ornamental grasses (original, colab. Proiectare 6)

Conclusions

In the four sites, the ten most common tree and shrub species account for 50% of the total inventoried vegetation (Central Park 50%, Teleki Castle Garden 90%, Cişmigiu Garden 50%, and Grozăveşti Park 80%).

In these four sites, most species are drought-resistant (Central Park 75.88%, Teleki Castle Garden 73.2%, Cişmigiu Garden 78.41%, and Grozăveşti Park 92.9%), so irrigation is only necessary under extreme conditions, at certain times, or for new plantings until they become established.

For the proposed rehabilitation of Grozăveşti Park, the studies conducted—including vegetation and water requirements for the existing vegetation—formed the basis for the rehabilitation proposal, facilitating the creation of hydrozones, irrigation priorities, and the zoning of a sustainable irrigation system.

Planning methodology for sustainable irrigation of green spaces

1. Conduct site studies: perform topographic, geological, vegetation, soil, and climatic studies.
2. Determine optimal vegetation composition: identify the most beneficial plant composition for the studied site.
3. Develop a vegetation zoning plan: create a plan for zoning the proposed vegetation based on water requirements (hydrozones).
4. Design the irrigation system: develop a plan for the irrigation system, including proper irrigation methods for the selected vegetation (drainage, drip irrigation, sprinklers, sensors, hydrants, evaluation of alternative water sources, etc.).
5. Create quantity lists and cost estimates: prepare lists and estimates that show water usage efficiency (reducing lawn areas, percentage of zones, etc.).
6. Develop an implementation plan for irrigation systems: ensure that the installation of irrigation systems protects existing mature vegetation by avoiding cutting roots closer than the canopy projection on the ground.
7. Establish a watering schedule: create a watering plan based on vegetation type, season, and time of day.
8. Create an irrigation system management plan:
    a. adjust irrigation systems according to plants and season.
    b. inspect the systems at least twice a year, ideally once a month.
9. Develop a vegetation management plan: manage vegetation based on season and species (pruning, watering, fertilizing, pest control, etc.).
10. Create a plan for maintaining healthy soil: ensure soil is healthy, un-compacted, and retains necessary moisture (aeration, mulching, root protection, etc.).
11. Use innovative management technologies: implement advanced technologies in management, such as GIS (Geographic Information Systems).

Originality and innovative contributions of the thesis

Study of four existing green spaces: the research focuses on four green spaces, including three historic ones and one from the 1980s, located in different regions of Romania. The goal is to define sustainable irrigation solutions. This approach is novel due to the development in the field of landscaping and the pressures of recent climate changes.

Study of four existing green spaces, three historical and one from 1980, in different regions of Romania with the aim of defining sustainable irrigation solutions. A novel approach resulting from advances in the field of landscaping and the pressures of recent climate change.

The use of advanced technologies (TreePlotter software, LiDAR, AutoCAD, Revit, and Lumion) which significantly enhance the ability to manage and study green spaces. The advantages of modern technologies include precision, efficiency, and decision support.

Detailed analysis and creation of a database with representative woody plant species in Romania.

Inventorying vegetation and mapping for use in the Green Registry.

Detailed study of green space irrigation issues and provision of sustainable solutions.

Utilization of native plants and plant associations for ornamental and sustainable purposes. Zoning based on the water requirements of plants (Hydrozones).

Irrigation studied in plant compositions, as recommended for green spaces.

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