Indoor Navigation Linked Data at Óbuda University

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***Abstract*— Publishing information about university buildings in Linked Data format allows the information to be freely consumed and aggregated with other data sources, filtered and delivered via multiple channels and devices to potential users: students, lecturers and visitors of universities. In this paper the loc ontology for indoor navigation is introduced and its usage is demonstrated in publishing the Óbuda University indoor data as LOD. Best practices for indoor modeling of a building is presented and the possible use of the data is demonstrated by outlining some SPARQL queries for the navigation features of future applications.**

I. Introduction

The principles of Linked Open Data are related to publishing and interlinking structured data on the Web so that computers can read it automatically. This method enables that data from different sources can be connected and queried. The Linked Data concept was- invented by Tim Berners-Lee in 2006 and is based on the following four principles [1]:

1. Use URIs as names for things
2. Use HTTP URIs, so that people can look up those names
3. When someone looks up a URI, provide useful information, using the standards (RDF, SPARQL)
4. Include links to other URIs, so that they can discover more things

The 4th principle ensures that there are links within different datasets. The standard data model for Linked Open Data is the Resource Description Framework (RDF). In RDF data is structured in triples in the form of subject, predicate and object, which is called a statement. The predicate specifies how the subject and object are related. The subject and the predicate are both URIs and the object is a URI or a string literal. SPARQL is an RDF query language, designed to retrieve and manipulate data stored in RDF format. Linked Data builds links between arbitrary things described in RDF. In RDF, URIs identify any kind of object or concept.

The use of Linked Data is growing and appearing in more and more domains, including the use cases of higher education as well. Linked Universities [2] and Linked Education [3] are two European initiatives that appeared to enable education with the possibilities of Linked Data.

The objective of this paper is to support the implementation of Smart Universities by generating indoor navigation data of the Óbuda University as Linked Data. In order to achieve our goal we defined the following partial objectives:

- to develop a data model in the form of ontology that supports the indoor location description and free-text type navigation features,
- to describe the generation of indoor navigation data at Óbuda University as LOD according to the ontology,
- to provide best practices for indoor modeling of a building,
- to demonstrate the possible use of the above data by presenting SPARQL queries for enabling the navigation.

The rest of the paper is organized as follows. In Section 2 we describe research fields that are related to the topic. In Section 3 the developed ontology is presented, in Section 4 the method of indoor navigation linked data generation is analyzed. Section 5 shows examples for SPARQL queries using the ontology and the generated data. Section 6 provides some conclusive remarks.

II. Related Work

There are already several universities in Europe that publish university open data as LOD [2]. The Open University in the UK was the first one that created a linked data platform to publish information from its departments [4, 5] as LOD. This platform is now the key information service at the Open University, with several applications and websites exploiting linked data through it. The Open University datasets are classified in the following six groups: Open Educational Resources, Scientific production, Social media, Organizational data, Research project output, Metadata. As far as we know there is no university publishing indoor navigation data in linked data form until now.

Constructing Linked Data requires well designed vocabularies, schemas or ontologies. There were several attempts already to provide indoor navigation ontologies. Worboys [6] provides a thorough overview of the state of the art, and defines a top level taxonomy to classify indoor models into semantic and spatial categories. Semantic indoor space models represent entity types, their properties and relationships. Topological models are concerned with the connectivity within a space. Geometrical models add quantification of distance and finally hybrid or multilayered models provide combined features of all the above.

OntoNav [7] is a semantic indoor navigation system and an ontological framework of handling routing requests. OntoNav navigates the users inside floors and buildings, but it does not provide navigation instructions within rooms, while in case of a large hall with many entrances it is useful to have routes inside the hall as well.

ONALIN [8] provides routing for individuals with various needs and preferences; it takes the ADA (American Disability Act) standards, among other requirements, into consideration. Buildings are modeled as hallway networks, and feasible routes can be identified for users having specific constraints. Geodint [9] uses standard shortest path algorithm in a derived graph model for navigation

None of the above ontologies is accessible at the moment of writing this paper, however some parts of the conceptual semantic model were reused from these earlier work inspiring the hierarchy of the *loc:Location* class.

III. ONTOLOGY

In the first phase of the work a data model was developed supporting the description of the indoor location data and the possibility of free-text type navigation. As we proposed to apply Linked Data principles to publish the indoor location data, the data model was created in the form of ontology, where the aim was to provide the indoor location description and navigation features. In the process of the ontology development the guidelines described in [2] were used, aiming to design a 4-star vocabulary.

In this section specification of the *loc* ontology is presented, including the class definitions, the properties of the entities of the classes and the relationships between classes (the parent-child relations between two classes). The documentation of the ontology can be found at http://lod.nik.uni-obuda.hu/oloud-indoor. The overview of the classes and properties is shown in Figure 1. External class is marked with dashed line, dotted arrows mark the subclass relationships. Classes are represented as ovals, properties as arrows. The ontology uses the prefix *loc*.

The *Location* class is used to represent all the necessary entities describing indoor locations. It has three direct subclasses Building, Building Part and POI. Entities of the *Building* class have internal structure that the ontology aims to describe. *BuildingPart* provides an abstract concept to the different parts of the internal structure of a building. It has two subclasses: *Floor* and *Room*. The Room class has further subclasses that give more precise classifications of the entities, like Hallway, Lab, Office or LectureHall. These subclasses are not used in navigation; they can be used as custom filters to get a list of specific type of rooms. The Room class has a special subclass: *VerticalPassage*, which has two further subclasses: *Stairway* and *Elevator*. The VerticalPassage instances connect Floors, which can be exploited in the simpler form of our navigation methods.

The *POI* (Point of Interest) class has significant role in the navigation, as its entities constitute the elements of a classical indoor route. The *POI* class has one subclass: Entrance, which is further specified as *RoomEntrance* and *BuildingEntrance*. The Entrance instances have the special meaning of defining the connections between rooms or the entry point to buildings.

The *isPartOf* object property expresses hierarchical structural relationship in the ontology, e.g. a specific Room entity can be in *isPartOf* relation with a specific Floor entity, or a specific Floor entity with a Building entity. The *connectsPOI* describes a direct route between two POI instances, and a consecutive sequence of such direct routes generates a possible navigation between two POIs. The *hasPOI* property and its inverse property *belongsToRoom* express POI and Room relationships, a specific Room entity contains a given POI entity.

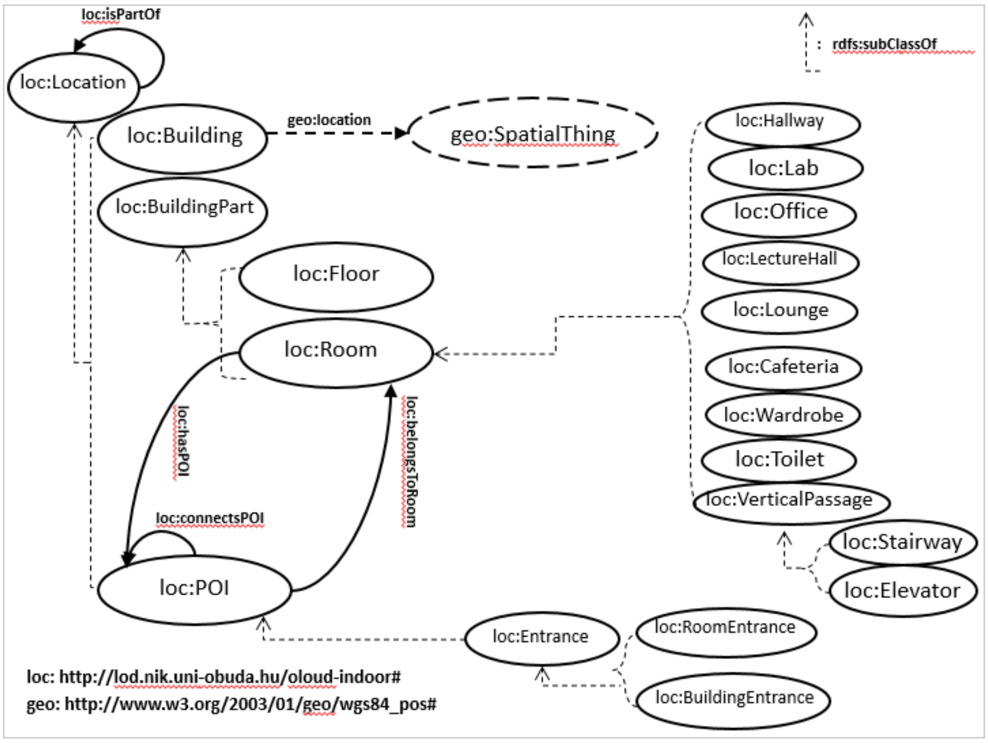

Figure 1. The overview of the loc ontology

In the process of ontology development the aim was to provide the indoor location description and navigation features. The ontology supports two levels of verbal indoor path description: The first option is based on the structure of the building (and based on the loc:isPartOf property) and provides simple instructions like „Enter the main building. Go to the 2nd floor. Look for Room 212.” The second option builds on the top of the structural description, introducing special points in the space: „Point of Interest (POI)”. The route one can choose to navigate through is a network of POIs within the building. The second approach is more aligned to instructions one would expect asking someone familiar with the building: „Enter the main hall. Pass the coffee machine. Go to the elevator. Go to the 2nd floor. Pass the restrooms. Look for Room 212.” While the second approach allows more accurate navigation, there is the extra cost of modelling the POI network compared to the first approach.

IV. Generating indoor navigation data as LOD

The indoor navigation RDF data of the Óbuda University was generated manually, since only the maps of the building floors in jpg form were available as the base of the work. First the BuildingPart (Room and Floor) class entities were recorded, like Labs, Lecture Halls, Hallways, Stairways, Elevators and Floors. The relevant Room entities are in loc:isPartOf property with the relevant Floor entities, except for the Vertical Passage entities, which are in loc:isPartOf property with the relevant Building entity.

The following excerpt describes the Building and some BuildingPart entities. In the description of the data besides the loc ontology, the geo, vcard and rdfs are also used.

```
@prefix : <http://lod.nik.uni-obuda.hu/data/> .
@prefix loc: <http://lod.nik.uni-obuda.hu/oloud-indoor#> .
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#> .
@prefix
geo:<http://www.w3.org/2003/01/geo/wgs84_pos#> .
@prefix vcard:
<http://www.w3.org/2006/vcard/ns#> .
:360a a loc:Hallway ;
        loc:isPartOf :Third_floor_oe_building .

:E70 a loc:Elevator ;
        loc:isPartOf :OE_Main_Building .

:Office_307 a loc:Office ;
        rdfs:label "307 iroda"@hu ;
        loc:isPartOf :Third_floor_oe_building .

:OE_Main_Building a loc:Building ;
        rdfs:label "OE Main Building"@en ;
        geo:location :AddressOE .

:AddressOE a geo:SpatialThing , vcard:Work ;
        vcard:postal-code "1034" ;
        vcard:street-address "Bécsi út 96/B" ;
        vcard:hasLocality :Budapest ;
        vcard:hasCountryName :Hungary .
```

The next step was the planning and implementation of the POI network. The POI network is a graph with POI vertices. There is an edge between two POIs if the route between them can appear in the navigation. In the process first the POI entities were drawn and connected with each other by hand on the map. The complexity of this task required to work out a methodology to achieve the goal. In the following the main steps of the POI network modeling are described:

- POIs should exist at Room entities entrances, at stairway and elevator exits, at building entrances. In most cases there should be a POI at each stairway exit. Exceptions might occur at short stairways, where only one POI might be enough.
- When defining Hallway entities the larger hallway spaces should be divided up to smaller ones in such a way, that one is able to see all POIs of a certain Hallway entity nearby. It means, that a route between two POIs of the same Hallway entity is taken for granted, so it will not be computed. This point ensures that the computed route does not contain obvious route descriptions, so is not unnecessarily long. Figure 2 shows the result of this step in case of the third floor hallway, which is divided into four parts (360a, 360b1, 360b2, 360c).
- In each Hallway entity there should be a central POI acting as a POI-hub, which will provide the connections to the POIs of the surrounding rooms in the same Hallway entity. So in the graph the POI-hub is connected with all POIs belonging to the same Hallway entity. In some cases, a secondary hub can be also very practical. Entrances to Vertical Passages are good POI-hub candidates. Figure 3 shows the POI-hub structure in Hallway class entity 360a.

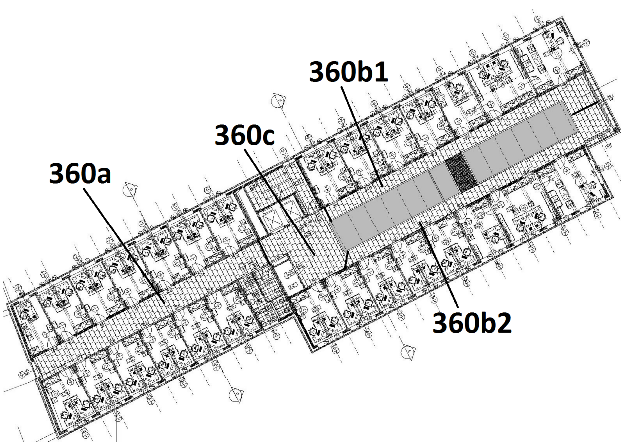

Figure 2. Hallway entities on the third floor

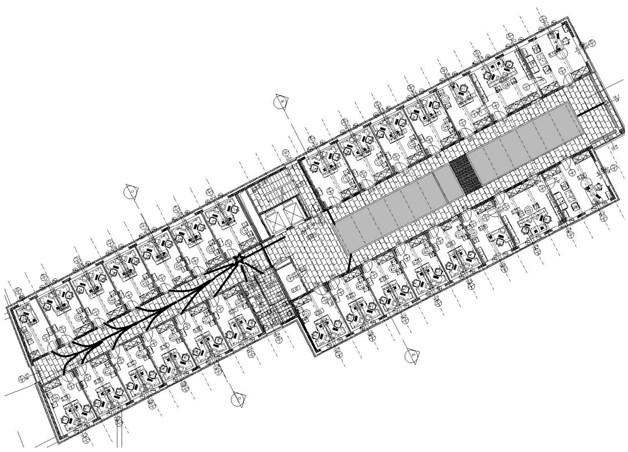

Figure 3. POI-hub in Hallway entity 360a

- The POI-hubs are acting as major decision points in the traversal. When planning the POI network first the POI-hubs should be connected with each other. Then if necessary some other POI-POI connection should be also included in the POI network. This step is illustrated on Figure 4.
- Staircases connect different floors, but sometimes large auditoriums also have doors to different floors. In this sense the floor level of a room can be ambiguous.
- A stairway or elevator exit POI should be connected with all other exit POIs belonging to the same Stairway or Elevator entity. This optimizes the route generation time in the navigation process.

The following excerpt describes the P302 hub-POI instance, which belongs to Office 307 and has a photo assigned to it with the foaf:depiction property.

```
@prefix : <http://lod.nik.uni-obuda.hu/data/>
@prefix loc: <http://lod.nik.uni-obuda.hu/oloud-indoor#> .
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#> .
@prefix foaf: <http://xmlns.com/foaf/0.1/> .
.:P302 a loc:POI ;
        rdfs:label "Office_307 entrance"@en ,
"307 iroda bejárata"@hu ;
        rdfs:comment "Starpoint" ;
        loc:belongsToRoom :360a , :Office_307 ;
        loc:connectsPOI :P301 , :P303 , :P304 ,
:P305 , :P306 , :P307 , :P308 , :P309 , :P310 ,
:P311 , :P312 , :P313 , :P314 , :P315 , :P316 ;
        foaf:depiction <http://lod.nik.uni-obuda.hu/indoor/POI/Office_307.jpg>.
```

The validity of the indoor location data and its conformance to the ontology were tested by Protégé. The data can be reached from the SPARQL endpoint of the Óbuda University (http://lod.nik.uni-obuda.hu/marmotta/). The data is organized in the named graph http://lod.nik.uni-obuda.hu/graphs/indoor-locations. The dataset contains 1755 RDF triples. The LOD server hosting the indoor navigation data of the Óbuda University runs Apache Marmotta [11]. During the project experiments were made also with Apache Fuseki [12].

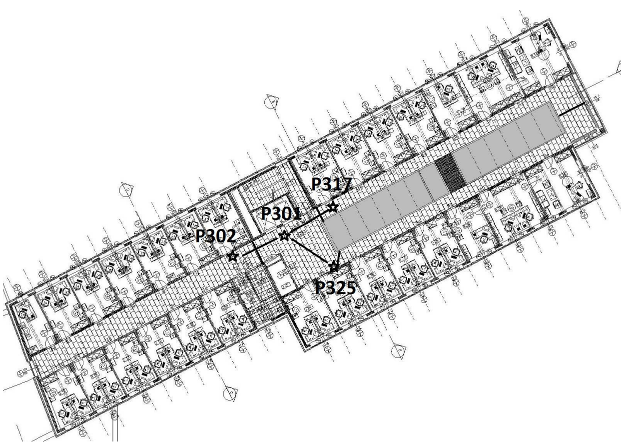

Figure 4. Connecting POI-hubs on the third floor

V. USAGE EXAMPLES

The objective of publishing indoor location data as LOD is to support the development of mobile and web applications using this dataset. In this section example SPARQL queries are presented to demonstrate the way of querying data that application exploiting the dataset can use.

The first query returns the list of Room instances, that the user can choose from to determine the start and end of the route planning:

```
prefix loc: <http://lod.nik.uni-obuda.hu/oloud-indoor#>
prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#>
SELECT DISTINCT ?label ?room WHERE
{
  OPTIONAL{?room rdfs:label ?label.}
  FILTER (EXISTS { ?room a loc:Toilet } ||
          EXISTS { ?room a loc:Office } ||
          EXISTS { ?room a loc:LectureHall } ||
          EXISTS { ?room a loc:Wardrobe } ||
          EXISTS { ?room a loc:Cafeteria } ||
          EXISTS { ?room a loc:Lab })
  FILTER(LANG(?label) = "en")
}
```

The following query generates the list of POIs that belong to a given Room instance. Querying the navigation route, the user can choose from this list to determine the start or the destination point.

```
prefix loc: <http://lod.nik.uni-obuda.hu/oloud-indoor#>
prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#>
SELECT DISTINCT ?poi ?label WHERE {
  BIND (<room1> AS ?start) .
  ?poi loc:belongsToRoom ?start.
  ?poi rdfs:label ?label.
  FILTER(LANG(?label) = "en")
}
```

As described in the previous section before calculating the route between two points, it must be examined whether they belong to the same Hallway class instance (if so the route is not computed). The following ASK query returns the Boolean value for this question:

```
prefix loc: <http://lod.nik.uni-obuda.hu/oloud-indoor#>
prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#>
ASK WHERE {
  BIND (<room1> AS ?start) .
  BIND (<room2> AS ?end) .
  ?p1 loc:belongsToRoom ?start .
  ?p2 loc:belongsToRoom ?end .
  ?p1 loc:belongsToRoom ?z .
  ?p2 loc:belongsToRoom ?z .
  ?z rdf:type loc:Hallway .}
```

The *loc* ontology supports free-text type indoor navigation in two levels. The first level uses the structure of the building and is based on the *loc:isPartOf* property. The following SPARQL query can be used to select a route between two rooms. The query builds on the loc:isPartOf property hierarchy, the ?helptext variable contains information about the floor matching of the start and destination floors.

```
prefix loc: <http://lod.nik.uni-obuda.hu/oloud-indoor#>
```

```
prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#>
SELECT DISTINCT ?helptext ?sl ?fl1 ?fl2 ?el where {
  BIND (<room1> AS ?start ).
  BIND (<room2> AS ?end).
  OPTIONAL {?start rdfs:label ?sl. FILTER(LANG(?sl) = "en" ).}
  OPTIONAL {?floor1 rdfs:label ?fl1. FILTER(LANG(?fl1) = "en" ).}
  OPTIONAL {?floor2 rdfs:label ?fl2. FILTER(LANG(?fl2) = "en" ).}
  OPTIONAL {?end rdfs:label ?el. FILTER(LANG(?el) = "en" ).}
  ?start loc:isPartOf ?floor1.
  ?end loc:isPartOf ?floor2.
BIND (if( ?floor1 = ?floor2 , "start and end at same floor", "start and end at different floors") AS ?helptext) .
}
```

The second level of the navigation builds on the special navigation points in the space, the Points of Interest (POI) and their network. One POI instance is connected to one or multiple other POI by the loc:connectsPOI property. The start and the destination of the navigation route might be a Room or a POI class instance. The loc:belongsToRoom and loc:hasPOI properties are responsible to connect the Room instances to the POI network by the nearby or including POIs. The following is an example SPARQL query to select the shortest (least intermediate steps) route between two rooms in the same or different building (with maximum length of 3 steps for brevity):

```
prefix loc: <http://lod.nik.uni-obuda.hu/oloud-indoor#>
prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#>
SELECT ?distance ?sl ?l1 ?l2 ?l3 ?el WHERE {
  BIND (<room1> AS ?start ).
  BIND (<room2> AS ?end).
  OPTIONAL {?start rdfs:label ?sl.}
  OPTIONAL {?p1 rdfs:label ?l1.}
  OPTIONAL {?p2 rdfs:label ?l2.}
  OPTIONAL {?p3 rdfs:label ?l3.}
  OPTIONAL {?end rdfs:label ?el.}
  ?p1 loc:belongsToRoom ?start.
  ?p1 loc:connectsPOI ?p2.
  ?p2 loc:connectsPOI ?p3.
  ?plast loc:belongsToRoom ?end.
  FILTER (?p3 = ?plast || ?p2 = ?plast || ?p1 = ?plast )
BIND ((if( ?p3 = ?plast , 3, if( ?p2 = ?plast , 2, if( ?p1 = ?plast , 1, -1)))) AS ?distance)
} ORDER BY ?distance LIMIT 1
```

VI. CONCLUSION AND FUTURE WORK

In this paper we presented a new ontology for indoor navigation in universities. The ontology defines classes, properties and relationships between classes to enable verbal indoor path description. We demonstrated the use of this ontology by describing the generation of indoor location data of the Óbuda University building as LOD. Furthermore the methodology is described that was used in the process of indoor modeling of the university building. This methodology can provide best practices for the indoor modeling of other type of buildings as well. Finally we demonstrated the possible use of the data by presenting SPARQL queries on it, that future application can build on to provide navigation features.

The run time of the SPARQL query calculating the shortest route between two places was tested using Apache Marmotta and Apache Fuseki LOD servers. The results of the tests revealed that the number of POIs in the route is limited to a specific number (e.g. in case of Apache Marmotta 7) if we want to get an acceptable response time. In the future we want to evaluate Virtuoso [13] as well, as its custom extension for property transitivity could fit the task well. In standard SPARQL 1.1 one cannot get the length of the property path, which would be very useful in this case. Virtuoso might be faster regarding the response times in finding routes, but then we need to use its non-standard extensions.

In the future the *loc* ontology can be extended to provide navigation features for people with special need or description possibilities for restricted areas (e.g. requiring a special card to enter). Another possible extension point is to generalize subclasses of Room and POI classes by introducing a property which can point to room and POI categories defined in DBpedia or in other LOD datasets.

The architecture of the POI network could be extended by using QR codes in the building. QR codes provide a low-cost opportunity to connect the real life POI with the URI it is representing. At each POI location there could exist a QR code on the wall. The QR code encodes the URI of the POI and by scanning it in the indoor navigation app, the location can be immediately determined and used for the starting point of the navigation.

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