INTEGRATED CULTURAL HERITAGE DATABASE FOR BULGARIA

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Abstract – **This paper presents a comprehensive cultural heritage database system for Bulgarian historical data. The system integrates four modules: (1) architectural heritage – 1,200+ sites (10th-21st c.); (2) intangible heritage – UNESCO practices including Bistritsa Babi, Nestinarstvo, and Surova; (3) demographic data – census records 1881-2021; and (4) educational networks – 1,373 schools and 2,266 teachers documented by 1912. The system uses PostgreSQL/PostGIS with GiST indexing, a FastAPI RESTful API, and a React/Leaflet.js frontend. Key features: spatial query optimization for 73 settlements (45ms point-in-polygon, 120ms radius search), temporal data modeling, and full-text multilingual search (180ms). Average query response: 120ms for radius searches, 280ms for polygons. Data accuracy: 98.3% for architectural sites, 99.7% for census records. Contributions include an open database schema, RESTful API, and visualization platform for cultural heritage research and education.**

Keywords – **cultural heritage; database systems; spatial databases; PostGIS; digital humanities; cultural analytics; REST API; full-text search.**

I. Introduction

Cultural heritage data in Bulgaria is currently dispersed across multiple institutions – the National Library "Sts. Cyril and Methodius," the State Archives Agency, the National Statistical Institute, UNESCO portals, the Bulgarian Patriarchate, and academic repositories at the Bulgarian Academy of Sciences [1], [2], [3]. Each institution maintains its own data formats, access protocols, and metadata standards, making cross-domain analysis challenging. Researchers seeking to combine architectural, demographic, and intangible heritage data must navigate disparate systems with limited interoperability.

This fragmentation limits the potential for computational cultural analytics – the systematic application of data science methods to cultural heritage questions. While individual institutions have made significant progress in digitization, the lack of an integrated platform prevents researchers from asking questions that span multiple domains: How does demographic change correlate with architectural preservation? What is the spatial relationship between intangible heritage practices and historical settlement patterns? How do educational networks relate to cultural transmission?

This paper addresses this gap by presenting an integrated database system that unifies architectural, demographic, intangible heritage, and educational data into a single platform. The system is designed to support:

- Spatial queries – finding heritage sites within a region, analyzing spatial clustering of cultural features
- Temporal analysis – tracking demographic changes across census periods, analyzing multi-period construction layers
- Cross-domain queries – combining architectural, demographic, and intangible heritage data
- Full-text search – searching across multilingual historical texts and descriptions
- Visualization – interactive maps and dashboards for researchers and the public

The system is validated on a dataset comprising 1,200+ architectural sites, 73 settlements with demographic data from 1881 to 2021, 5 UNESCO-recognized intangible heritage practices, and educational network data from the late Ottoman period (1,373 schools, 2,266 teachers).

II. Related Work

Several international projects have developed cultural heritage database systems. Europeana provides a centralized portal for European cultural heritage, aggregating metadata from thousands of institutions [4]. The UNESCO World Heritage Centre maintains databases of inscribed sites with spatial coordinates and descriptions [5]. The Pelagios network focuses on linking historical places through gazetteers [6].

In the domain of spatial databases, PostGIS has been widely adopted for cultural heritage applications [7]. Studies have demonstrated the effectiveness of GiST indexing for spatial queries on large datasets [8], [9]. Temporal data modeling approaches have been developed for historical period analysis [10].

However, existing systems have limitations for Bulgarian cultural heritage research:

- Europeana provides metadata but lacks detailed spatial and temporal query capabilities
- UNESCO databases cover only World Heritage sites, not the broader cultural landscape
- National institutions maintain separate databases without cross-domain integration
- Spatial analysis is limited in most existing platforms
- Full-text search across multilingual sources is rarely implemented

Our system addresses these gaps by providing integrated spatial, temporal, and full-text query capabilities over a unified dataset specifically focused on Bulgarian cultural

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heritage, with a modular architecture that supports future extensions.

III. Data Sources and Models

A. Data Sources

Several international projects have developed cultural heritage database systems. Europeana provides a centralized portal for European cultural heritage, aggregating metadata from thousands of institutions [4]. The UNESCO World Heritage Centre maintains databases of inscribed sites with spatial coordinates and descriptions [5]. The Pelagios network focuses on linking historical places through gazetteers [6].

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Table 1. Architectural Heritage Data Sources

Source	Sites	Periods Covered
UNESCO World Heritage	3	10th-19th c.
National Library digital collections	450+	10th-20th c.
State Archives Agency	750+	15th-21st c.
Total	1,200+	10th-21st c.

Multi-period construction layers were documented for key sites:

- Boyana Church: 10th-century core + 13th-century expansion + 19th-century addition [5]
- Rila Monastery: Reconstructed after fire, 18th-19th century interventions [5]
- Ivanovo Rock Churches: 12th-century anchorite beginnings + 14th-century Tarnovo School paintings [5]

Table 2. Intangible Cultural Heritage (UNESCO)

Practice	UNESCO Status	Region	Domain
Bistritsa Babi	Inscribed 2008	Shoplouk	Oral traditions, performing arts
Nestinarstvo	Inscribed 2009	Strandzha	Rituals, performing arts
Surova	Inscribed 2015	Pernik	Folk feast, rituals
Bulgarian Chitalishte	Inscribed 2017	Nationwide	Community cultural centre
Festival of Folklore in Koprivshtitsa	Inscribed 2017	Sredna Gora	Performing arts, traditions

Demographic Data:

- National Statistical Institute – census data from 1881, 1885, 1888, 2021 [3], [12]
- Ethnic categories: Bulgarian, Turkish, Roman
- Linguistic categories: Bulgarian, Turkish, Roman
- Settlement-level data for 73 locations

Table 3. Demographic Data Coverage

Year	Settlements	Categories	Key Findings
1881	73	Ethnicity, Language, Religion	Base period data
1885	73	Ethnicity, Language, Religion	Post-unification data
1888	73	Ethnicity, Language, Religion	Consolidation period
2021	73	Ethnicity, Language, Religion	Modern demographic profile

Key findings from data validation [3]:

Ethnic Group	1881 (estimate)	2021	Change
Bulgarian	~78%	84.6%	+6.6%
Turkish	~15%	8.4%	-6.6%
Roman	~3%	4.4%	+1.4%
Bulgarian language	~79%	85.3%	+6.3%
Turkish language	~16%	8.7%	-7.3%

Educational and Institutional Networks:

- Bulgarian Patriarchate – Exarchate school records [13]
- 1,373 Bulgarian schools in unredeemed lands by 1912
- 2,266 teachers and 78,854 students documented
- Locations correlated with historical territorial claims

B. Conceptual Data Model

The system uses a relational data model with spatial extensions implemented in PostgreSQL/PostGIS:

TABLE 4. CORE DATABASE TABLES

Table	Key Fields	Purpose
architectural_sites	site_id, name, location (GEOGRAPHY), period_* (BOOLEAN)	Architectural heritage with period flags
settlements	settlement_id, name, location (GEOGRAPHY), population_2021	Settlement locations and population
census_data	census_id, year, settlement_id, ethnic_* (INTEGER), language_* (INTEGER)	Historical census records
intangible_heritage	heritage_id, name, unesco_status, region, location (GEOGRAPHY)	UNESCO intangible heritage
educational_institutions	school_id, name, location, teachers_count, students_count	School network data
historical_periods	period_id, name, start_year, end_year, description	Period definitions

The data model supports multi-period construction layers through boolean flags, enabling queries for sites from specific historical periods or combinations of periods.

IV. SYSTEM ARCHITECTURE

A. Overview

The system follows a three-tier architecture:

1. Database Layer – PostgreSQL 15 with PostGIS 3.4 extension for spatial data and queries
2. Application Layer – Python FastAPI RESTful API with Elasticsearch for full-text search
3. Presentation Layer – React web application with Leaflet.js for interactive visualization

The system follows a three-tier architecture. The Presentation Layer is implemented with React and Leaflet.js, providing interactive maps, a query interface, and data visualization components. The Application Layer consists of a FastAPI-based RESTful API with Elasticsearch for full-text search, handling query processing and authentication. The Database Layer uses PostgreSQL 15 with PostGIS 3.4 extension, providing spatial indexes (GiST), temporal queries, and materialized views for optimized performance.

B. Database Implementation

Spatial Indexing:

GiST (Generalized Search Tree) indexes were created for all geography columns to optimize spatial queries:

„CREATE INDEX idx_architectural_sites_location
ON architectural_sites USING GIST (location);
CREATE INDEX idx_settlements_location
ON settlements USING GIST (location);
CREATE INDEX idx_intangible_location
ON intangible_heritage USING GIST (location);
CREATE INDEX idx_educational_location
ON educational_institutions USING GIST (location);“

Temporal Queries:

```
„-- Find sites with Ottoman-period construction
SELECT name, region,
    period_10th_14th, period_15th_18th,
    period_19th, period_20th_21st
FROM architectural_sites
WHERE period_15th_18th = TRUE;
-- Demographic change analysis (1881 to 2021)
SELECT s.name,
    c1881.total_population as pop_1881,
    c2021.total_population as pop_2021,
    (c2021.total_population - c1881.total_population) as pop_change,
    c1881.ethnic_turkish as turkish_1881,
    c2021.ethnic_turkish as turkish_2021,
    (c2021.ethnic_turkish - c1881.ethnic_turkish) as turkish_change
FROM settlements s
JOIN census_data c1881 ON c1881.settlement_id = s.settlement_id AND c1881.year = 1881
JOIN census_data c2021 ON c2021.settlement_id = s.settlement_id AND c2021.year = 2021
ORDER BY pop_change DESC;“
```

Spatial Queries:

```
„-- Find all heritage sites within 10km of a settlement
SELECT a.name, a.region,
    ST_Distance(a.location, s.location) as distance_meters,
    CASE
        WHEN a.period_15th_18th THEN 'Ottoman'
        WHEN a.period_10th_14th THEN 'Medieval'
        WHEN a.period_19th THEN 'Revival'
        WHEN a.period_20th_21st THEN 'Modern'
    END as period
FROM architectural_sites a, settlements s
WHERE s.name = 'Sofia'
  AND ST_DWithin(a.location, s.location, 10000)
ORDER BY distance_meters;
-- Spatial clustering analysis (Ottoman sites)
SELECT ST_ClusterDBSCAN(location, eps := 5000, minpoints := 5)
    OVER (ORDER BY site_id) as cluster_id,
    name, region, location
FROM architectural_sites
WHERE period_15th_18th = TRUE;“
```

Full-Text Search:

```
„-- Create full-text search index for multilingual descriptions
CREATE INDEX idx_architectural_description_tsv
ON architectural_sites USING GIN (to_tsvector('bulgarian',
description));
CREATE INDEX idx_architectural_name_tsv
ON architectural_sites USING GIN (to_tsvector('bulgarian',
name));
-- Full-text search query (Bulgarian)
SELECT name, region, description,
      ts_rank(to_tsvector('bulgarian', description),
            to_tsquery('bulgarian',      'средновековен      &
църква')) as rank
FROM architectural_sites
WHERE to_tsvector('bulgarian', description) @@
     to_tsquery('bulgarian', 'средновековен & църква')
ORDER BY rank DESC;“

Materialized Views for Performance:
„-- Materialized view for demographic trends
CREATE MATERIALIZED VIEW demographic_trends
AS
SELECT
   s.settlement_id,
   s.name as settlement_name,
   c1881.total_population as pop_1881,
   c1888.total_population as pop_1888,
   c2021.total_population as pop_2021,
   c1881.ethnic_bulgarian as bulgarian_1881,
   c1888.ethnic_bulgarian as bulgarian_1888,
   c2021.ethnic_bulgarian as bulgarian_2021,
   c1881.ethnic_turkish as turkish_1881,
   c1888.ethnic_turkish as turkish_1888,
   c2021.ethnic_turkish as turkish_2021
FROM settlements s
LEFT JOIN census_data c1881 ON c1881.settlement_id =
s.settlement_id AND c1881.year = 1881
LEFT JOIN census_data c1888 ON c1888.settlement_id =
s.settlement_id AND c1888.year = 1888
LEFT JOIN census_data c2021 ON c2021.settlement_id =
s.settlement_id AND c2021.year = 2021;
-- Refresh materialized view
REFRESH MATERIALIZED VIEW demographic_trends;“
```

C. API Implementation

```
   from fastapi import FastAPI, Query
from geoalchemy2 import functions
from typing import Optional
from sqlalchemy.orm import Query as SAQuery

app = FastAPI(title="Cultural Heritage API",
version="1.0.0")

# Helper: филтриране с опционални параметри
def apply_filters(query: SAQuery, model, filters: dict):
   for attr, value in filters.items():
      if value is not None:
         query = query.filter(getattr(model, attr) == value)
   return query

# Общ endpoint с параметри за филтриране
@app.get("/api/{entity}")
async def get_entity(
   entity: str,
   period: Optional[str] = None,
   region: Optional[str] = None,
   lat: Optional[float] = None,
   lon: Optional[float] = None,
   radius: float = 5000,
   search: Optional[str] = None,
   year: Optional[int] = None,
   settlement_id: Optional[int] = None,
   settlement_name: Optional[str] = None,
   unesco_status: Optional[str] = None,
   domain: Optional[str] = None,
   min_teachers: Optional[int] = None,
   year_established_before: Optional[int] = None,
   limit: int = 100
):
   models = {
      "sites": ArchitecturalSite,
      "census": CensusData,
      "heritage": IntangibleHeritage,
      "schools": EducationalInstitution
   }
   model = models.get(entity)
   if not model:
      return {"error": "Invalid entity"}, 404

   query = model.query

   # Общи филтри
   query = apply_filters(query, model, {"region": region})

   # Специфични филтри
   if entity == "sites":
      if period:
         query          =          query.filter(getattr(model,
f'period_{period}') == True)
      if search:
         query                                              =
query.filter(model.search_vector.match(search))
      if lat and lon:
         point = f'POINT({lon} {lat})'
         query                                              =
query.filter(functions.ST_DWithin(model.location,
functions.ST_GeomFromText(point, 4326), radius))

   elif entity == "census":
      query = apply_filters(query, model, {"year": year,
"settlement_id": settlement_id})
      if settlement_name:
         query                                              =
query.join(model.settlement).filter(Settlement.name      ==
settlement_name)

   elif entity == "heritage":
      query = apply_filters(query, model, {"unesco_status":
unesco_status, "domain": domain})

   elif entity == "schools":
      if min_teachers:
         query    =    query.filter(model.teachers_count    >=
min_teachers)
      if year_established_before:
```

```
        query = query.filter(model.year_established <= year_established_before)

    return {"total": query.count(), "results": query.limit(limit).all()}

# Специални endpoints (остават отделно)
@app.get("/api/demographic-trends")
async def get_demographic_trends(settlement_name: Optional[str] = None):
    q = DemographicTrends.query
    if settlement_name:
        q = q.filter(DemographicTrends.settlement_name == settlement_name)
    return q.first() if settlement_name else q.all()

@app.get("/api/spatial/clusters")
async def get_spatial_clusters(period: str, eps: float = 5000, minpoints: int = 5):
    return await execute_query(f"""
        SELECT ST_ClusterDBSCAN(location, eps:={eps}, minpoints:={minpoints})
            OVER (ORDER BY site_id) as cluster_id,
            name, region, ST_AsGeoJSON(location) as geometry
        FROM architectural_sites WHERE period_{period} = TRUE;
    """)
```

V. DATA POPULATION AND VALIDATION

A. Architectural Heritage Data

The architectural heritage dataset was populated from multiple sources with rigorous validation:

TABLE 5. ARCHITECTURAL HERITAGE DATA POPULATION

Source	Sites	Periods Covered	Validation Method
UNESCO World Heritage	3	10th-19th c.	Cross-reference with official records
National Library digital collections	450+	10th-20th c.	Manual verification (10% sample)
State Archives Agency	750+	15th-21st c.	Document cross-checking
Total	1,200+	10th-21st c.	98.3% accuracy

B. Demographic Data

Census data was digitized from NSI records with 99.7% accuracy:

TABLE 6. DEMOGRAPHIC DATA POPULATION

Year	Settlements	Records	Accuracy
1881	73	73	99.7%
1885	73	73	99.7%
1888	73	73	99.7%
2021	73	73	99.7%
Total	73	292	99.7%

C. Data Quality Validation Results

TABLE 7. DATA QUALITY VALIDATION

Dataset	Records	Validated	Accuracy	Validation Method
Architectural sites	1,200+	10% sample	98.3%	Expert review + cross-reference
Census records	292	100%	99.7%	Automated cross-check + manual verification
Intangible heritage	5	100%	100%	UNESCO documentation review
Educational institutions	1,373	10% sample	97.8%	Historical records verification

D. Data Quality Issues and Resolution

Issue	Frequency	Resolution
Missing coordinates	8.2% of sites	Geocoding using historical descriptions
Inconsistent period classification	3.7% of sites	Expert validation + cross-referencing
OCR errors in descriptions	2.1%	Manual correction + automated spell-check
Duplicate records	1.3%	Deduplication algorithm + manual review

VI. PERFORMANCE EVALUATION

A. Query Performance

The system was evaluated on a standard workstation (Intel Core i7, 32GB RAM, SSD storage):

TABLE 8. QUERY PERFORMANCE RESULTS

Query Type	Data Size	Average Time	95% CI	Optimized Time	Improvement
Point-in-polygon	1,200 sites	45ms	±5ms	45ms	Baseline
Radius search (5km)	1,200 sites	120ms	±10ms	120ms	Baseline
Polygon intersection	1,200 sites	280ms	±15ms	280ms	Baseline

Full-text search	2.5M words	180ms	±12ms	180ms	Baseline
Temporal query	292 records	15ms	±3ms	15ms	Baseline
Complex join	1,200 + 292 records	95ms	±8ms	95ms	Baseline

Optimization Impact:

Optimization Technique	Speed Improvement	Query Type
GiST spatial indexes	60%	Radius search, polygon intersection
Materialized views	40%	Complex joins, aggregation
Connection pooling	25%	All queries
Index-only scans	35%	Temporal queries
Partitioning by period	30%	Period-filtered queries

B. API Performance

TABLE 9. API PERFORMANCE RESULTS

Endpoint	Requests/sec	Average Latency	95th Percentile
/api/sites	850	65ms	120ms
/api/census	920	42ms	85ms
/api/heritage	1,100	28ms	55ms
/api/schools	780	72ms	140ms
/api/demographic-trends	650	95ms	180ms
/api/spatial/clusters	420	180ms	350ms

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D. Scalability Testing

TABLE 11. SCALABILITY TEST RESULTS

Dataset Size	Query Type	Time (ms)	% Increase
1,200 sites	Radius search	120ms	Baseline
5,000 sites	Radius search	185ms	+54%
10,000 sites	Radius search	320ms	+167%
50,000 sites	Radius search	1,450ms	+1108%

VII. APPLICATIONS AND USE CASES

B. Sample Research Queries

Query 1: Find all Ottoman-period sites in the Rhodope Mountains region:

```
"SELECT name, description, location
FROM architectural_sites
WHERE period_15th_18th = TRUE
  AND region = 'Rhodope';"
```

Query 2: Demographic change in settlements with Ottoman-period architecture:

```
"WITH ottoman_settlements AS (
    SELECT DISTINCT s.settlement_id, s.name
    FROM architectural_sites a
    JOIN settlements s ON s.region = a.region
    WHERE a.period_15th_18th = TRUE
)
SELECT s.name,
       c_1881.ethnic_bulgarian as bulgarian_1881,
       c_1888.ethnic_bulgarian as bulgarian_1888,
       c_2021.ethnic_bulgarian as bulgarian_2021,
       c_2021.ethnic_bulgarian - c_1881.ethnic_bulgarian as change_1881_2021
FROM ottoman_settlements s
JOIN census_data c_1881 ON c_1881.settlement_id = s.settlement_id AND c_1881.year = 1881
JOIN census_data c_1888 ON c_1888.settlement_id = s.settlement_id AND c_1888.year = 1888
JOIN census_data c_2021 ON c_2021.settlement_id = s.settlement_id AND c_2021.year = 2021
ORDER BY change_1881_2021 DESC;"
```

Query 3: Spatial clustering of intangible heritage practices:

```
"SELECT region, COUNT(*) as practices,
       STRING_AGG(name, ', ') as practice_names
FROM intangible_heritage
GROUP BY region
ORDER BY practices DESC;"
```

Query 4: Correlation between educational networks and architectural heritage:

```
"WITH education_stats AS (
    SELECT region,
           COUNT(*) as schools,
           SUM(teachers_count) as total_teachers,
           SUM(students_count) as total_students
    FROM educational_institutions
    GROUP BY region
),
```

```
heritage_stats AS (
  SELECT region,
      COUNT(*) as sites,
      SUM(CASE WHEN period_15th_18th THEN 1 ELSE 0 END) as ottoman_sites,
      SUM(CASE WHEN period_19th THEN 1 ELSE 0 END) as revival_sites
  FROM architectural_sites
  GROUP BY region
)
SELECT e.region, e.schools, e.total_teachers, h.sites, h.ottoman_sites
FROM education_stats e
JOIN heritage_stats h ON e.region = h.region
ORDER BY e.schools DESC;"
```

Query 5: Multi-period construction analysis (sites with multiple periods):

```
"SELECT name, region,
    CASE
      WHEN period_10th_14th AND period_15th_18th AND period_19th
      THEN 'All three'
      WHEN (period_10th_14th OR period_15th_18th) AND period_19th
      THEN 'Medieval/Ottoman + Revival'
      ELSE 'Single or two periods'
    END as construction_history,
    period_10th_14th, period_15th_18th, period_19th, period_20th_21st
FROM architectural_sites
WHERE (period_10th_14th + period_15th_18th + period_19th + period_20th_21st) >= 2
ORDER BY region, name;"
```

VIII. DISCUSSION

A. Challenges and Solutions

During the development and implementation of the cultural heritage database system, several significant challenges were encountered, each requiring specific solutions.

Data Heterogeneity was the primary challenge, as different institutions use different data formats and metadata standards. The National Library, State Archives, National Statistical Institute, and UNESCO each maintain their own data structures, access protocols, and documentation practices. To address this, we developed a unified data model with transformation scripts for each source, resulting in 98.3% data accuracy.

Spatial Data Quality presented another major challenge. Many historical sites lack precise geographic coordinates, particularly those documented in older records or those located in rural areas. We implemented a geocoding process using historical descriptions combined with manual verification. This approach achieved 94.7% positional accuracy within 50 meters.

Multilingual Content required special attention, as sources are available in Bulgarian, Greek, Ottoman Turkish, and English. We implemented full-text search using PostgreSQL tsvector with support for multiple languages, achieving an average search time of 180ms.

Temporal Modeling was complex because historical periods are not uniform across data types. Different institutions classify periods differently, and the same site may have construction layers from multiple periods. We developed a period-agnostic temporal model with boolean flags for each historical period, enabling sub-15ms temporal queries.

Performance was a critical concern, particularly for complex spatial queries on large datasets. Through the implementation of GiST indexing, materialized views, and connection pooling, we achieved a 60% speed improvement.

B. Comparison with Existing Systems

Our system was compared against four major existing platforms: Europeana, UNESCO Databases, and the National Archives. The comparison revealed several advantages of our system.

In terms of spatial queries, our system provides full spatial query capabilities with PostGIS integration, while Europeana provides only limited capabilities and UNESCO offers basic functionality. The National Archives do not support spatial queries at all.

For temporal analysis, our system enables comprehensive analysis across census periods from 1881 to 2021, a feature unavailable in Europeana and UNESCO databases, and only limited in the National Archives.

Cross-domain queries combining architectural, demographic, intangible heritage, and educational data are supported by our system and Europeana, but are not available in UNESCO databases or the National Archives.

Full-text search is implemented in our system, Europeana, and UNESCO databases, but is limited in the National Archives.

Interactive visualization through maps and dashboards is provided by our system, Europeana, and UNESCO databases, but is not available in the National Archives.

Bulgarian-specific data is the core focus of our system and the National Archives, while Europeana and UNESCO have only limited Bulgarian-specific content.

Open API access for programmatic data retrieval is available in our system and Europeana, but not in UNESCO databases or the National Archives.

Multi-period construction layers are a unique feature of our system, documenting sites with construction from multiple historical periods, which is not supported by any of the compared systems.

C. Limitations

Despite its comprehensive design, several limitations must be acknowledged. Data completeness is incomplete, particularly for the medieval period (10th-14th c.), with an estimated 15-20% data missing. Geocoding accuracy varies – overall 94.7% within 50m, but rural sites have errors up to 200m. Language coverage is optimized for Bulgarian and English; support for Greek, Ottoman Turkish, and Latin would improve accessibility for medieval and Ottoman sources. Real-time updates are not supported – manual updates create integration delays; automated ETL pipelines are planned. Scalability is a concern: testing with 50,000+ sites shows an 1108% increase in query time, indicating the need for horizontal scaling for national or international expansion.

D. *Lessons Learned*

The development and implementation of this system provided several valuable lessons that may inform similar projects.

The Importance of Spatial Indexing cannot be overstated. GiST indexes were critical for achieving acceptable performance, providing a 60% improvement in spatial query response times. This underscores the necessity of proper database optimization in spatial applications.

Materialized Views proved to be highly effective for performance optimization. Pre-computed views for common queries delivered a 40% improvement, significantly enhancing the user experience for frequently accessed data.

Connection Pooling in production deployment was essential for handling concurrent users, providing a 25% improvement in overall performance. This highlights the importance of considering production deployment requirements during the design phase.

Data Quality emerged as a critical success factor. Manual validation remains essential, as automated methods alone achieved only 92% accuracy, which improved to 98.3% with expert validation. This suggests that hybrid approaches combining automated processing with expert oversight yield the best results.

API Design requires careful consideration of research use cases. A RESTful API with comprehensive filtering options proved essential for supporting diverse research workflows. This suggests that API design should be informed by user requirements analysis.

E. *Future Extensions*

Several future directions have been identified. Machine Learning Integration will enable automated classification of architectural periods using CNNs (ResNet-50), reducing manual annotation effort. Predictive Modeling will predict cultural change based on historical patterns, with applications in policy, education, and preservation planning. Public API with authentication will provide open access for researchers and educators. Mobile Application with offline capabilities will enable real-time field data collection. Linked Data integration with Europeana and other platforms will enable cross-platform queries. Automated ETL pipelines will address the current manual update limitation through scheduled updates.

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