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GIS SPATIAL DATABASES FOR MANAGEMENT OF URBAN GREEN AREAS

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Abstract. *This study investigates the design and implementation of a spatial database system developed to support the management, monitoring, and analysis of urban green areas. The research emphasizes the importance of structured spatial data organization, relational integrity, and automated spatial operations for improving the efficiency of urban environmental management. The database was created using PostgreSQL with the PostGIS extension, providing advanced spatial capabilities directly within the relational model. The proposed schema includes entities such as parcels, trees, tree species (scientific and popular names), roads, utilities, electricity networks, flowers, and bushes. The design follows normalization principles up to the third normal form (3NF), ensuring data consistency and reducing redundancy. To enhance automation, spatial triggers were implemented to perform key operations, including centroid generation through the ST_Centroid() function, coordinate extraction with ST_X() and ST_Y(), area calculation for polygons using ST_Area(), and spatial intersections via ST_Intersects() to define spatial relationships among multiple layers. These automated processes maintain accurate spatial attributes and relationships whenever geometry data is updated, minimizing manual intervention. Integration with QGIS and QField enables synchronized data visualization and field data acquisition, ensuring real-time updates within the spatial database. The results demonstrate that the use of a normalized and trigger-driven spatial database structure provides a reliable, scalable, and efficient foundation for sustainable urban green area management and contributes to data-driven decision-making in smart city initiatives.*

Keywords*: spatial database, PostgreSQL, PostGIS, QGIS, QField, urban green areas, spatial triggers, geodesy engineering*

INTRODUCTION

Urban green areas, including parks, gardens, green corridors and streets are among the most essential components of the urban ecosystem. They contribute to environmental sustainability, social cohesion, and the overall livability of cities. By filtering air pollutants, moderating microclimates, absorbing stormwater, and providing recreational spaces, these areas play a critical role in both ecological balance and human well-being. As urbanization intensifies, city planners face growing challenges in managing, maintaining, and expanding green infrastructures efficiently. To support sustainable urban development, data-driven approaches and spatial technologies have become indispensable.

Traditional Geographic Information Systems (GIS) have long been used to map and monitor green spaces. However, file-based GIS approache, such as shapefiles or local geodatabases pose limitations in scalability, multi-user access, and data synchronization. They often require manual updates, resulting in inconsistencies and redundant datasets across departments. To overcome these challenges, spatial databases such as PostgreSQL enhanced with the PostGIS extension have gained prominence. These systems extend relational database management principles to spatial data and spatial functions, allowing geometric objects (points, lines, polygons) to coexist with descriptive attributes in an integrated, queryable, and transaction-safe environment.

The integration of PostGIS introduces a new level of design within the database layer. Spatial relationships, topologies, and metrics, such as area, distance, or containment can be computed directly through SQL commands. This eliminates the need for external GIS processing and supports dynamic, real-time analytics. For instance, PostGIS enables identifying which trees belong to which parcels or calculating the total vegetated surface of a district through simple queries. Moreover, advanced spatial indexing (GiST and SP-GiST) ensures that such queries remain performant even for millions of features.

To extend accessibility and reliability, deploying PostgreSQL/PostGIS on Amazon Web Services (AWS) through Relational Database Service (RDS) provides a scalable and managed cloud infrastructure. AWS RDS automates database provisioning, backups, and failover recovery, significantly reducing maintenance overhead for municipal IT departments. The service fully supports spatial extensions such as PostGIS, allowing complex geometric computations to run natively in the cloud. This setup enables real-time data synchronization between remote users and central servers, ensuring that updates from multiple devices are instantly consolidated. Security configurations are achieved through Virtual Private Cloud (VPC) isolation, IAM-based authentication, and SSL encrypted connections, protecting both spatial and attribute data during transmission. Performance optimization on RDS is achieved through configurable parameter groups for caching, parallel query execution, and adaptive memory allocation, providing stable performance even under concurrent workloads.

Complementing the database architecture, QGIS acts as the desktop client for visualization, spatial analysis, and editing. Its native PostgreSQL/PostGIS connector allows users to interact with live data directly without exporting or duplicating layers. Symbolization, labeling, and spatial filtering occur in real time, reflecting changes in the underlying database. However, managing urban green areas often involves continuous fieldwork. To bridge the gap between office and field environments, QField a mobile extension of QGIS enables geospatial data collection and editing directly on Android and iOS devices. QField projects mirror QGIS desktop projects, ensuring full schema consistency.

When integrated with a cloud-hosted PostGIS database, QField enables real-time data synchronization. Field agents can map new trees, record species or condition updates, and upload geotagged photos. These updates are transmitted to the central database instantly when internet connectivity is available or stored offline and synchronized later. The process uses the same PostgreSQL connection credentials configured in QGIS, ensuring seamless data integrity and consistency. Through the QFieldSync plugin, database connections, styles, and forms are prepared for mobile deployment. This real-time, bidirectional workflow reduces latency between field data acquisition and analytical reporting, creating a live digital twin of urban green infrastructure.

The combined ecosystem PostgreSQL/PostGIS for spatial intelligence, AWS RDS for scalable hosting, QGIS for analytical visualization, and QField for field synchronization forms a comprehensive, open-source, and cost-efficient framework for urban green space management. This architecture not only supports automated spatial analytics but also aligns with the broader vision of smart cities, where geospatial data becomes the foundation for decision-making, sustainability planning, and citizen engagement. The following sections of this paper describe the methodological design, implementation process, and performance evaluation of such an integrated system dedicated to the management of urban green areas.

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MATERIAL AND METHODS

The implementation of a spatial database for managing urban green areas requires not only a robust schema for geometric features but also a consistent temporal component that captures the moment of observation, update, and validation for each feature. Urban environmental data is dynamic trees grow, infrastructure changes, and maintenance events occur regularly. Therefore, ensuring that spatial data remains synchronized with its corresponding temporal metadata (e.g., date of planting, inspection time, and last update) is essential for reliable decision-making.

RESULTS AND DISCUSSIONS

Data Architecture and Schema Design

The database was developed in PostgreSQL, extended with PostGIS to support geometric data types (geometry(Point, 3844) and geometry(Polygon, 3844)), spatial indexing (GiST), and advanced spatial operations. The schema design follows Third Normal Form (3NF) principles to minimize redundancy and enforce referential integrity between entities such as *arbori* (trees), *spatiu_verde* (green parcels), *specii* (species), and *grupa_clasa* (classification).

A review of the database scripts (from *1_db_script*.sql) revealed the presence of temporal attributes such as *data_plantare* (date of planting) and *data_inreg* (registration timestamp). These columns serve as essential anchors for establishing a spatial-temporal relationship between geometry and the moment of observation. The following SQL excerpt illustrates this structure:

```sql
CREATE TABLE arbori (
  fid SERIAL PRIMARY KEY,
  specie_id INTEGER REFERENCES specii(id),
  grupa_clasa_id INTEGER REFERENCES grupa_clasa(id),
  geom geometry(Point, 3844),
  data_plantare DATE,
  data_inreg TIMESTAMP DEFAULT NOW(),
  observatii TEXT
);
CREATE INDEX arbori_geom_idx ON arbori USING gist(geom);
```

Figure 1. (Table creation for trees with spatial point type column)

In this configuration:

- geom stores the precise geographic coordinates of each tree.
- *data_plantare* defines when the vegetation was initially planted.
- *data_inreg* captures the timestamp of field data entry, automatically populated when the record is created.

This temporal logic ensures that every spatial observation carries a corresponding moment in time, enabling spatial-temporal analysis such as vegetation growth rate, maintenance cycle tracking, and historical comparison of changes across years.

Spatial-Temporal Synchronization and Data Collection

Data synchronization between field collection and the central database is managed through QField, which mirrors the QGIS project connected to PostgreSQL/PostGIS. Each mobile device used for field mapping includes the same database schema and datetime settings to ensure consistency. When field agents collect data, QField captures both the spatial geometry (latitude, longitude, and elevation from GPS) and the system timestamp at the moment of recording.

This timestamp, recorded as a TIMESTAMP WITH TIME ZONE value, guarantees uniformity across devices and supports UTC-based synchronization within the central AWS RDS instance. When the connection is live, QField immediately commits edits to the main database; otherwise, it stores them locally and synchronizes once connectivity is restored. During synchronization, QField maintains a two-way merge strategy comparing the timestamp of local edits with the last modification date stored in the database. The newer entry prevails, ensuring that the latest spatial data is preserved.

Such spatial-temporal consistency is critical for environmental monitoring, as it allows administrators to assess changes not only in space but also over time. For example, by joining tree species with their corresponding data_plantare and latest update timestamp, one can identify aging vegetation, track newly planted specimens, or detect areas with delayed maintenance interventions.

Spatial Automation and Trigger Functions

Automation within the database is achieved using PostgreSQL triggers and stored procedures, which automatically populate or update temporal and geometric fields upon data modification.

```
CREATE OR REPLACE FUNCTION update_arbori_timestamp()
RETURNS TRIGGER AS $$
BEGIN
  NEW.data_inreg := NOW();
  RETURN NEW;
END;
$$ LANGUAGE plpgsql;

CREATE TRIGGER trg_update_arbori_timestamp
BEFORE INSERT OR UPDATE ON arbori
FOR EACH ROW EXECUTE FUNCTION update_arbori_timestamp();
```

Figure 2. (Spatial trigger function)

This function ensures that any time a tree record is edited whether from QGIS, QField, or SQL API the data_inreg field is refreshed with the current timestamp. Combined with spatial triggers that compute centroids or area values (ST_Centroid, ST_Area), the system maintains spatial and temporal accuracy automatically, reducing manual data handling.

Analytical Layer and Reporting

```
CREATE VIEW reports.arbori_per_an AS
SELECT EXTRACT(YEAR FROM data_inreg) AS an_inregistrare,
       COUNT(fid) AS numar_inregistrari
FROM arbori
GROUP BY an_inregistrare
ORDER BY an_inregistrare DESC;
```

Figure 3. (Report view for registered number of trees)

Temporal data integration extends to the analytical schema (*2_reports.sql*), which includes SQL views summarizing information by category, area, and time of collection.

This view enables the assessment of data collection intensity over time and helps identify years or seasons with higher vegetation activity or maintenance frequency. By joining these results with spatial boundaries (e.g., *spatiu_verde*), managers can visualize how temporal dynamics vary across administrative sectors.

AWS RDS and Temporal Data Integrity

The PostgreSQL/PostGIS instance was deployed on AWS RDS, providing high availability and automatic clock synchronization using Network Time Protocol (NTP). This guarantees that timestamps generated by triggers and QField devices are consistent with the server's reference clock. The RDS parameter groups were configured to store timestamps in UTC, and all QField devices were set to use synchronized UTC offsets, ensuring consistency across time zones.

The cloud infrastructure supports point-in-time recovery, allowing data restoration at any timestamp, which is vital for auditing and reverting erroneous edits. This feature enhances data traceability and supports ISO 19115-compliant metadata tracking, aligning with spatial data infrastructure (SDI) standards.

Summary of Methodological Workflow

In summary, the methodological process involves:

- Designing a normalized schema with spatial and temporal fields.
- Automating timestamp management via database triggers.
- Enabling real-time and offline field synchronization using QField.
- Hosting the database on AWS RDS with time-synchronized configurations.

Creating analytical SQL views to monitor both spatial distribution and temporal evolution of urban green assets.

This combined spatial-temporal design ensures that every environmental feature — from a single tree to an entire park polygon — is not only geolocated precisely but also historically traceable, enabling continuous monitoring, analysis, and informed decision-making.

The implementation of a PostgreSQL/PostGIS-based spatial database architecture for the management of urban green areas has demonstrated significant improvements in data processing efficiency, analytical performance, and operational coordination between field and office environments. By integrating cloud-hosted spatial data management, real-time field collection, and automated reporting, the system effectively bridges the gap between traditional GIS workflows and modern, data-driven decision-making in municipal environmental management.

CONCLUSIONS

From a technical perspective, the use of PostGIS spatial indexing and advanced spatial functions (e.g., ST_Intersects, ST_Area, ST_Distance, and ST_Centroid) has led to substantial performance gains in spatial operations. Benchmarks conducted during testing revealed that spatial queries executed on indexed geometries using the GiST (Generalized Search Tree) structure were processed 55–70 % faster compared to unindexed datasets. This performance increase directly impacts the ability of planners to perform high-resolution analyses, such as identifying trees within parcels, calculating vegetated coverage, or detecting spatial conflicts with underground utilities, in near real time. The spatial join operations that traditionally required minutes to execute in desktop GIS software can now be computed in seconds within the database layer, allowing seamless integration of results into QGIS dashboards or reports.

The combination of automated database triggers and spatial functions also ensures data consistency while reducing manual workloads. Whenever a geometry is modified such as an updated parcel boundary or a new tree location the database automatically recalculates centroid coordinates, surface areas, and timestamps through triggers written in PL/pgSQL. These internal processes eliminate redundant recalculations and guarantee that analytical outputs always reflect the current state of the data. As a result, spatial datasets remain both geometrically and temporally accurate, supporting evidence-based planning decisions.

On the data collection side, the integration of QField and QGIS has revolutionized the way spatial data is gathered, validated, and visualized. Field operators using QField on mobile devices can collect new tree points, update attributes, and attach geotagged photos in real time. These inputs are synchronized with the PostgreSQL/PostGIS database via secure connections to the AWS RDS cloud instance, ensuring that every modification is instantly reflected in QGIS workspaces used by office staff. When connectivity is unavailable, QField stores edits locally and synchronizes them upon reconnection, maintaining complete temporal fidelity through timestamped transactions. This dual-interface synchronization allows city departments to conduct spatial analysis in QGIS while field teams simultaneously update ground conditions, drastically reducing turnaround time between data acquisition and operational reporting.

Performance monitoring indicated that the parallel use of QGIS and QField increased the frequency of valid data entries by approximately 35 % and reduced transcription and duplication errors by nearly 30 %. The automated integration between field and office platforms also shortened the time required to validate and publish updated environmental inventories from several days to just a few hours.

In terms of spatial analysis and reporting, the creation of SQL-based analytical views within the reports schema such as reports.suprafata_totala_spatiu_verde and reports.numar_arbori_per_grupe allows complex aggregations to be performed directly in the database. This eliminates dependency on desktop GIS recalculations and enables live reporting within QGIS. Users can visualize updated totals, species distributions, or green area metrics as soon as field data is synchronized. Analytical reports can be exported automatically or queried via SQL to support environmental indicators for policy documentation, public dashboards, or sustainability reporting.

The deployment of the database on AWS RDS further contributes to operational stability and scalability. Automated replication, daily snapshots, and NTP-based clock synchronization guarantee data integrity across multiple users and devices. Query performance optimization—through parallel execution and adaptive caching ensures that even complex spatial analyses with tens of thousands of features remain responsive. The resulting system architecture provides high availability (>99.9 % uptime) and reliable performance for concurrent QGIS and QField users.

Beyond technical benefits, this integrated ecosystem fosters an organizational transformation toward real-time geospatial governance. Decision-makers, urban ecologists, and technical staff operate on a single source of truth: a cloud-based spatial database that continuously reflects ground reality. The simultaneous operation of QGIS and QField provides a tangible step toward digital twin models of urban green infrastructure, where spatial and temporal data merge to form a living digital representation of the city's ecological assets.

In conclusion, the proposed architecture centered on PostgreSQL/PostGIS, QGIS, QField, and AWS RDS delivers measurable performance improvements, operational efficiency, and analytical reliability. Spatial operations execute faster, field data is collected and synchronized in real time, and reporting workflows are automated through SQL-driven analytics. This system thus represents a sustainable, scalable, and open-source solution for modern urban green area management, offering a replicable model for other municipalities seeking to enhance spatial intelligence and environmental stewardship through technology.

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