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Querying CityGML Data through Virtual Knowledge Graphs

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Abstract:

CityGML (Gröger *et al*. 2012) is a widely adopted standard by the *Open Geospatial Consortium* (OGC) for the representation and exchange of 3D city models. It defines the three-dimensional geometry, topology, semantics, and appearance of the most relevant topographic objects in urban or regional contexts. The representation of semantic and topological properties makes it possible to query such 3D city data to perform analysis in various applications. However, the potential of query answering over CityGML data has not been fully exploited. The official GML/XML encoding of CityGML is only intended as an exchange format but is not suitable for query answering. The most common way of dealing with CityGML data is to import them into the 3DCityDB system as relational tables and then query with the standard SQL query language. One limitation of this approach is that it is not compliant with Knowledge Graph standards, and thus it is difficult to interoperate with other open Knowledge Graphs (e.g., Wikidata, DBPedia). There have been early attempts to convert CityGML to knowledge graphs (Chadzynski *et al.* 2021), which uses a straightforward ad-hoc implementation.
In our previous work (Ding *et al.* 2022), we have described the *CityGML VKG framework* to expose the 3DCityDB as a Virtual Knowledge Graph (VKG) (Xiao *et al.* 2019). In this framework, a VKG specification (i.e., an ontology and a mapping) is used as input to the popular VKG system Ontop (Calvanese et al., 2017) to expose the underlying CityGML data as a VKG. This VKG can be queried using the standard SPARQL query language. We have also shown the feasibility by a minimal proof-of-concept system (Ding et. al 2022). In this work, we significantly extend this implementation and demonstrate some interesting queries.
Test data. We use the CityGML building 3D model data at LoD2 of the municipality of Tartu, Estonia[1] from 2022 as test data (Figure 1). The GML file has a size of 300MB and comprises 20742 buildings.
Virtual Knowledge Graph Specification. We adopt the CityGML ontology[2] created by the University of Geneva. We have developed a suitable R2RML mapping to 3DCityDB using the ontology editor Protégé with the Ontop plugin. We extended the 4 mappings from the previous implementation to 161 mappings, which now cover most of the classes of the CityGML ontology.

[1] https://geoportaal.maaamet.ee/eng/Download-3D-data-p837.html
[2] http://cui.unige.ch/isi/onto//citygml2.0.owl

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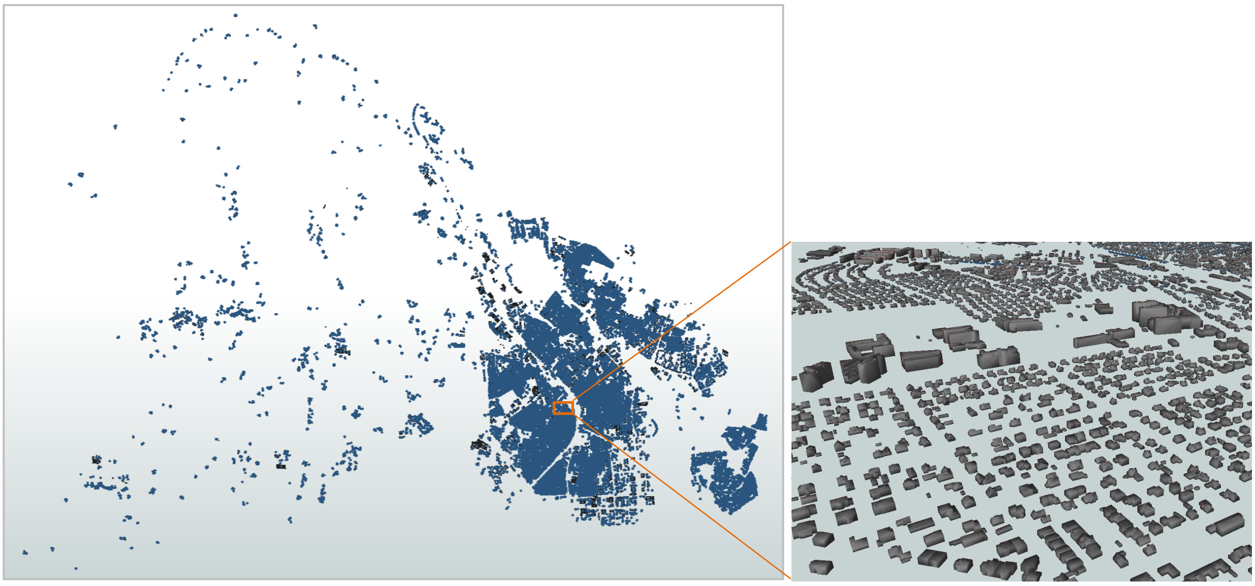

Figure 1. The test 3D building data of the municipality of Tartu (left) with a small area enlarged (right).

Example queries. Based on the ontology and mappings, we could formulate and execute more complex queries. Two example queries are shown in Figure 2. The first query (Figure 2 left) retrieves buildings with height over 40 meters. The second query (Figure 2 right) retrieves building solids and their addresses, and orders the results by the number of surfaces on the building solids. This query is more complicated and uses aggregation operations. Regarding the results from the second query, we found that the building with the address "Ludvig Puusepa tänav 8" is the most complicated building regarding the number of surfaces (with 640 surfaces) and refers to the Tartu University hospital. The second most complicated building at "Ringtee tänav 75a" (with 483 surfaces) refers to a big shopping mall.

Figure 2. Two example queries. The first query (left) retrieves buildings with height over 40 meters and the second one (right) retrieves all surfaces of buildings ranked by the number of surfaces on the building solids.

Conclusions. We have extended the work of Ding et. al (2022) for exposing CityGML data as a VKG by enriching the mappings significantly and testing more complicated queries on a larger test area (from one university campus to one city). In the future, we will extend the coverage of the mapping, integrate other datasets into the VKG (e.g., digital landscape model data), and apply the technology in real-world applications. Moreover, we would like to develop intuitive visualizations for understanding the queries and query results using specific techniques, e.g., cartographic representations.

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