**AccessKB: Linked Open Data for Accessible Travel**

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**Abstract.** Recent developments in Information Communication Technologies and digital map services have empowered aspects of digital inclusion. These developments can benefit people with disabilities with an increasingly wider range of information regarding accessible travel. However, accessibility data collection and management is one of the grand challenges in the field of research relating to accessible map information and travel. Most research projects in this area are still in the early stages of development, leading to difficulties in the provision of sufficient data about the barriers encountered by people with disabilities. This results in time-consuming searches for physical accessibility data. For instance, those with mobility impairments using public transport, public places, services and facilities may wish to search for step free access and an accessible toilet. This paper presents an approach for accessibility data management and modelling, by introducing the AccessKB, a Linked Data-driven knowledge base designed for barrier-free or accessible travel.

**Keywords:** Linked Data *·* open accessibility data *·* accessible travel *·*

decision support system.

# Introduction

According to the Family Resources Survey 2018/19 (FRS)[1](#_bookmark0), there were 14.1 mil- lion (21%) of the people reported with a disability in 2018/19, an increase from

11.3 million (19%) in 2008/09. Mobility impairments were the most prevalent mentioned in the report, accounting for 48% of the total number of those with disabilities. This is where an individual’s mobility is affected due to a functional or structural issue that causes activity limitations or difficulties [ref]. Independent travelling for people with disabilities remains one of top difficulties. This is not just because there has always been a large sector of the population who have mobility impairments. More recently this has been caused by the complexity of modern public transport, inaccessible transport hubs, facilities and services, and the absence of accessibility information about these facilities or services. Moreover, research has shown that it can be very time consuming and financially costly for those with

1 [https://www.gov.uk/government/statistics/family-resources-survey-](https://www.gov.uk/government/statistics/family-resources-survey-financial-year-201819) [financial-year-201819](https://www.gov.uk/government/statistics/family-resources-survey-financial-year-201819)

mobility impairments to find relevant accessibility information.

Jon E. Froehlich et al’s [[3]](#_bookmark7) interdisciplinary research in the area of Information Communication Technology (ICT) and digital services, concluded that there were five grand challenges in the area of accessible map development. These included data collection, data management, modelling, accessible maps and user foci. An example of one of these challenges has been the development of applications such as ‘wheelmap.org’ using crowdsourcing to improve data quantity. However, it was felt that the application often failed to provide quality data [[2].](#_bookmark5) Therefore, as a linked open data knowledge base for accessible travel, AccessKB aims to manage accessibility, as well as model accessibility needs. The goal being to contribute to the research of accessible map information development by providing barrier free travelling decision support, for individuals who find getting around public transport hubs, onto the services and using the systems a struggle, both financially and physically.

# Related Works

As discussed above, accessible travel has been listed as one of top difficulties for people with mobility disabilities. There have been a limited number of research projects working on these fundamental challenges. ASK-IT project [[1]](#_bookmark6) was one of early projects that combined activity theory with content modelling to improve the travelling experience for people with mobility disabilities. User groups were categorized into different groups: lower limb impairment, wheelchair users, upper limb impairment, upper body impairment, physiological impairment, psychological impairment, cognitive impairment, vision impairment, hearing impairment, and communication production/receiving impairmen[t [8].](#_bookmark12) AEGIS [[6]](#_bookmark10) was another project, which used an ontology to model and integrate accessible information between users and devices. Once again, the application developers categorized users by different groupings. The modelling was based on their special needs and interactions, namely users with visual, hearing, motion, speech and cognitive impairments, O[ASIS [7]](#_bookmark11) established an open ontology driven architecture to integrate and standardize accessible services to benefit the quality of life of all aged people. Most importantly, this project proposed a hyper-ontology approach that could match determine correspondences between concepts with other ontologies from different domains.

In summary, one of the challenges exposed by these projects has been data availability. It has always been difficult to find publicly available, high quality and structured data sets that also contain accessibility data. Additionally, the projects mentioned were also faced with the challenge of data reusability and interoperability. There remain no standard guidelines for accessibility data, no examples of metadata to annotate accessibility data, or standard data models to represent the accessibility data. Furthermore, it has been difficult to link the requirements of disabilities with the facilities by using ontology reasoning and inference. Therefore, it is felt that the use of Linked Data principles to accessibility data provides a fundamental improvement in data collection, management and accessibility modelling.

# Methodology

In order to construct the knowledge base for accessible travel, it is important to understand the accessibility requirements of people with mobility disabilities. The method applied in this research was based on the study conducted by M. Wiethoff et al. [[8],](#_bookmark12) which combined the Activity Theory and International Classification of Functioning, Disability and Health (ICF) code. As presented in Table [1,](#_bookmark1) functional difficulties and activity limitations in travelling scenarios can be classified into different functional categories: (1) lower limb limitations, (2) user with upper limb limitations, (3) upper body limitations. Each category contains its own subcategories.

**Table 1.**Classification of mobility difficulties and limitations

|  |  |  |
| --- | --- | --- |
| Category | Sub-Category | Limitation Description |
| Lower Limb  Limitations | Light Walking Limitations | Can walk 1*/*4 mile but not more distance  and can climb 10 steps without rest |
| Severe Walking Limitations | Very difficult or cannot walk 1*/*4 mile or  very difficult or cannot climb 10 steps |
| Wheelchair (Manual) | Use manual wheelchair |
| Wheelchair (Power) | Use the powered wheelchair |
| Upper Limb  Limitations | Upper Limb Limitations | Only one upper limb functionalities or  both weak upper limbs functionalities, or no upper limb functionalities |
| Upper Body  Limitations | Light Upper Body Limitations | Weak upper body functionalities |
| Severe Upper Body Limitations | Very week or no upper body functionalities |

## Requirements Study

Moreover, in order to model accessibility requirements, there was an online sur- vey conducted to study the user requirements for accessible travelling data. People with mobility impairments having difficulties with public transport were asked to take part in the survey via an online website, social networking, a mailing list of interested groups and personal interviews. The questionnaire used a 4-point Likert Scale for candidate’s answers to the proposed questions (i.e. 4=Strongly Agree, 3=Agree, 2=Disagree, 1=Strongly Disagree). Overview, there were 48 valid participant responses. 23% of the respondents were aged between 18 to 35 years old and 77% of the respondents were 36 to 64 years old. Based on the statistical analysis of the result, the most important accessible facilities in the transport hubs, such as train stations were: a lift to all areas (90.32%), an accessible entrance (87.10%), road slope to the place (83.87%), the road surface to the place (83.33%), accessible car park around the building (83.33%) and accessible toilets (80.65%). For those questions on accessibility requirements for public transport such as a bus or tram, the most important accessible facilities were: ramp access (93.33%), accessible interchange (83.33%), accessible ticket machine (80.00%), accessible toilet (76.67%), and personal assistance (73.33%).

As a conclusion, the analysis of this requirement study for accessible travel for those with a range of mobility impairments provided the evidence to aid the development of the ontologies and reasoning rules; thereby contributing to the development of the final knowledge base.

## Ontologies for Accessible Travel

An ontology is the “formal, explicit specification of a shared conceptualization” [[4].](#_bookmark8) Applying an ontology for an accessibility requirement specification process was proposed by Van [Heijst[5]](#_bookmark9) and there have several projects that have applied similar approaches, such as the framework proposed by the AccessOnTo project to integrate the standard checklist into the requirement specification [[9],](#_bookmark13) WTO-ICF Ontology and ASK-IT On[tology[8].](#_bookmark12) However, none of these ontologies fully met the requirements for accessible travel. Therefore, some ontologies were proposed and constructed based on the aforementioned requirement’s study, namely, a mobility difficulty, ontology, place accessibility ontology and transport accessibility ontology. Furthermore, a list of core vocabularies and ontologies were used in the accessible travelling domain (presented in Table [2),](#_bookmark2) such as FOAF (friend of a friend) ontology, Geo Ontology, Simple Knowledge Organization System (SKOS) Schema, Places Ontology and spatial relations.

**Table 2.**Ontologies for accessible travel domain

Core Ontologies

|  |  |
| --- | --- |
| Ontology | Namespace |
| FOAF | <http://xmlns.com/foaf/0.1/\cdot> |
| geo | [http://www.w3.org/2003/01/geo/wgs84\_pos#](http://www.w3.org/2003/01/geo/wgs84_pos) |
| SKOS | [http://www.w3.org/2004/02/skos/core#](http://www.w3.org/2004/02/skos/core) |
| Schema | <http://schema.org/> |
| Places Ontology | [http://purl.org/ontology/places#](http://purl.org/ontology/places) |
| Spatial relations | [https://www.ordnancesurvey.co.uk/docs/](https://www.ordnancesurvey.co.uk/docs/ontologies/spatialrelations.owl) |
|  | [ontologies/spatialrelations.owl](https://www.ordnancesurvey.co.uk/docs/ontologies/spatialrelations.owl) |

Proposed Ontologies

|  |  |
| --- | --- |
| Ontology | Namespace |
| Mobility Difficulty Ontology  Place Accessibility Ontology Transport Accessibility Ontology | [http://purl.org/net/ontology/modo#](http://purl.org/net/ontology/modo) [http://purl.org/net/ontology/paco#](http://purl.org/net/ontology/paco)  [http://purl.org/net/ontology/taco#](http://purl.org/net/ontology/taco) |

**The Mobility Difficulty Ontology (MODO)** aimed to be a lightweight ontology to model users’ categorization of concepts based on their mobility limitations and their difficulties accessing public transport generally. This ontology applied Negative Property Assertion Pattern (NPAs) to distinguish the categories of mobility limitations. Although, built-in OWL2 (Web Ontology Language), negative object property assertions were not reasoning with the Semantic Web Rule Language (SWRL) so one of proposed solutions was to apply the reasoning rule in the data querying phase, where the SPARQL1.1 was support the negation feature.

For example, there were two negative object property assertions applied in *Category NNL*(No-Upper-Limb-Limitation, No-Upper-Body-Limitation, Light-Walking-Limitation) class to validate the ontology consistence, which could be represented as following SWRL rules: information of physical places and built environment.

*'→* lowerLimbLimitation) -> CategoryNNL(?p)

*'→* p,?lowerLimbLimitation)^LightWalkingLimitation(?

*'→* ubl)^UpperBodyLimitation(?ubl)^hasLowerLimbLimitation(?

*'→* UpperLimbLimitation(?ull)^hasNoUpperBodyLimitation(?p,?

Person(?p)^hasNoUpperLimbLimitation(?p,?ull)^

**Place Accessibility Ontology (PACO)** was used to model the accessibility. There were a list of existing ontologies used to model places, buildings and spatial things, such as Places ontology, ifcOwl ontology and LinkedGeoData ontology. However, if-cOWL was a formal description of the Building Information Modelling (BIM) data, which was extremely complex for usage in the accessible travelling domain. Places ontology was a lightweight ontology to describe geographical places and reused as intended, to describe places or buildings of interest. LinkedGeoData was the Linked Data version of Open Street Map, which was used as a geographical reference. *Place* class in PACO ontology was equivalent to *schema:Place* in Schema vocabulary. And *Building* class was the subclass of the class *geo:SpatialThing*. Two other primary classes *Facility* and *Service* were presented with the following syntax:

*'→* subClassOf(Room, BuildingPart)

-> spatialrelations:contains (Building, Room)

*'→* subClassOf(Floor, BuildingPart)

-> spatialrelations:contains (Building, Floor)

spatialrelations:contains (Building, BuildingPart)^rdfs:

*'→* subClassOf (Entrance, BuildingPart)

-> spatialrelations:contains (Building, Entrance)

spatialrelations:contains (Building, BuildingPart)^rdfs:

spatialrelations:contains (Building, BuildingPart)

rdfs:subClassOf (Entrance, BuildingPart) rdfs:subClassOf(Floor, BuildingPart) rdfs:subClassOf(Room, BuildingPart) spatialrelations:contains (Building, BuildingPart)^rdfs:

**Transport Accessibility Ontology (TACO)** was the transport accessibility ontology built on top of The Linked General Transit Feed Specification (GTFS)[2](#_bookmark3) vocabularies, which was mapped from the GTFS to the Resource Description Framework (RDF). Therefore, the TACO ontology reused Linked GTFS ontologies and imported the PACO ontology to describe the accessibility information of physical places in the public transport domain, such as the stations, stops, and terminals.

2 [http://vocab.gtfs.org/terms#](http://vocab.gtfs.org/terms)

Moreover, class like *Facility* and *Service* were designed to describe on board accessibility facilities and services such as AccessibleSeat, AccessibleTable and AccessibleToilet and PersonalAssistance. TACO also reused accessibility related vocabularies in the Linked GTFS ontology, *WheelchairBoardingStatus* class, which represented the different status of wheelchair boarding.

# Data Publishing and Reasoning

The previous section demonstrated the study of the accessibility requirements for people with mobility impairments. The ontologies for accessible travel were also introduced to address the urgent need for quality data collection, management, and accessibility modeling in the research area of accessible travel. This section introduces the publication methods for the accessibility data as the AccessKB by applying the proposed ontologies. In order to publish the users’ specifications as Linked Data, the syntax below has been provided as an example: *Person 1* with the following limitations: no upper limb limitation, no upper body limitation and has light walking limitation.

PREFIX [rdf:<http://www.w3.org/1999/02/22-rdf-syntax-ns#>](http://www.w3.org/1999/02/22-rdf-syntax-ns) PREFIX [modo:<http://purl.org/net/ontology/modo#>](http://purl.org/net/ontology/modo)

PREFIX [owl:<http://www.w3.org/2002/07/owl#>](http://www.w3.org/2002/07/owl)

<modo:Person\_1>

rdf:type modo:Person . rdf:type owl:NamedIndividual .

modo:hasNoUpperLimbLimitation modo:UpperLimbLimitation . modo:hasNoUpperBodyLimitation modo:UpperBodyLimitation . modo:hasLowerLimbLimitation mod:LowerLimbLimitation .

Having gathered the data about a person’s limitations, as defined in the syntax above, a set of inference rules automatically defined the individual instance into the corresponding categories. The following syntax statement shows the customized OW2L-RL rule set written in the Semantic Graph database (GraphDB), which represented the inference rules for class *CategoryNNL*.

Prefices {

rdf: [http://www.w3.org/1999/02/22-rdf-syntax-ns#](http://www.w3.org/1999/02/22-rdf-syntax-ns) modo: [http://purl.org/net/ontology/modo#](http://purl.org/net/ontology/modo)

} Rules {

id:category\_nnl

x <rdf:type> <modo:Person>

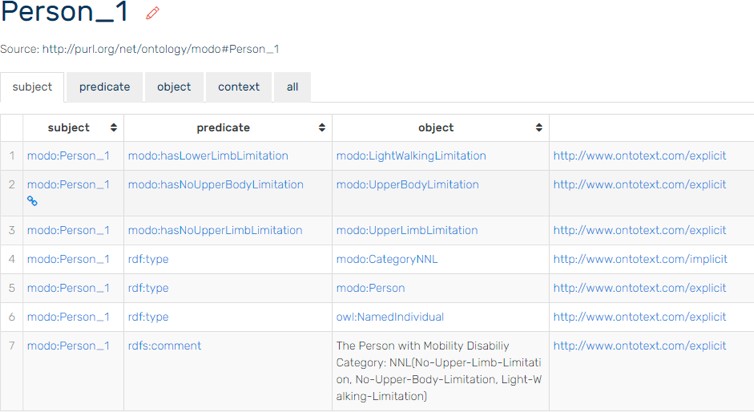
x <modo:hasNoUpperLimbLimitation> <modo:UpperLimbLimitation>

<modo:hasNoUpperBodyLimitation> <modo:UpperBodyLimitation>

<modo:hasLowerLimbLimitation> <mod:LowerLimbLimitation> }

As a result, the reasoner or rules engine embedded in the GraphDB could apply the forwarding chaining strategy to infer the person’s instance into the class *Catego- ryNNL* automatically. Figure [1](#_bookmark4) demonstrates the embedding of this rule set into the knowledge base.

The triple with object (modo:CategoryNNL) was the implicit context inferred by the rule engine or reasoner. The explicit context was the asserted statement and the implicit context was the inferred statement. Compared with applying a rule-based inference to publish the dataset, using SPARQL directly to insert the rule set into the triple store would keep the rules up to date for inference.



**Fig. 1.**Person instance inferred by OWL2-RL rule set

Place accessibility ontology provided vocabularies to represent the accessibility facilities and services within the built environment described in the following steps:

1. Publish the place area data within which the building is geographically located. In general, there are multiple buildings within one place area and the place instance could include name, geographic information, category and contact etc.
2. Publish the building data including name, geographic information, category,

organization and contact etc.

1. Publish the accessible facilities and services connecting all floors, such as the lifts and stairs.
2. Publish rooms, accessible facilities and services on each floor.

Publishing accessibility data of the *Station* class was similar to the steps of publishing the place accessibility of built environment described above. Proposed steps were as follows:

1. Publish the instance of target built environment in the public transport class (i.e. stations, terminals or stops).
2. Publish instances of accessible facilities and services in all floors or platforms,

such as lifts and stairs.

1. Publish instances of rooms, accessible facilities and services within each floor or platform.

# Conclusion

This paper set as its goal the presentation of a research study applying semantic web technologies for accessibility data management and modelling to construct a knowledge base for automatic accessible travel decision support. It also aimed to address a grand challenge in the area of accessible map information. Classification of user groups based on mobility impairments affecting physical activity were introduced. Three lightweight ontologies were developed based on the study of user requirements. Data publishing and reasoning methods were proposed for the accessibility data and inference rules. The final version of the AccessKB dataset from across the UK was made up of 2,577 railway station instances, 362 tube station instances, 10,629 restaurant instances and 6,586 place instances published and annotated with accessibility information. As a result of the research work, AccessKB would not only provide an open and readily available knowledge base for the study of accessible travelling decision support, but also contribute to the research of accessibility data management and accessibility modelling for accessible map information.

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