Prospects for the use of digital technologies for monitoring green spaces in Saint-Petersburg

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Abstract. The article analyzes the composition of Saint-Petersburg green spaces, the availability of green spaces for residents, the assortment of tree and shrub plants and their resistance to anthropogenic impact. We propose a solution to the problem of obtaining scientifically based information about the state of urban and suburban plantations based on modern digital technologies - Tree Talker monitoring. The organization of a monitoring system using modern methods in combination with traditional methods allows you to get reasonable and timely recommendations for the protection of plantings.

1. Introduction

Digitalization covers various areas of human activity, primarily in cities. One of the criteria determining the quality of life in a modern city is the condition of green spaces. In St. Petersburg with a population of more than 5 million and a total green area of 35.4 thousand hectares (24.6% of the city’s area) [1], innovative environmental monitoring technologies and services for processing and interpreting environmental information are necessary.

The green infrastructure of the city is the most important environment-forming factor, providing to a large extent the formation of the ecological and social situation in the city. The role of green spaces in reducing the negative impact of anthropogenic factors in cities can hardly be overestimated. Green spaces enrich the air with oxygen and absorb carbon dioxide, delay tens of tons of dust, accumulate heavy metals, determine the speed of air flows, the value of insolation and the formation of temperature and humidity conditions, reduce noise loads. Green spaces are assigned one of the leading places in the architectural and planning structure of the city. They have a beneficial effect on the psychological state of people and are sources of aesthetic perception of the urban environment [2].

Green spaces in cities experience a high anthropogenic load, which leads to an unsatisfactory state, a decrease in decorativeness, a decrease in life expectancy, and an increase in the likelihood of outbreaks of diseases and pests. To assess the state of plantings, the most promising are the technologies of express analysis and data transmission in real time, which allows a quick assessment of the situation and decision-making in the shortest possible time by structures operating and maintaining green spaces of the city.
2. Methods and Materials

The solution to the problem of obtaining scientifically grounded information on the condition of green spaces is proposed on the basis of combining two independent but substantially complementary information blocks - monitoring of green spaces on the basis of generally accepted methods and monitoring using digital technology (Tree Talker monitoring).

In this study, we examined laws and legislative documents related to green areas and their organisation and planning that were available from St. Petersburg Administration and district administrations. An inventory of individual sites of various types of green area in St. Petersburg was carried out. The data in passports (documents which contain common information about the type and characteristics of green areas) of green common areas, green plantations performing special functions (including street planting), greenery of residential areas were analysed. An assessment was carried out on the condition of trees, shrubs and lawns, and on architectural and design elements.

During the inventory of green spaces in St. Petersburg the following data were usually taken into consideration:

Trees: Type of plantation (common, group planting), tree numbers, species, age, diameter, and current condition.

Shrubs: Type of plantings (alley or group), species, age, number of bushes, length (for avenue plantings) and current condition.

Lawns and flowerbeds: Area and coverage.

The condition of a green area was determined by the following characteristics:

- Good – Trees and shrubs: healthy plants with a well-developed crown, without significant damage. Lawns: Well-developed grass stand. Flowerbeds: No wilted plants.

- Satisfactory – Trees: The plants are healthy, but with a badly developed crown, with significant damage or damage that is not threatening to the life of the tree and hollows in the trunk. Shrubs: Stand is without weeds and with occasional presence of sprouting. Lawn: Poorly maintained. Flowerbeds: Wilting parts of plants visible.

- Unsatisfactory – Trees: Incorrect and poorly developed crown, with significant damage and visible infection by diseases or pests which threaten the tree’s existence. Shrub: Presence of sprouting and dead parts, as well as weeds. Lawns: Patchy, dying and full of weeds. Flowerbed: Large amounts of dead flowers and wilted plants.

The inventory plan showed the number of trees and shrubs in the target area. Based on the corrected graphic material and the full records from a work diary, a final inventory plan of the area was drawn up. The plan also included: external boundaries of a landscape-architectural object with linear dimensions, description of the external situation outside the boundaries, boundaries and numbers of recorded areas and biogroups. During the analysis of materials, computer databases were created using GIS technology. Mathematical and statistical processing of research results was carried out using Excel applications. The recording of green spaces and elements of landscaping was carried out using the computer program "Electronic Passport of the Green Areas of St. Petersburg" (technical passports of green areas created by the Committee for the Improvement of St. Petersburg).

The methodology using digital technologies is based on the author's know-how of Tree Talkers technology for comprehensive monitoring of the state of green spaces. The most important is the solution of two problems: assessment of vertical stability and physiological state of green spaces [3]. Within the framework of the project “Smart technologies for monitoring, modeling and evaluating ecosystem services of green infrastructure and soils to support decision-making in the field of sustainable urban development against the backdrop of global changes”, the technology of continuous monitoring and data transmission using the know-how of measuring equipment Tree Talker (TT) is being tested two modifications: TT-G, which determines vertical resistance and TT +, which assesses the physiological state of woody plants.

The multi-functional Tree Talker device at the individual tree level provides continuous measurement, storage and remote transmission of data on its vertical stability (angular deviation of the trunk from the normal along three coordinate axes), water transport intensity, radial growth,
photosynthetic activity (vegetative indices) and microclimatic indicators (temperature, relative humidity). The measurement of the above parameters is carried out on the basis of highly accurate methodological approaches widely used in international practice. Thus, the vertical stability of a tree is estimated using an automatic accelerometer (gyroscopic sensor), the intensity of water transport - a thermal dispersion sensor (Temperature Dissipation Probe), radial growth - an infrared distance sensor (resolution 0.2 mm), photosynthetic activity - analysis of multispectral data (12 spectra: visible and near infrared wavelengths) about sunlight passing through the crown. Measurements are taken every hour and a half (can be adjusted). The received data from the Tree Talker measuring device is regularly transmitted (LoRA wireless data transfer technology) to the TT-Cloud microcontroller, which, in turn, sends them to the web server using the GSM network via the GPRS modem. Thus, the Tree Talker device allows you to monitor in real time the dynamics of the physiological state of the tree, its vertical stability, as well as microclimatic indicators of the environment.

3. Results and Discussion

The total area of St. Petersburg is 143999 hectares, and the area of green infrastructure is 35390 hectares, which is 24.6% of the total area of the city. Around 65% of the green areas of the city are located within the territory of urban forests (22,900 hectares), concentrated mainly in the five administrative districts of St. Petersburg: Kurortnoye, Primorsky, Vyborgsky, Krasnoselsky and Petrodvorets (table 1). Fifteen specially protected natural areas with a total area of 6142.5 hectares have been established. Green common areas cover 5980 hectares, which is 16.9% of the total area of green spaces of the city. The area of street planting is 2420 hectares (6.8% of total green area) and the area of residential greenery is 1410 hectares (4% of total green area) (table 1).

| №  | Type of green area               | Area, thousand hectares | %   | Notes                                                                 |
|----|---------------------------------|-------------------------|-----|----------------------------------------------------------------------|
| 1  | Urban forests                   | 22.9                    | 64.7| 15 specially protected natural area 6.142 thousand hectares          |
| 2  | Common green areas              | 5.98                    | 16.9| 85 parks, 134 gardens, 1618 green areas in squares, 108 boulevards   |
| 3  | Street greening                 | 2.42                    | 6.8 | -                                                                    |
| 4  | Residential housing green areas | 1.4                     | 4   | -                                                                    |
| 5  | Green areas that perform special functions | 2.69 | 7.6 | -                                                                    |
|    | TOTAL                           | 35.39                   | 100 | -                                                                    |

The Law "On green spaces in St. Petersburg" sets standards for the quality of green spaces and the minimum standards for the provision of the population of St. Petersburg in all types of green areas [4]. The standards for the quality of green spaces are established for the entire territory of St. Petersburg according to the biological indicators of the state of the environment and the stability of natural complexes. Currently, the indicator of the per capita provision with green areas is determined for each district of St. Petersburg as the ratio of the sum of types of green areas (common green, limited use and multifamily greenery) to the total number of persons registered in the district [1] (table 2).
Table 2. Provision of green area per capita in St. Petersburg [1]

| №  | St. Petersburg districts       | Total urban greening, m² | Number of inhabitants (2018) | Minimum standard of provision of green area, m² per person | Actual provision of green area, m² per person |
|----|-------------------------------|--------------------------|-----------------------------|------------------------------------------------------------|----------------------------------------------|
| 1  | Admiralteisky                 | 1 599 565                | 172 704                     | 6                                                          | 9                                            |
| 2  | Wasileostrovsky                | 1 823 405                | 207 267                     | 6                                                          | 9                                            |
| 3  | Wiborgsky                     | 8 085 355                | 482 450                     | 12                                                         | 17                                           |
| 4  | Kalininsky                    | 7 070 419                | 447 984                     | 12                                                         | 16                                           |
| 5  | Krasnogvardeisky              | 3 573 703                | 293 923                     | 12                                                         | 12                                           |
| 6  | Krasnoselsky                  | 7 095 727                | 356 074                     | 12                                                         | 20                                           |
| 7  | Kirovsky                      | 4 378 715                | 334 028                     | 12                                                         | 13                                           |
| 8  | Kolpinsky                     | 4 030 778                | 185 497                     | 6                                                          | 22                                           |
| 9  | Kronshadsky                   | 704 135                  | 44 335                      | 18                                                         | 16                                           |
| 10 | Kurortny                      | 7 062 780                | 69 691                      | 18                                                         | 101                                          |
| 11 | Moskovsky                     | 4 896 382                | 276 141                     | 12                                                         | 18                                           |
| 12 | Nevsky                        | 5 123 479                | 467 919                     | 12                                                         | 11                                           |
| 13 | Petrogradsky                  | 4 330 050                | 139 298                     | 6                                                          | 31                                           |
| 14 | Petrodvortzovy                | 21 142 703               | 133 668                     | 18                                                         | 158                                          |
| 15 | Primorsky                     | 6 801 831                | 544 032                     | 12                                                         | 13                                           |
| 16 | Pushkinsky                    | 6 819 653                | 109 289                     | 18                                                         | 62                                           |
| 17 | Frunzensky                    | 4 671 548                | 405 745                     | 12                                                         | 12                                           |
| 18 | Tzentralny                    | 1 595 431                | 226 390                     | 6                                                          | 7                                            |
|    | Total                         | 100 805 659              | 4 896 435                   | 12                                                         | 21                                           |

The minimum standard for provision of green area per capita in St. Petersburg is as follows: for the Admiralty, Vasileostrovsky, Petrogradsky, Central, Kolpinsky districts of St. Petersburg it is 6 m² per capita; for Vyborgsky, Kalininsky, Kirovsky, Krasnogvardeisky, Krasnoselsky, Moscovsky, Nevsky, Primorsky and Frunzensky districts it is 12 m² per capita; and for Kronstatts, Kurortny, Lomonosovskiy, Petrodvortzovy and Pushkinsky districts it is 18 m² per capita [1]. The actual provision of green area to residents of St. Petersburg ranges from 7 to 158 m² per capita (Table 2) In Kronshatsky and Nevsky districts, the actual provision of green areas is lower than the standard, while in the Central, Krasnogvardeisky, Kirovsky, Primorsky and Frunzensky districts, the provision is approaching the level of the minimum standard [1, 4, 5].

For an objective assessment of this indicator, we advise a change in the methodology for calculating the green area per capita indicator for St. Petersburg. It is important to include in the calculation all types of green areas that are part of the green infrastructure and are located within district’s administrative boundaries. A similar practice is applied in other regions of the Russian Federation and throughout the world.

At present, there are 1.68 million trees and 3.77 million shrubs growing in common green areas and street planting of St. Petersburg [6]. The predominant species are broadleaved trees (79.33% of the total population), followed by coniferous trees (20.67%). Around 78% of these trees are over 20 years old. According to our monitoring of the status of tree species, 30% of aged trees have approached the natural limit of their life expectancy. Therefore, the most important problem is the preservation of old-growth trees and an increase in planting to fill the gap left by lost specimens. The existing practice of annual planting of about 20 000 trees and 200 000 shrubs in common green areas and street planting [1] is not sufficient for St. Petersburg and should be revisited. In addition, to improve the sustainability of urban green areas in selecting species of trees and shrubs, it is recommended to use a...
comprehensive method for assessing the suitability of woody and shrub vegetation for the urban environment: gas resistance, resistance to anti-icing materials (which is a reality in St. Petersburg) and winter hardiness [7, 8].

We have developed a list of recommended gas- and winter-resistant trees and shrubs for street planting and common green areas in St. Petersburg. It includes 19 species and varieties of coniferous and 131 species and varieties of deciduous trees and shrubs.

Direct instrumental measurements in combination with expert assessment, which were used in the inventory of green spaces, provide detailed information at the level of an individual tree. Depending on the purpose of the survey and the information available, the results of the assessment may contain a certain degree of uncertainty, however, expert opinion remains an important part of assessing the state of green spaces, especially taking into account the specifics of the urban environment in comparison with natural ecosystems [9].

The main disadvantage of direct examination in the city conditions is the high diversity and fragmentation of the object of investigation, which significantly increases labor intensity and requires a sufficient number of qualified personnel. Moreover, direct instrumental methods are focused on point measurements (a particular tree in a certain period of time) and do not imply regular (let alone continuous) monitoring of the condition and functioning of the greening, which is a serious limitation for monitoring the functional condition and vertical stability.

Many countries have legislation in place to minimize the risk of injury from falling trees [10]. The assessment of vertical stability can be made as a result of visual evaluation by a specialist. However, such assessment data are difficult to use for accurate forecasting of wind risks due to the lack of information about the root system condition, dominant wind direction and force and other natural and anthropogenic factors affecting vertical stability.

The interpretation of visual assessment data for wind risk prediction is limited by the subjectivity of the results. Risk assessment is traditionally based on the analysis of probability and expected effects of [11].

At the same time, the assessment of the probability of a fall largely depends on the level of expertise of the appraiser, as well as the information available to him [12].

In the conditions of the city, green spaces experience increased stresses of both natural and anthropogenic origin, which leads to a deterioration in their condition, a decrease in functionality and decorativeness, and ultimately to death. Diagnosing signs of stress in the early stages allows you to identify problematic situations and take preventive measures. A variety of green spaces (breed, age) and their growing conditions in the metropolis leads to a high uncertainty in the values of their state parameters to identify signs of stress. Continuous monitoring of the dynamics of the parameters of the state of green spaces will allow us to separate the ranges of fluctuations in the normal range (daily and seasonal deviations) and extreme deviations associated with risks. Tree Talker (TT) - a modern technical tool for monitoring green spaces, a new type of device, the principle of which is based on the technology of the Internet of things.

In summer 2019 the Department of Landscape Architecture of St. Petersburg State Linguistic University became a co-implementer of the Project "Smart technologies for monitoring, modeling and assessment of ecosystem services of green infrastructure and soils to support decision-making in the field of sustainable development of cities against the background of global changes", which is being developed by the PFUR scientific team (Project Manager - Professor Riccardo Valentini, Nobel Prize winner of the IPCC 2007). The head organization of the project is the Laboratory of Smart Technologies for Sustainable Urban Development in the Context of Global Change of PFUR.

In 2019, monitoring was carried out in Moscow (PFUR) and St. Petersburg (SPbGLTU). The project envisages the creation of an operational environmental monitoring system Smart Urban Nature for cities in European Russia [13]. The priority cities in which the Smart Urban Nature system will be deployed in 2020-2021 are Voronezh, Rostov-on-Don and Apatity.

By early 2020, more than 200 devices had been installed in Moscow, and 10 devices had been installed at test sites in St. Petersburg: FTU Botanical garden (figure 1) and Summer garden (figure 2),
which made it possible to study the condition of green spaces (table 3), taking into account species and age diversity, as well as the contrasting anthropogenic load.

**Figure 1.** TT device in FTU Botanical garden.  
**Figure 2.** TT device in Summer garden.

### Table 3. Characteristics of the tested trees on the territory of St. Petersburg.

| №  | Species                                | IN\(^a\) | Diameter, см | Age, (years) |
|----|----------------------------------------|----------|--------------|--------------|
| 1  | English oak (*Quercus robur*)          | 28-16    | 75           | 145          |
| 2  | Linden small-leaved (*Tilia cordata*)  | 28-34    | 100          | 145          |
| 3  |                                        | 25-18    | 70           | 115          |
| 4  |                                        | 30-91    | 40           | 60           |
| 5  |                                        | 36-1     | 40           | 60           |
| 6  | English oak (*Quercus robur*)          | 6-23     | 108          | 215          |
| 7  | Linden small-leaved (*Tilia cordata*)  | 2-52     | 92           | 130          |
| 8  |                                        | 2-47     | 76           | 125          |
| 9  |                                        | 5-50     | 50           | 80           |
| 10 |                                        | 7-76     | 43           | 65           |

*IN, inventory number (section – tree)

### 4. Conclusion

Placement of green spaces in different areas of St. Petersburg is uneven. Availability of green spaces for St. Petersburg residents varies from 7 to 158 m\(^2\) per person. In Krasnogvardeisky, Kirovsky, Primorsky, Frunzensky, and Centralny Districts the actual security indicators are close to the values of minimum security standards. In Nevsky and Kronshtadt Districts, actual indicators of provision with greenery are below the normative ones.

According to the data of monitoring of wood species condition 30% of trees have approached the natural limit of life expectancy. Therefore, an important problem is the preservation of old-age trees and the increase of plantings to replenish lost plantations. For this purpose the list of recommended assortment of trees and shrubs for St.-Petersburg has been developed. It includes conifers of 19 species and varieties, deciduous trees and shrubs of 131 species and varieties.

In order to monitor the condition of the green stock of St. Petersburg and to obtain a spatially differentiated picture of the dynamics of planting (including phenology) with reference to age, breeds and species of woody plants, it is necessary to apply Tree Talker technologies. Application of this technology will allow to obtain databases and groups of data necessary for decision-making in the care and maintenance of green spaces.
The use of digital technology, compared to traditional visual methods of monitoring green spaces, allows to obtain arrays of data on the condition of green spaces in real time. Continuous monitoring of changes in the green area condition allows the identification of ranges of fluctuating values within the normal range or extreme deviations, which are associated with risks.

Compared to other technologies, the TreeTalker has the following advantages:

1) combining a complete set of measurements for monitoring trees using the most advanced technologies available in one compact unit;

2) ensuring continuous and cost-effective monitoring, as opposed to collecting data on tree inventories as a whole, time intervals (several years) or time "snapshot" are derived from remote image perception;

3) the possibility of early detection of tree damage due to simultaneous observation of the crown properties (multispectral radiometric data) and functionality of the tree (diameter growth, water transport), as well as the stability of the tree;

4) the ability to transmit and store data in the cloud, which allows easy, fast and cost-effective search and tracking of parameters.

In general, we can conclude that the TreeTalker technology is unique in its multifunctionality while maintaining high accuracy of individual parameters at the tree level. Sensors on individual parameters in the device are comparable with existing analogues in terms of measurement accuracy and purchase and operation costs. Their combined use in a single instrument, along with the ability to continuously and remotely transmit, store and primary analyze data, makes the technology unique.

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