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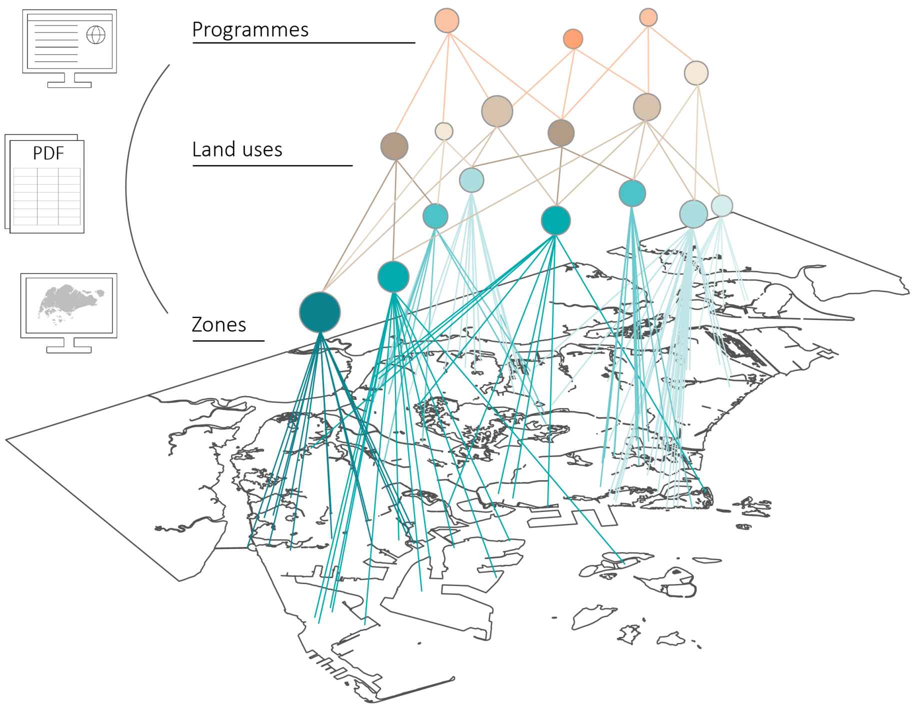
Abstract

Data related to urban planning is diverse both in terms of sources and formats. To facilitate urban analyses and public access to regulatory information, greater data interoperability is needed. Semantic web technologies, which use ontologies to link diverse data, are a promising solution to this problem. In this paper, we describe OntoZoning, an ontology representing relationships between zoning types, land uses and programmes (more specific land uses) in Singapore. We link the ontology to geospatial data stored in a knowledge graph, which allows executing multi-domain queries on urban data. We demonstrate how such queries can improve access to urban data, and in particular facilitate site selection and exploration. These are common tasks in urban planning and urban development processes. We also discuss how certain parts of zoning regulations are difficult to represent through ontologies, and would likely need to be defined more explicitly to fully represent city planning knowledge digitally.



Highlights

- We develop an ontology representing land uses and programmes allowed in each zoning type in Singapore.
- We link this ontology to multi-domain geospatial data in a knowledge graph.
- We query the data to explore sites and access zoning regulations.

Contents

1 Introduction

1.1 Data interoperability in urban planning: a challenge

Data used in urban planning are notoriously diverse, since planning deals with a broad range of issues related to domains such as transportation, environmental sustainability, economics, public health and general quality of life. These data originate from many different sources, and have a wide range of formats and scales. Such data heterogeneity presents challenges for urban planners wishing to analyse the impacts of planning in different domains, and for governments wishing to provide accessible, open data for stakeholders involved in the urban development process.

There is increasing recognition of the need to analyse the effects of planning holistically, however doing so is difficult due to the siloed nature of the required data and tools. For example, separate tools exist to analyse the effect of land use on the urban heat island effect [31], land use on energy systems [39], land use on mobility [14], or land use on air quality [4]. Yet these phenomena are interrelated, since for example land use and urban form affect both energy consumption and the urban heat island effect [35]. Integrated tools that combine interrelated analyses of this kind would arguably be better.

Many cities also emphasise the importance of open urban data in enabling citizen participation, efficient real estate development, or the creation of smart city applications by third parties [1, 12, 36]. However, government-provided urban data are still often heterogeneous and distributed in different databases, making it difficult for interested parties to make effective use of them [see *e.g.* 8, 43, 49]. These data also come in various formats, ranging from PDF text documents to DWG maps and 3D models, PDF maps or images, to KML files, GML files and georeferenced shapefiles [12, 17].

In this paper, we investigate these interoperability issues in relation to zoning documents. Zoning documents specify restrictions and requirements for development, including the zoning types of plots, which land uses are allowed in each zoning type, and plots' allowed density of development. Such information may be used when analysing the impact of urban planning on, for example, energy or transportation systems [14, 49]. Zoning information is also essential for stakeholders in the urban development process, and allowing easy access to it is therefore important [12]. The main obstacle to efficiently accessing and analysing zoning information is that it is typically distributed across geospatial formats and interfaces, and one or several documents. This means that obtaining a complete and accurate idea of zoning information requires substantial manual work related to searching for and integrating data [12, 17, 49].

We seek to link zoning-related data together using SWT (Semantic Web Technologies). SWT are often used to improve data interoperability, and thereby reduce manual data processing work. SWT allow semantically linking diverse data in a machine-readable way, and making these linked data available on the web to be reused and extended by others. In this case, we use SWT to link plots, zoning types, and land use types. Such links could enable digitally searching for a plot that allows a certain combination of uses, or conversely checking which uses a given plot or set of plots would allow. This search functionality could be augmented with other data, outlined above, such as the plot's Gross

Plot Ratio (GPR), or its location in a certain geographical area. It would also be possible to display other information encoded in the zoning documents, such as whether a plot is subject to additional urban design guidelines or control plans.

Linking geospatial data with zoning information would fill an existing research gap in the urban planning literature (see Section 2 for details). In terms of practical benefits, it could improve access to zoning-related data, and also facilitate analyses of the impacts of zoning. For example, it may be possible to automatically assess how changes in zoning rules would affect outcomes such as city-wide housing supply. Additional information on actual (as opposed to allowed) land use and programme distributions could also be used to improve urban energy simulation results [40]. SWT allow linking diverse data in a machine-readable way, and making these linked data available on the web to be reused and extended by others.

1.2 Semantic Web Technologies to improve data interoperability

The present paper is part of the Cities Knowledge Graph (CKG) project [37]. It fits within the framework of Semantic City Planning Systems (SCPS), which aim to facilitate different aspects of city planning through the use of SWT [48].

As its name suggests, the CKG is based on Dynamic Geospatial Knowledge Graphs [10]. This means that data is stored in graphs as nodes and edges, representing, respectively, concepts and their semantic relations. Data can be accessed through queries, which search for unknown values based on known concepts and relationships. Different data are linked in the graph with the help of ontologies, which specify the meanings of and relationships between different concepts [22]. A knowledge graph is easy to expand with new data, as the ontology helps to define new concepts' relationships to existing concepts (see Section 2.1 for details). For details on CKG architecture and use cases, consult Chadzynski et al. [10], Chadzynski et al. [11] and Grisiute et al. [21].

The CKG is a project that will be integrated into The World Avatar, a broader research effort which aims to create a digital 'avatar' of the world in a dynamic knowledge graph, using ontologies [2, 11, 18, 19].Autonomous agents are used to update the graph and to retrieve and analyse the information stored in it [10, 11].

1.3 Introducing a zoning and land use ontology

We have developed *OntoZoning*, a zoning and land use ontology, to address the need for more integrated data related to zoning. As discussed above, this could improve data access and facilitate analyses of the impacts of zoning. The ontology links zoning types used in Singapore to the land uses and programmes they allow.

Some key terms require defining at the outset. We use 'zoning' interchangeably with 'land use planning', which may be defined as 'the process of allocating different activities or uses... to specific units of area within a region' [42]. A land use is typically defined as a human activity that takes place within space [7, 15]. It is thus distinct from land cover, which describes the physical matter existing on the Earth's surface. However, as both Dickinson and Shaw [15] and Bibby and Shepherd [7] acknowledge, classifying land according to its use is surprisingly difficult. Firstly, each activity may consist of a wide range of tasks with different levels of specificity, which means that the activities chosen to describe land use are partially subjective and influenced by the interests of the classifier [7]. Secondly, activities may be associated with specific configurations of physical matter and types of ownership, which may also be of interest [15]. Arguably, this is the case in the zoning domain. Zoning documents usually do not describe allowable land uses purely from the perspective of activities, but may also specify whether the land is used by a public or private institution, and the kind of physical form that may be built on the land. Particularly physical structures are often strongly associated with activities: for example, the intension of the term 'school' includes various activities related to education.

Given our purpose of representing the knowledge encoded in Singapore's zoning regulations, we adopted the broad definition of land use described above, which combines activities, physical forms and ownership types. Documents by Singapore's Urban Redevelopment Authority (URA), the authority on zoning regulations, use the term 'land use' in this way (see Section 3.3). We use the term 'land use' to refer to broad categories of land uses allowed in a zoning type. 'Land uses' are tied to zoning types, and thus not generalisable.

We therefore introduce the general term 'programme' to describe specific land uses that may exist in different 'land use' categories (for a full explanation, see Section 3.3). Thus programmes may be nouns like 'Restaurant' that refer to physical objects but whose intentions include activities; or nouns that refer explicitly to activities such as 'Media production.' Programmes may occupy entire plots or their subparts, such as buildings, building units (in the case of *e.g.* a restaurant) or areas in parks (in the case of *e.g.* a playground). Programmes have a spatial nature, and thus have spatial attributes such as surface area.

We discuss our rationale for constructing the ontology based on our review of existing land use planning ontologies and Singapore's zoning documents and data (Section 2). In Section 3, we explain how the ontology was built. We then present the ontology itself and demonstrate how to integrate it with geospatial data, allowing queries related to multi-criteria site selection (Section 4). We review the benefits of such site-selection for stakeholders, particularly through improved access to data (Section 5). We outline future research topics which include adding further regulatory information to the knowledge graph, and developing a knowledge graph and query-based application to support site selection and various urban analyses (Section 6).

2 Background

This section provides background information necessary to understand our approach to building the OntoZoning ontology. First, Section 2.1 provides an overview of ontologies and how they can improve data interoperability. In Section 2.2, we discuss the benefits of ontologies for our specific use case, urban planning in Singapore. In section 2.3, we review existing ontologies in the urban planning and design field.

2.1 An introduction to ontologies

An ontology is defined as shared conceptualisation of a field of interest that formally specifies the meanings of and relationships between different concepts [22]. A conceptualisation is a simplified, abstracted view of the world or field of interest. A specification fixes the language used to describe the field, including its concepts, relationships and attributes. While such specifications implicitly exist in any database - and even in natural language – an ontology makes them explicit and formal, and thus machine-readable [23]. Ontologies are commonly represented in description logics and serialised in OWL (Web Ontology Language).

By formally and precisely fixing the meanings of concepts in this way, ontologies enable applications to automatically and unambiguously make use of multi-domain information [26]. An ontology or set of ontologies may contain concepts from different domains. For example, a pizza ontology - to use a popular example [38] - may be linked to a drink ontology specifying which drinks go together with which food ingredients. When both ontologies use the same terms to describe ingredients, it is easy to build an application that automatically recommends a drink most suited to a particular type of pizza (based on its ingredients), without having to manually link drinks to suitable pizzas.

Another benefit of ontologies is inferencing [26]. To expand the example, if a vegetarian pizza is defined as having only vegetarian toppings, then it is possible to infer whether an individual pizza is a vegetarian pizza or not, based on its list of toppings. Thus ontologies enable inferring new information based on domain knowledge encoded in the ontology. The benefit of such inferencing is that different applications do not have to specify rules corresponding to the inferences within the applications' business logic layer (which consists of custom algorithms that handle data exchange between the user interface and the database). Instead, the inferences come directly from the ontology, which can be reused by many different applications, thus saving time required for application development.

2.2 Urban planning ontologies for Singapore

In Singapore, publicly available zoning and urban regulatory data are distributed across several platforms in several formats. The Singapore government publishes the Singapore Masterplan on an online interface, where it can be downloaded in KML format [46]. This Masterplan is a map that brings together regulatory urban data from different departments. Most importantly, it states each plots' zoning type and Gross Plot Ratio (GPR), as shown in Figure 1. An associated text document (the Masterplan Written Statement) provides an overview of each zoning type in terms of its allowed land uses, and also specifies how to interpret zoning type and GPR rules in exceptional cases, such as when the plot is partly covered by a waterbody. In addition, separate online Development handbooks (*e.g.* [44]) contain more detailed lists of land uses allowed in each zoning type, and also contain references to further maps and websites that specify restrictions on the plot's allowed land uses and other features owing to its specific location (in *e.g.* a conservation area). Thus, accessing all zoning data related to a specific plot requires a labour-intensive process of data collection from a wide range of sources.

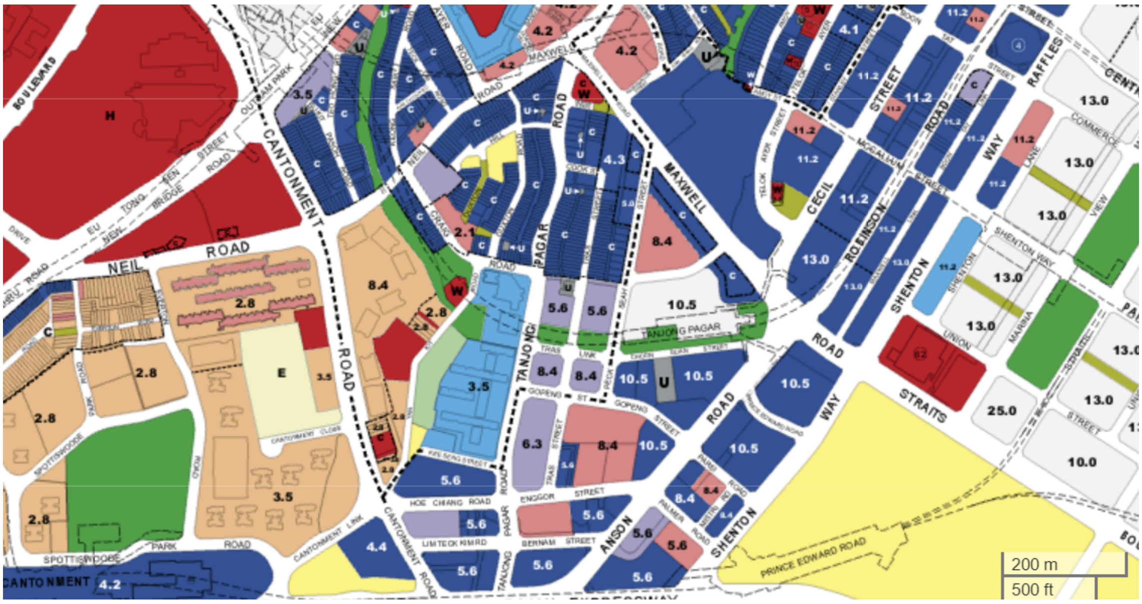


Figure 1: *An extract of the Singapore's 2019 Master Plan, as shown in URA Space [45]. This Masterplan is a map stating, among other regulatory information, the zoning type of plots.*

Singapore government agencies have recognised this issue. The Singapore Land Authority (SLA) has embarked on a project to automate cadastral job processing, which involves building a semantic 3D model of Singapore [41]. Additionally, as part of an effort to enhance planning with the use of Artificial Intelligence (AI), the URA is building a knowledge base which semantically links a wide range of planning-related data [24, 47], in order to support digital planning tools to help urban planners and industry stakeholders access relevant data more efficiently, enable urban analyses and 'evaluat[ions] of planning options', 'automat[e] routine tasks', and develop 'optimisation models' to assess changes in land use needs based on factors such as demographics [24].

2.3 Existing zoning and land use ontologies

Zoning and land use ontologies have also been explored previously. We found six ontologies which have similar goals as ours, including enabling better access to zoning and regulatory data [12], enriching geospatial data with zoning and/or land use data [5, 13, 29, 33], and facilitating transportation and urban analyses by integrating data [26]. The specific content of these ontologies are reviewed in more detail in the Section 3.2, where their potential for reuse is examined.

Although these past works have similar motivations as our work, there is still a gap in execution. None of the ontologies reviewed here offer a robust link between detailed land use data and geospatial data, which would be crucial for achieving the two main goals of the present ontology (enabling queries of zoning regulations and queries on allowed land uses on plots - as discussed in Section 3.1).

3 Methods

Following the ontology creation methodology by Mizen et al. [32], we built our ontology in six steps (see Appendix A.1 for details). First, we defined the purpose and scope of the ontology with the help of competency questions (Section 3.1). Second, we reviewed existing ontologies for reuse potential (Section 3.2). Third, we collected the relevant source material for building the ontology and listed and defined terms to be included in the ontology (Section 3.3). Fourth, we translated the terms found into networks of concepts, relationships and attributes, recording any information lost and evaluating the network against the purpose and competency questions (Section 3.4). Fifth, we created and evaluated the logical ontology using Protégé (Section 3.5). Finally, we linked the ontology to geospatial data to provide a foundation for querying which plots allow which land uses, and, ultimately, the plots' zoning regulations more generally (Section 3.6).

3.1 Purpose and scope of the OntoZoning ontology

When creating an ontology, the first step should be to define its purpose [32]. We did so by formulating a set of competency questions, essentially queries that the ontology should be capable of representing and answering [28]. Competency questions can be used to check whether the ontology contains correct and sufficient concepts and relationships to represent the domain of interest.

As stated in the Introduction, the primary purpose of the ontology is to facilitate access to zoning and regulatory data, and secondly to support urban analyses. These purposes were specified through the following competency questions (for a definition of programme, see Section 1.3).

- CQ1. What kind of programme, or mix of programmes, is allowed on a given plot?
- CQ2. Where are *all* the plots that allow a specific programme, or mix of programmes?
- CQ3. Where can I find a plot that allows a certain surface area of a specific programme to be built?

Further competency questions that were identified as important to take into account, but beyond the scope of the present paper, include:

- CQ4. What kinds of programmes are allowed on a given plot given its zoning type but also taking into account whether it is located in an area with additional requirements (related to for example urban design or conservation)?
- CQ5. What kinds of regulations on the height and building setback exist for the plot, given its unique context?
- CQ6. What is a typical quantity and distribution of uses for a plot with a certain zoning type and a certain GPR?

The additional competency questions (CQ4-6) require integrating the ontology and plot data with further data. In the case of CQ4 and 5, this means further regulatory data, including on geospatial data on areas with specific regulatory requirements. CQ6 implies the use of dynamic big urban data sources, such as government datasets, Google Maps Places or Open Street Maps (OSM) tags. Interoperability with such datasets is arguably essential to the use and interoperability of a zoning ontology; accurate, up to date, and multi-source data on land use quantities and distributions is essential to advanced uses, such as simulating and analysing *e.g.* urban energy systems, mobility patterns, or economics models.

3.2 Existing ontologies' potential for reuse

We reviewed the reusability of existing ontologies based on our objectives and competency questions. Although our ontology is focused on Singapore (with its own unique zoning types), other ontologies might contain reusable land use classes and their relations to zoning types. We analysed six relevant, existing ontologies from the perspective of reuse [5, 12, 13, 27–29, 33]. The first four ontologies were not reused due to limitations in the number of useful concepts included, or differing focus, among other reasons (see Appendix A.2 for an analysis of each one). Below is a summary of the two interrelated ontologies that we did choose to reuse.

The first of these is the LBCS-OWL2 ontology [33], designed to enrich geospatial parcel data with land use data. The ultimate goal is to create an interface that allows access to all available information on urban space (including e.g. population data), in order to support the formulation of design solutions. The land use ontology describes land based on five key dimensions defined by the American Planning Association's Land Based Classification Standards model (LBCS): 'Function', 'Activity', 'Structure', 'Site development status', and 'Property rights.' This ontology has significant potential for reusability, given the methodological approach to selecting classes based on the LBCS, the high number of relevant function classes, and the similarity of its purpose compared to our ontology. We could not find this ontology online and could thus not reuse it; however, we reused an amended version that is available (see next paragraph).

The iCity suite of ontologies [27, 28] is proposed as a standard for transportation planning, to support integration and reuse of data. The suite contains an LBCSv2 ontology to describe land use (this is an extended version of the LBCS ontology described above). It also has separate ontologies to represent agents (including trips, travel behavior, *etc.*), transport infrastructure (including concepts related to walking, public transit, transport costs and fares, a.o.) and several foundational concepts related to transportation planning, such as time.

Of the five land use dimensions in the LBCSv2 ontology, activities are most relevant for our purposes, considering our definition of land use and programme 1.3. An activity is defined as 'an observable characteristic of land based on actual use [...]. It describes what actually takes place in physical or observable terms (*e.g.*, farming, shopping, manufacturing, vehicular movement, *etc.*). An office activity, for example, refers only to the physical activity on the premises, which could apply equally to a law firm, a nonprofit institution, a court house, a corporate office, or any other office use.' While land use planning regulates allowable use rather than actual use, clearly a regulatory framework intends to link these two types of use.

3.3 Collecting terms to include in the ontology

S/No	Zoning	Uses	Examples Of Developments	Remarks
4	Commercial	These are areas used or intended to be used mainly for commercial development. Recreation Clubs may be allowed subject to evaluation by the competent authority.	Developments for: 1. Offices 2. Mixed Uses (e.g. Office/ Shopping/Cinema/Hotel/ Flat) 3. Convention/Exhibition Centre 4. Commercial School 5. Bank 6. Market/Food Centre/ Restaurant 7. Cinema 8. Entertainment 9. Foreign Trade Mission/ Chancery	The developments in this zone are subject to controls on the type and quantum of commercial uses as determined by the competent authority.
5	Hotel	These are areas used or intended to be used mainly for hotel development.	1. Hotel 2. Backpackers' Hostel	At least 60% of the total floor area shall be used for hotel room floors and hotel related uses as defined in the Planning (Development Charges) Rules. Commercial and residential uses may be considered by the competent authority subject to control on the use quantum as determined by the competent authority and they shall not exceed 40% of the total floor area.

Figure 2: *An extract of the Master Plan Written Statement [46], with different concepts and relationships highlighted by the authors.*

The data required to answer competency questions CQ1-3 had three main sources: the Singapore Master Plan, its associated Written Statement and the URA's Development handbooks for each zoning type (first introduced in Section 2.2). The Master Plan data contains each plot in Singapore, along with the assigned zoning type and GPR (see 1). The data are available for download in KML format. The Written Statement (Figure 2) and Development handbooks describe the meaning of each zoning type in terms of the 'uses' and 'developments' that are, may, or may not be allowed. Despite this apparent direct link between zoning types and uses, translating the URA documents to an ontology is less straightforward than one might imagine due to 1) the different levels of detail with which the different documents themselves describe land uses; and 2) the breadth of meaning and scales that the URA terms encompass. Here, we explain how we translated the land use terms found in the URA documents into the concepts 'Land use' and 'Programme' in the ontology, and how we supplemented the list of terms with programmes from other sources.

The first task was to decide the correct level of detail for the ontology, given that the different URA documents describe land use at different levels of detail. The Masterplan Written Statement has the most general perspective, and states that several zoning types allow broad use categories such as 'Commercial use.' However, the more detailed Development handbooks specify that the exact definition of 'Commercial use' differs between zones. For example, the zoning type 'Commercial with Residential at First Storey' allows commercial uses except those that are likely to cause disamenity to residents, such as nightclubs, while other zoning types may contain other exceptions. We decided to make our ontology capable of representing such exceptions to make it more widely usable. Therefore, we could not directly link several zones to broad categories like 'Commercial use' which always refer to single sets of specific uses such as shops, restaurants and nightclubs. Instead, in the ontology, 'Land uses' are always specific to a zoning type. For instance, the ontology contains a different Commercial use for each zoning type (CommercialUseWhiteZone, CommercialUseInResidentialWithCommercialAtFirstStorey, *etc.*) which are linked to distinct sets of programmes (equivalent to the URA term 'use', as discussed below).

The second challenge is the breadth of meaning in terms found in the URA documents, such as 'use' and 'development.' Both may refer to either activities or physical developments. Uses mentioned in the Masterplan Written Statement include for example 'Commercial Use', 'Community facilities' and 'Religious building', while developments include for example 'Shopping', 'Restaurant', or 'School'. The more detailed Development handbooks do not mention developments, but instead describe 'allowed uses' at different levels of detail. For example, they state that the Business Park zoning type allows the use 'Test Laboratory' which is specified to include 'Scientific investigation and testing of products and processes including food and feed additives, bio-tech, pharmaceuticals, textiles and geological analysis.' Due to this lack of distinction, we decided not to directly use the terms 'use' and 'development' in the ontology. Instead, uses at different scales are included in the ontology as 'programmes.'

The programmes found in the URA documents are non-exhaustive and infinitely divisible. They range from broad categories like 'Entertainment', to developments such as 'Hotel', and even rooms such as 'Meeting room.' This breadth of scale, and the fact that the URA often only mentions 'examples' of uses (see Figure 2) means that the uses found in URA documents are non-exhaustive. For this reason, and to support our goal of linking a comprehensive list of programme types to zoning types (see Section 3.1), we supplemented the URA documents with other sources providing a broader set of programmes, which can be further expanded in the future.

Besides URA development handbooks, we sourced programmes from Google Place types and the LBCSv2 ontology (see Section 3.2). Google Places are 'establishments, geographic locations, or prominent points of interest' included in Google Maps, which are each tagged with a 'Place type' [20]. Compared to the URA documents, Google Place types provide a more comprehensive list of consumer-facing establishments occurring in Singapore, such as gyms and libraries, and were thus included in the list of programmes [20]. We also added activities found in the LBCSv2 ontology, which represent the observable activities taking place on the land. The ontology contains particularly many classes for recreational activities, and thus it complements the programmes sourced from the URA and Google well.

In sum, we sourced two concepts, 'land use' and 'programme', from three sources: URA documents, Google Places and LBCSv2 activities. Examples of land uses and programmes include, respectively, 'CommercialUseWhiteZone' and 'Restaurant', 'School', and 'Ebusiness'. As is to be expected in a regulatory system, there is a finite number of land uses that are allowed in each zoning type, but each land use could allow an almost infinite set of programmes. Programmes are universal concepts that may be found in any country, while land uses are specific to Singapore. We then manually scanned the URA documents, the list of Google Places and the LBCSv2 activities for concepts, relationships and attributes to be included in our ontology. This resulted in lists of zoning types, land use types, programme types and various relationships ('allows', 'may allow', *etc.*) found in our source data.

3.4 Creating a concept network

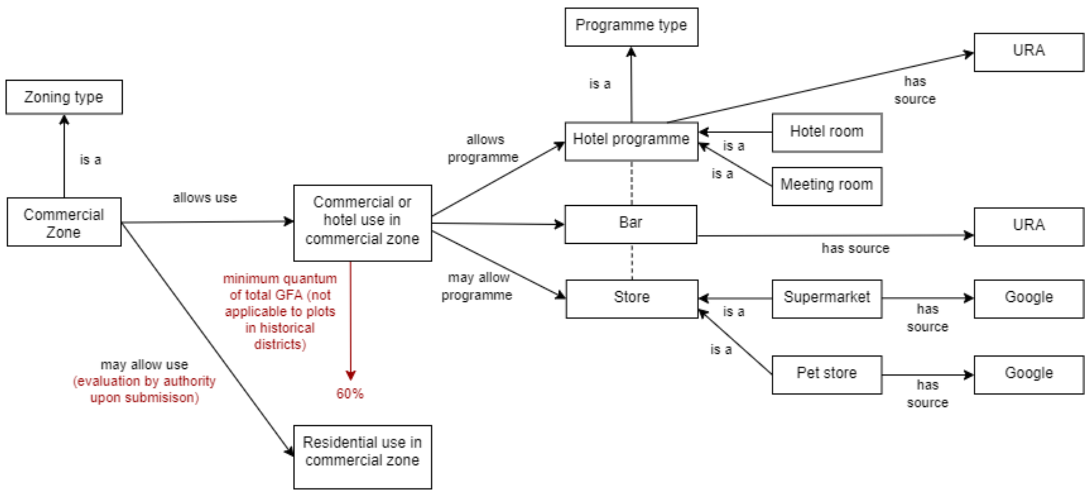


Figure 3: *An excerpt from the conceptual ontology, illustrating a selection of key concepts and relationships. The red information was not included in the final ontology.*

The next step was to organise the lists of concepts and relationships into a network format, which can be expressed as a spreadsheet or a diagram (for an excerpt, see Figure 3). This network should represent all required knowledge. We filtered the lists of land uses and programmes, collected in the previous step, for overlap. For example, the Masterplan Written Statement mentions 'Light industry' and 'General industry' as allowable programmes in the zone 'Business2', while the Development handbook does not use these terms but instead refers to more specific uses included in these categories, such as 'Core media use' and 'Storage of chemicals' respectively [45].

We also had to resolve the question of whether to organise the programmes into hierarchies. Given the large number of potential programmes, a hierarchy is useful as it facilitates finding relevant programmes quickly, by being able to first refer to more general common language terms rather than very specific sub-terms. However, forming such a hierarchy is difficult; we would even argue it is unlikely a universally applicable hierarchy exists. First, it is sometimes difficult to determine what concept is more general than another. For example, should 'Recreation club' be a subtype of 'Sports and recreation facility', and should an activity like 'Tennis' be a subtype of either? Second, a programme can be a subtype of several programmes, which implies the hierarchy cannot be a strict taxonomy (i.e. a tree structure) and will likely be cyclical. For example, a 'Bar' can be a subprogramme of both a Golf course and a Hotel (according to the URA documents). For these reasons, we only created a hierarchy as a proof of concept for those programmes where a clear hierarchy existed in the URA documentation: 'Store', 'Golf', 'Data Processing', 'Research and Development', 'Hotel Programme', 'Core media', 'E-business' and 'Test laboratory. In cases where a programme was a subtype of two different programmes (like 'Bar'), it was made a subtype of neither (see Figure 3). In the future, we plan to explore a system of selectable hierarchies, so different domains and their users can be catered for.

Relationships between concepts were also modelled at this stage. Each zoning type is linked to land uses through three kinds of relationships found in URA documents: 'allows', 'may allow', and (rarely) 'does not allow' [45]. However, in the URA documents, these statements naturally come with qualifiers such as 'mainly' or 'subject to the evaluation of the competent authority' [45]. Allowed uses might also depend on the context of the plot (see Figure 3). These qualifiers were noted down alongside the relationships they referred to. In addition, for most zoning types, the URA specifies a maximum or minimum quantum for the allowable uses (as a percentage of total floor area, as shown in Figure 3). Although this information is relevant to precisely answer our competency question 3, use quantums were not included in the current version of the logical ontology. We will explore linking them in the future.

After this filtering process, we linked zoning types to land use types through three relationships: 'allows use', 'may allow use', and 'does not allow use.' Land uses and programmes are similarly linked through the relationships 'allows programme' (for programmes explicitly mentioned by the URA) and 'may allow programme' (for programmes sourced from our non-URA sources, Google and the LBCSv2 ontology). These data were translated into spreadsheets listing the land uses allowed in each zoning type, the programmes allowed in each land use type, and also the sources and possible subprogrammes of each programme.

Although the scope of the present ontology was limited to Singapore, we also considered the ontology's extendability at this point. Land uses and zoning types from other countries may be added to the ontology later and linked to the (universal) programmes. This could be done by adding country-specific superclasses above each zoning type and land use type class, or by adding labels or properties to each zoning and land use type class to indicate its area of application. This plan, however, assumes that all zoning regulation systems follow the same basic structure in which zoning types allow certain land use types, which in turn allow programme types. In the future, we plan to verify whether this is generally the case by collecting zoning and land use data from other cities. Since this verification was not done, however, we chose not to add any country-specific superclasses, labels or properties for zoning and land use types.

3.5 Creating and evaluating the logical ontology

Next, the spreadsheets created as part of the conceptual ontology were translated into a logical ontology using Protégé, an open-source ontology editing software [34]. The translation was done with Python, using the Owlready2 library [30]. In this step, the conceptual ontology's concepts are translated into classes or individuals, relationships into object properties, and attributes into data properties, each with a unique identifier.

The consistency of the ontology was checked using Protégé's HermiT reasoner. The accuracy of the ontology was checked with Protégé's Debugger plugin by writing a list of correct and incorrect statements and checking that the reasoner infers the correct ones, but not the false ones. At this point, we also tested the ontology through SPRAQL queries. The statements and queries used were derived from our competency questions 1-3, and are described in more detail in Appendix A.3.

3.6 Linking the ontology to geospatial data

Answering competency questions 1-6 requires links to geospatial data. Besides the URA Master Plan plots in KML format, we required several other datasets such as building footprints. The data were converted into CityGML format and uploaded into the Cities Knowledge Graph, which uses Blazegraph as its graph database (see Chadzynski et al. [10] for details about this process). The zoning types, land use types and programme types in the zoning ontology were then linked to the geospatial plots based on each plot's zoning type in the raw data. Specifically, we used the RDFlib library [9] to create a Python script that translates the same spreadsheets used to generate the ontology (see Section 3.4 into an RDF file consisting of subject-predicate-object-graph quads. These quads express the concepts and relationships included in the ontology (e.g. 'zoning type' 'allows use' 'land use'), and also the links between zoning types and the URIs of each plot in Singapore. This RDF file was then loaded into Blazegraph.

We then created a Python script to query, analyse and visualise the data described above, using a SPARQL wrapper and the Geopandas and Contextily libraries [3, 25]. While we are working towards a full integration of data analysis and visualisation into our knowledge graph architecture, for the results of this paper our Python scripts did not interact with the knowledge graph after the query stage; rather, query results were downloaded and then analysed and visualised on a local machine. The next section presents the results of these analyses and visualisations.

4 Results and Demonstrations

We now present the zoning ontology and four proof of concept demonstrators of multi-criteria site selection. The latter show how the ontology can be used to query urban planning-related data stored in a knowledge graph, in order to answer competency questions 1-3. The demonstrations included are only a small subset of all the queries that would be possible based on all the different geospatial data and zoning ontology concepts stored in our knowledge graph; these particular queries were chosen because of their demonstrative potential, considering our purposes (see Section 3.1).

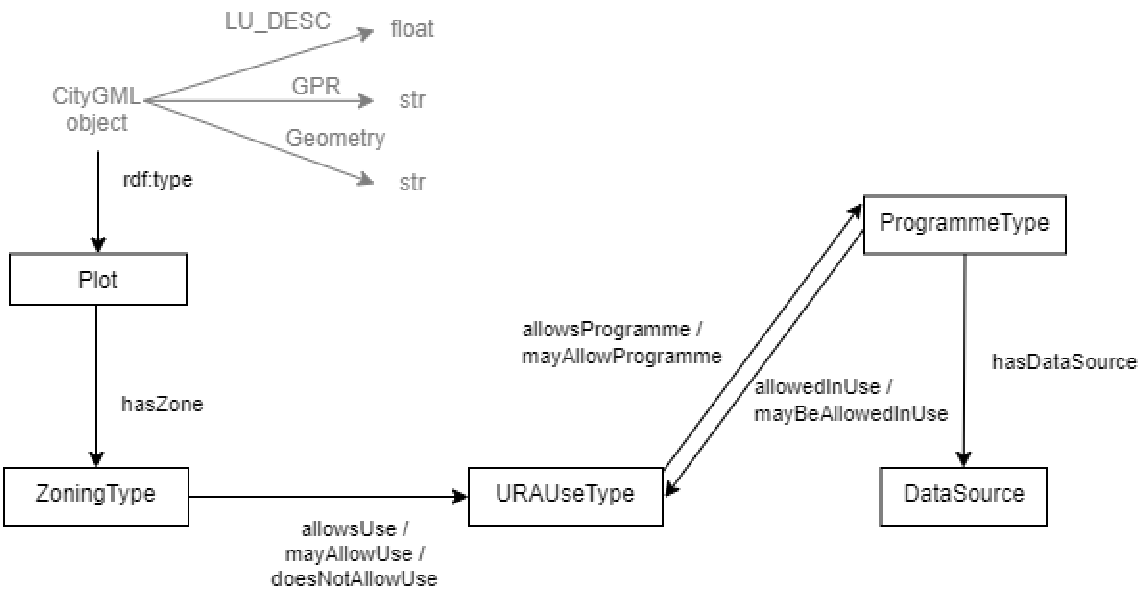


Figure 4: *Diagram illustrating the zoning and land use ontology. CityGML geospatial objects (grey) may be classified as Plots with a certain ZoningType that is known based on the object's LU_Desc value (short for land use description).*

4.1 The OntoZoning ontology

The ontology represents five core classes: 'Plot', 'Zoning type', 'Land use type', 'Programme type' and 'Data source'. These classes, as well as their relationships, are shown in Figure 4. There are 33 distinct zoning types, 49 land use types, and 346 programme types. All classes and their relationships are listed in Appendices 4-7 (A.4, A.5, A.6, A.7).

The ontology may be linked to geospatial CityGML objects by classifying these objects as plots with a certain zoning type. The CityGML objects are based on master plan data from the URA, originally in KML format, and have an attribute called 'LU_desc' (short for 'land use description') which is equivalent to the zoning type of the plot.

4.2 Query 1: uses allowed in a plot

The first query shows which uses and programmes are allowed in a plot with a certain URI (Figure 5), addressing competency question 1. The plot in the query has zoning type ‘Sports and Recreation’, which allows uses ‘Recreation club use’, ‘Marina use’, ‘Sports complex use’, ‘Resort use’, ‘Stadium use’, ‘Water sports centre use’ and ‘Golf use.’ Each of these uses allows or may allow distinct sets of programmes, such as ’BowlingAlley’, from GoogleMaps, and ’Water-skiing’, from the LBCSv2 ontology. Thus the query shows how uses (which are always derived from URA documents and which are each linked to only one zoning type) can be linked to specific programmes, which may come from other sources. This query only requires data on plot IDs, their zoning types, the uses allowed in each zoning type, and the programmes that each use contains. As such, it is the most basic demonstrator of our ontology.

4.3 Query 2: plots allowing a combination of uses

Our second demonstrator is a query for plots which allow developments containing both a printing press and tennis activities, addressing competency question 2. This combination of land uses is rare, meaning that it is not intuitively obvious which zoning type would allow it. Indeed, this combination is allowed in multiple zoning types, and manually going through the allowed uses for each type would require significant effort. Querying the zoning types that allow these programmes is easier. Unlike the first query, this query uses geospatial plot data across Singapore, which makes it possible to visualise the query result, as shown in Figure 6.

4.4 Query 3: adding geospatial conditions

The third query searches for plots that 1) are located within 1000 m of an MRT (mass rapid transit) station entrance; 2) contain no existing buildings; and 3) allow or may allow building a gym and a hotel. The result is visualised in Figure 7. Like the previous query, it addresses competency question 2: ‘where can I place a specific programme, or mix of programmes?’ In addition, this example demonstrates how further geospatial conditions (proximity to MRT), stemming from different urban datasets, can be incorporated in a query.

4.5 Query 4: adding geospatial conditions and new datasets

This is a query to find plots that allow residential development and have unused gross floor area (GFA), and are located adjacent to a park. We approximated unused GFA for each plot by multiplying the area of each building footprint found on the plot with the height of the building (as represented in the CKG, and subtracting the result from the total GFA allowed on the plot (calculated by multiplying the plot’s area and GPR, as specified in the Masterplan). Two plots were considered adjacent if their boundaries shared at least one common point. The query result is visualised in Figure 8. Like the previous query, this

```
PREFIX ocgml: <http://www.theworldavatar.com/ontology/ontocitygml/citieskg/OntoCityGML.owl#>
PREFIX zo: <http://www.theworldavatar.com/ontology/ontozoning/OntoZoning.owl#>
SELECT ?zone ?use ?programme
WHERE {
      GRAPH <http://127.0.0.1:9999/blazegraph/namespace/singaporeEPSG4326/sparql/ontozone> {
            <http://127.0.0.1:9999/blazegraph/namespace/singaporeEPSG4326/sparql/cityobject/UUID_9195a574-bca8-4deb-9151-a23cad79aad1/>
                        zo:hasZone                                  ?zone_uri.
            ?zone_uri   zo:allowsUse | zo:mayAllowUse               ?use_uri.
            ?use_uri    zo:allowsProgramme | zo:mayAllowProgramme   ?programme_uri.

            BIND (strafter(STR(?zone_uri), "#") as ?zone).
            BIND (strafter(STR(?use_uri), "#") as ?use).
            BIND (strafter(STR(?programme_uri), "#") as ?programme )}

} GROUP BY ?use  ?programme ?zone
.
```

zone	use	programme
SportsAndRecreation	GolfUse	Restaurant
SportsAndRecreation	GolfUse	Chalet
SportsAndRecreation	GolfUse	GolfCourse
SportsAndRecreation	GolfUse	Bar
SportsAndRecreation	GolfUse	ClubHouse
SportsAndRecreation	GolfUse	DrivingRange
SportsAndRecreation	GolfUse	Golf
SportsAndRecreation	GolfUse	Guesthouse
SportsAndRecreation	GolfUse	Lounge
SportsAndRecreation	GolfUse	ProShop
SportsAndRecreation	MarinaUse	Marina
SportsAndRecreation	MarinaUse	BoatMooring,Docking,Servicing
SportsAndRecreation	MarinaUse	Water-skiing
SportsAndRecreation	MarinaUse	Boating,Sailing,Etc
SportsAndRecreation	MarinaUse	Canoeing,Kayaking,Etc
SportsAndRecreation	MarinaUse	Fishing,Angling,Etc
SportsAndRecreation	MarinaUse	Port,Ship-building,RelatedActivities
SportsAndRecreation	MarinaUse	Sailing,Boating,OtherPort,MarineAndWater-basedActivities
SportsAndRecreation	RecreationClubUse	RecreationClub
SportsAndRecreation	RecreationClubUse	BowlingAlley

Figure 5: *A screenshot of the Blazegraph interface which is used to query data on stored in a knowledge graph. Once instantiated, the contents of OntoZoning can be queried through SPARQL. The top of the image contains the code for Query 1, asking for a plot's zoning type, allowed uses, and allowed programmes per use. An excerpt of the results is shown at the bottom.*


```
PREFIX ocgml: <http://www.theworldavatar.com/ontology/ontocitygml/citieskg/OntoCityGML.owl#>
PREFIX zo: <http://www.theworldavatar.com/ontology/ontozoning/OntoZoning.owl#>
SELECT DISTINCT ?zone ?id ?geometry
WHERE {
      GRAPH <http://127.0.0.1:9999/blazegraph/namespace/singaporeEPSG4326/sparql/ontozone>{
            ?zone1  zo:allowsUse | zo:mayAllowUse
                   [zo:allowsProgramme | zo:mayAllowProgramme zo:Tennis] ,
                   [zo:allowsProgramme | zo:mayAllowProgramme zo:PrintingPress].
            ?id     zo:hasZone                    ?zone1.
            BIND ( strafter( STR(?zone1), "#" ) as ?zone ) }

      GRAPH <http://127.0.0.1:9999/blazegraph/namespace/singaporeEPSG4326/sparql/cityobject/>
          { ?s2     ocgml:gmlId  ?gmlid ;
                  ocgml:id  ?id.}

      GRAPH <http://127.0.0.1:9999/blazegraph/namespace/singaporeEPSG4326/sparql/surfacegeometry/> {
            ?s1     ocgml:cityObjectId  ?gco_id ;
                  ocgml:GeometryType ?geometry.
            BIND ( strafter( STR(?gco_id), "genericcityobject/" ) as ?gco_id2 ).
            BIND ( strbefore( ?gco_id2, "/" ) as ?gmlid ).}

  }
```

Figure 6: *Visualisation of the second query results, showing plots allowing a printing press and tennis activities, coloured by zoning type. The map is focused on the centre of Singapore.*

query addresses competency question 2. It demonstrates the use of a different geospatial condition in the query (adjacency to a park), as well as the incorporation of gross plot ratio and building height information (used to calculate Unused GFA). Building height data originates from a different dataset (see [16]) than the other attributes used in this and other queries, demonstrating once more how different data sources can be combined in these knowledge graph-based queries.

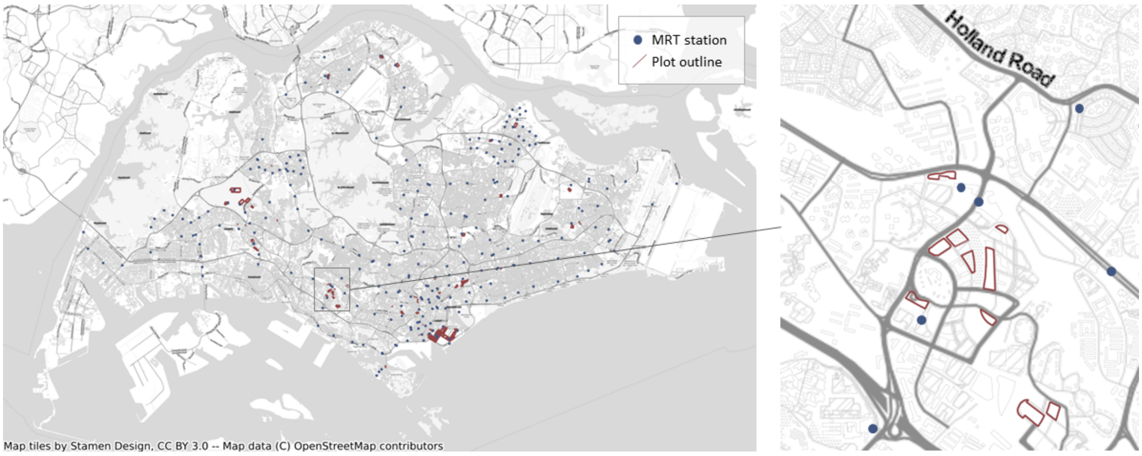


Figure 7: *Visualisation of Query 3, showing empty plots located within 1000 m of an MRT station, that allow building a gym and hotel development.*

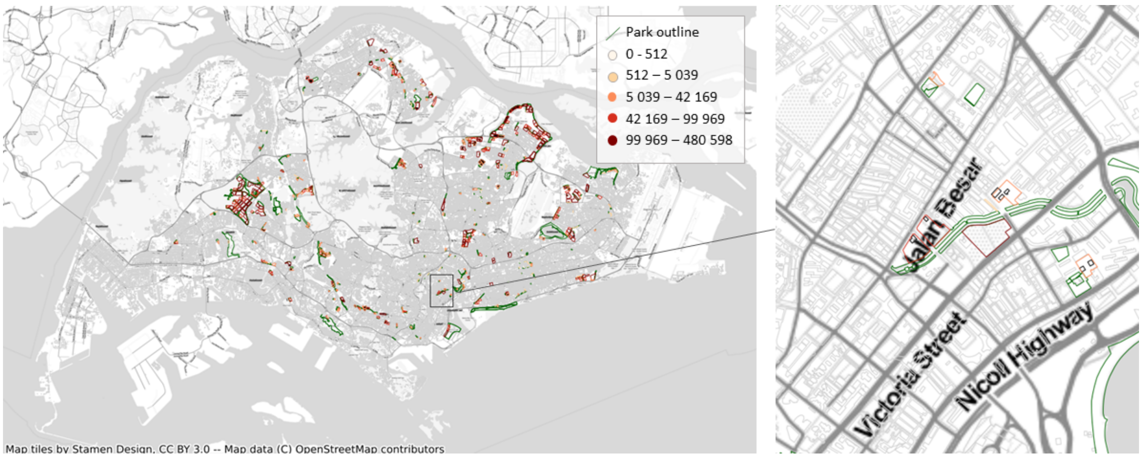


Figure 8: *Visualisation of Query 4, showing plots that allow residential development, are adjacent to a park, and have unused GFA. Parks adjacent to the plots of interest are shown in green, while plots are colored according to the amount of unused GFA (m^2), shown in the legend. Buildings located within the selected plots have black outlines, while other buildings' outlines are grey.*

5 Discussion

Our discussion will focus on opportunities and challenges identified in the three key areas that relate to our work: 1) representing zoning-related information in ontologies; 2) storing data in a knowledge graph; and 3) the practical benefit of accessing zoning data represented and stored in this way, particularly to enable multi-criteria site selection.

Our approach demonstrates the potential of ontologies to achieve better data interoperability of zoning and regulatory data. We found that urban planning documents, including those used in Singapore, come from several sources, have different formats, and contain overlapping information. There is potential to make these documents machine readable, and develop applications that allow users to easily access the information.

Although urban planning documents are designed to be read by humans, and as such contain many implicit assumptions, we found it was possible to translate a significant share of zoning concepts and regulations into machine-readable format. A particular challenge was defining 'land use', which may connote physical developments and activities at different levels of detail, and sometimes also ownership (see Sections 1.3 and 3.3). We introduced a new term 'programme' which explicitly incorporates all these dimensions into a single concept. This approach contrasts with previous ontologies, which either do not explicitly define land use, or, in the case of LBCSv2, describe land use through separate dimensions [28]. Although the LBCSv2 dimension 'activity' is relevant to zoning, the activities in the LBCSv2 ontology do not span the range of allowed and not allowed uses specified in the URA documents. No LBCSv2 category exactly corresponds to the kinds of allowed 'developments' which the URA uses to define zoning types. Our programmes are tailored to the zoning and planning domain, and thus contribute to the existing literature on zoning ontologies.

Our work also explored the storage of zoning and land use data in a knowledge graph. Compared to a relational database, a clear benefit of storing planning data in a graph database is the ability to link heterogeneous data in a single place, so that the data can be extended and updated easily. To create the demonstrations included in this paper, we used a data analytics package that did not directly operate on data stored in the knowledge graph, but rather data downloaded from it. However, we are currently developing a visual user interface to allow the user to directly consult data and query results from the knowledge graph on a map-based visualisation [11] —which is a requirement to fully realise the benefits of linking (geospatial) data in knowledge graphs.

Our demonstrators show that linking geospatial and regulatory data in knowledge graphs in this way presents exciting opportunities, particularly for multi-criteria site selection. We showed how data from the URA master plan geospatial map and associated written documents can be combined with geospatial building data and Google programme types, enabling site exploration queries. These queries may incorporate conditions related to topology, proximity to other land uses, and the types of developments that are allowed to be built, and they can be executed over a large geographical area such as Singapore, to find all plots that fulfill the conditions in the query. To our best knowledge, such queries have not been demonstrated before, and in general little attention has been paid to integrating zoning data with geospatial data using ontologies, as discussed in Section 2.3.

Potential users of such queries could include developers, planners, researchers, and citizens. For non-expert users, such an integrated workflow significantly simplifies the process of accessing zoning data, by reducing the need to check many different websites or documents. This benefit also applies - at least in part - to built environment professionals conducting analyses in specialist geospatial software. Although such software allows combining basic data layers like GPR, zoning types or plots, processing and updating these data is often labour intensive. More importantly, as we have shown, the allowable uses and programmes per zoning type are currently distributed across many documents, rather than being collected in a single dataset that could be imported to GIS. Our ontology provides semantic meaning to the zoning types, making it possible to link not only the zoning types themselves to geospatial data, but the meanings of those zoning types.

Despite these benefits, we also encountered a number of challenges that must be overcome to enable more effective use of our zoning and land use ontology. In the case of Singapore, one challenge is that, in practice, there are frequently exceptions to general land use rules described in the URA documents. Our ontology was designed to express exceptions for individual zoning types, by virtue of linking zoning types to unique allowed land uses, which are in turn linked to unique sets of allowed programmes. However, we can find examples of other exceptions that cannot be expressed by drawing on the multi-source data in our knowledge graph: for instance, several libraries (data from Google Places) are found in commercial malls located on plots with various commercial zoning types, even though libraries are only allowed on land zoned as Community Institution according to the represented documentation. Such cases are likely the result of incentive schemes or other special policies used to encourage developers to integrate programmes or features that benefit the general public. In addition, our ontology does not take into account exceptions to allowed uses based on a plot's specific location (e.g. in a conservation district), or the fact that some uses are only allowed subject to the URA's evaluation or approval. These features were beyond the scope of the present competency questions, but may be added in the future.

It should also be noted that exceptions are to be expected in a system that needs to adapt to a wide variety of contexts (land plots) and relies on human experts to judge the particularities of a case or situation, and we assume that exceptions are common in most - even all - land use planning regulatory systems. Nevertheless, a more explicit description of certain rules and exceptions would likely be necessary to fully represent city planning knowledge digitally, in machine-interpretable formats like ontologies. However, as our demonstration queries in Section 4 show, this forward concern should not be interpreted as a lack of suitability of SWT for land use planning applications.

6 Conclusions and outlooks

This work presents our ontology-based method for multi-criteria site selection. Our OntoZoning ontology of zones, land uses and programmes for Singapore links zoning types to detailed programme types in order to improve data integration and accessibility in the urban domain. We linked our ontology to a previously developed dynamic geospatial knowledge graph [10] containing geographical data for the Republic of Singapore. We demonstrated how this integration of geospatial, zoning and programme data allows querying for plots on which certain combinations of programmes could be placed. We also demonstrated how the diverse data stored in our graph database enables filtering query results based on multi-domain geospatial attributes such as distance of the plot from an MRT station, or the plot's content. We discussed the opportunities and challenges of improving data interoperability in the zoning domain through the use of ontologies.

This work contributes to improving data interoperability in the urban planning domain in two ways. First, our ontology provides machine-readable meanings to zoning types in Singapore by linking them to the allowed land uses and programmes. Although Singapore's zoning types and land use types are country-specific, programme types and the general structure of the ontology are also applicable to other contexts. Programme types are interoperable because they draw from types found in the URA documents, Google Places (an example of a data provider's classes), and LBCSv2 ([28]; an ontology of an American land-use classification system), with the option to integrate additional programme types from other sources. Secondly, our work addresses the data interoperability problem by linking zoning and programme data to geospatial data using knowledge graphs. This enables queries for multi-criteria site selection, examples of which were demonstrated in Section 4. To the best of our knowledge, such queries are novel.

Our work also contributes to existing literature by highlighting the importance of explicitly defining concepts and relationships found in the zoning and land use planning domain. This would enable semantically linking related data to improve data interoperability, and allow advanced forms of digital city planning such as AI assistants. In addition, by means of their explicit and quantified representation of (multi-domain) knowledge, ontologies like ours facilitate access to planning-related (regulatory) information. Even if our specific ontology is focused on Singapore, the challenges of data access are global and our general approach to solving this problem could be applied in any locale.

Our work has three main limitations. First, as discussed in Section 5, some information found in the URA documents was not represented in the ontology. Exclusions included qualifying statements designed to be interpreted primarily by humans rather than machines, and exceptions to allowed uses based on a plot's location. In addition, use quantums (the maximum or minimum area that a certain use may or should occupy) were left out of the ontology. The ontology has been designed in such a way, however, that use quantums could be added later by adding a data property to the land use of interest. A second limitation of our work that pertains to the ontology's content is that the ontology has not yet been validated by URA domain experts. These limitations mean that the presented version of our land use ontology is best used as a starting point to explore allowed programmes in a plot or zoning type, and not as a full and accurate reflection of Singapore's land-use regulation system.

A final, less important limitation of the ontology is its relative lack of user-friendliness. The ontology's 346 programmes are mostly not arranged in hierarchies, limiting the ability of a human user to find programmes of interest in queries. In addition, some of the land use terms included in the ontology may not be easy for users to understand due to our decision to make each land use unique to a zoning type. While this decision makes it possible to model exceptions to allowed programmes, and later extend the ontology with use quantums, it means that some land uses have names like 'CommercialInCommercialAndInstitutionZone', which are difficult to read. This issue could later be addressed by adding simplifying labels to each land use term, with more readable alternative names.

In addition to these improvements, we want to highlight three research outlooks to further advance land use planning applications in Semantic City Planning Systems. First, we are currently developing an application with a graphical user interface that could execute users' queries on the knowledge graph and visualise results directly, without need for the additional data processing steps described in Section 3.6. Second, we wish to use OntoZoning to augment particular urban planning assessments, such as how zoning impacts planning goals related to *e.g.* mobility or energy. Such assessments require data on the typical distributions of programmes that exist (rather than the programmes that are allowed), and hence these analyses are beyond our present scope. Third, we aim to add further content into the ontology and knowledge graph, which may also require enabling inferencing in queries (see 2.1). As mentioned in Section 3.4, adding zoning and land use types from other cities besides Singapore is possible, but would require further research. In addition, the ontology could be extended with further regulations that affect each zoning type's allowed land uses and programmes. This would enable more context-sensitive and insightful queries of the allowed programmes in specific plots. This paper provided an outline and demonstrations of the potential to improve data interoperability in the zoning domain, and through this work and these future research additions, we aim to help realise this potential.

Acknowledgements

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List of abbreviations

- AI – Artificial intelligence.
- CQ – Competency question. An ontology should be able to answer all competency questions; thus, such questions are used to define the scope and purpose of an ontology.
- DWG – a file format for storing 2D and 3D design data and metadata.
- GFA – Gross Floor Area. The total amount of floor area of a building or buildings located on a plot.
- GML – Geography Markup Language, a file format for storing geographic data.
- GPR – Gross Plot Ratio, a number associated with a plot which mandates how intensively the plot may be developed. For example, a GPR of two means that the amount of GFA that may be built on a plot is twice the area of the plot.

- KML – Keyhole Markup Language, a file format for storing geographic data.
- LBCS – Land Based Classification Standards (a land use classification system by the American Planning Association)
- LBCSv2 – A land use ontology originally created by Montenegro et al. [33] and expanded by Katsumi and Fox [28].
- OSM – Open Street Maps.
- SCPS – Semantic City Planning Systems.
- SWT – Semantic Web Technologies.
- URA – Urban Redevelopment Authority, Singapore's national urban planning authority.

A Appendices

A.1 Background on methods for creating ontologies

Given that our ontology seeks to integrate data from different Singaporean zoning documents, it is most feasible to construct it manually, based on domain expertise. This approach contrasts with various automated or semi-automated methods based on clustering and natural language processing techniques, which are typically used when the input dataset is very large [6]. In the manual method, the concepts and relationships in the ontology are modelled by a human based on their understanding of a domain. This approach consists of two steps: building a 'conceptual ontology' understandable to humans, and translating it into a final, logical ontology interpretable by machines using description logics serialised as OWL [32]. This separation of concerns is useful for two reasons: it allows 1) keeping track of all relevant concepts and relationships, which cannot always be represented in the final ontology due to limitations in the expressivity of description logics [32]; and 2) ensuring that the final ontology is logically correct, even if the domain contains relationships which could lead to logical errors.

The conceptual ontology is created by first defining the purpose and requirements of the ontology, then collecting necessary information to be encoded in the ontology, and finally organizing that information into networks of concepts, relationships and attributes [32]. In this network, concepts are typically based on nouns found in the source information, while relationships are based on verbs linking two concepts, and attributes are based on verbs or adjectives related to only one concept (examples of attributes could include having a height or an age, if these are not included as separate concepts in the ontology).

After this network of concepts is validated against the purpose of the conceptual ontology, it can be translated into a logical ontology using description logics. The logical ontology is typically built using specialised software such as Protégé, where concepts are translated into classes and individuals, relationships into object properties, and attributes into data properties, each with a unique identifier.

Since creating ontologies is labour-intensive, reusing existing ontologies is always recommended. Aside from saving resources, reuse supports the development of shared languages and interoperability described in the previous section [27].

A.2 Existing land use and planning ontologies that were not reused

1. Land use ontology for St Petersburg [12]

    - Purpose and contents. This ontology aims to answer two types of questions in the context of St Petersburg, Russia: 1) what kinds of restrictions on construction exist on a plot, and 2) which plots allow constructing a specific development, such as a factory. The ontology contains territorial zones, zoning types, permission types, land use types, and classes related to construction regulation, such as maximum number of floors. The purpose of this ontology is most similar to ours.

- Reusability. The zoning types are specific to the St Petersburg context, and hence not reusable. The ontology's 156 land use types are in Russian, making them difficult to reuse. The PermissionTypes ('primarily permitted', 'conditionally permitted', 'auxiliary permitted') are very few in number, limiting the benefits of reuse.

2. Land use ontology for Morocco [5]

   - Purpose and contents. This ontology represents land uses allowed in Morocco's zoning types. It contains classes belonging to 4 categories: zoning, services, infrastructure and easement.
   - Reusability. Of these categories, zoning types cannot be reused because they are different in Morocco compared to Singapore. Infrastructure and easement are not within the scope of our ontology, so there is no need to reuse these classes. The ten services in this ontology are more general (including 'Health', 'Education', 'Parking', 'Commercial', *etc.*). Although these are applicable to the Singapore context, we found that they are too broad and few in number for our purposes. Allowing stakeholders to search for a plot for a specific use or mix of uses, or the kinds of transportation and energy analyses envisioned in the Introduction, requires a more detailed list of services. Thus, we opted not to reuse this ontology.

3. Land use ontology for Taiwan [29]

   - Purpose and contents. Allowing users to retrieve land use data and semantic data linked to City GML data. The ontology contains land use classes such as 'Agriculture', 'Public use', or 'Traffic', as well as more specific subclasses for each one.
   - Reusability. Most of the classes in this ontology are not relevant to an urban development context, as the focus is more on agricultural land uses. In addition, the ontology is not available online, to the best of our knowledge. For these reasons, this ontology was not reused.

4. OSMOnto [13]

   - Purpose and contents. The purpose of this ontology is to link OSM tags for map locations to an ontology of activities. Rather than representing a domain, the aim is to facilitate the task of querying where to find activities of interest on the map, for example when planning a route. The ontology thus links OSM tags and activities. The Activity ontology (which is more relevant for our purposes) contains a wide range of classes, *e.g.* 'Charging station', 'Civil service' and 'Restaurant'.
   - Reusability. Despite this ontology's high granularity of activities, we opted not to reuse it. This is mainly because the ontology has a very different purpose than ours, which means that many of its activity classes and properties are irrelevant from our perspective. For example, the class 'Restaurant' has the property 'hasCuisineOfNationality', linking it to different countries. Another example of an overly granulated class is the Medicine class, which is

divided into a large number of specialisations (including nine subfields of internal medicine, among others).

A.3 OntoZoning debugger queries

The ontology was tested using the Protege debugger and through SPARQL queries. Below is an example of a SPARQL query which returns all the uses in which the programme 'Supermarket' may be allowed in. The query may be amended by replacing any values with prefix 'oz' with another concept or relationship in the ontology.

Query 1

```
PREFIX oz: <http://www.theworldavatar.com/ontology/ontozoning/OntoZoning.owl#>
PREFIX owl: <http://www.w3.org/2002/07/owl#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
SELECT ?o
WHERE {
    oz:Supermarket rdfs:subClassOf ?parent .
    ?parent rdfs:subClassOf ?x .
    ?x owl:onProperty oz:mayBeAllowedInUse .
    ?x owl:allValuesFrom ?o .
}
```

Query 1 results

```
OntoZoning.CommercialOrHotelUseCommercialAndResidentialZone | OntoZoning.
    WhiteUseBusiness2White | OntoZoning.CommercialUseHotelZone | OntoZoning.
    WhiteUseBusinessPark | OntoZoning.CommercialUseWhiteZone | OntoZoning.
    CommercialUseHealthAndMedicalCareZone | OntoZoning.ShopHouseUseGeneral |
    OntoZoning.WhiteUseBusiness1White | OntoZoning.CommercialUseCommercialZone |
    OntoZoning.CommercialUseWithoutDisamenity
```

The debugger tests are shown below in Table 1. We did not test those axioms that were explicitly stated when creating the ontology (see Appendices 4 to 7 A.4, A.5, A.6, A.7). Instead, we tested only axioms that should be inferred. These are relationships between uses and lower levels of the programme hierarchy. For example, if Supermarket is a subclass of Store, and Store may be allowed in the use CommercialUseWhiteZone, then the reasoner should be able to infer that Supermarket may also be allowed in that use. We conducted such tests for one subprogramme for each programme containing subprogrammes. These tests are expressed in description logic format in Table 1 below.

Table 1: *Entailed test cases used in debugging.*

Term	Axiom

(continues on next page)

Table 1: *Entailed test cases used in debugging. (*continued*)*

Term	Axiom
Supermarket	⊑ (Store ⊔ mayBeAllowedInUse ∀ (CommercialUseCommercialZone ⊔ CommercialUseWithoutDisamenity ⊔ CommercialUseHotelZone ⊔ CommercialUseWhiteZone ⊔ WhiteUseBusinessPark ⊔ WhiteUseBusiness1White ⊔ WhiteUseBusiness2White ⊔ CommercialUseHealthAndMedicalCareZone))
DrivingRange	subClassOf (Golf and allowedInUse ∀ GolfUse)
SupercomputingCentre	⊑ (DataProcessing and allowedInUse ∀ (MainUseBusinessPark ⊔ MainUseBusinessParkWhite))
PrototypeProduction	⊑ (ResearchAndDevelopment and allowedInUse ∀ (MainUseBusinessPark ⊔ MainUseBusinessParkWhite))
HotelLibrary	⊑ (HotelProgramme and allowedInUse ∀ (HotelUseHotelZone ⊔ HotelUseWhiteZone ⊔ HotelUseCommercialOrInstitutionZone ⊔ WhiteUseBusinessPark ⊔ CommercialUseWhiteZone ⊔ WhiteUseBusinessParkWhite ⊔ CommercialOrHotelUseCommercialAndResidentialZone))
TVNetworkProgramming	⊑ (CoreMedia and allowedInUse ∀ (MainUseBusinessPark ⊔ MainUseBusinessParkWhite ⊔ MainUseBusiness1 ⊔ MainUseBusiness2 ⊔ MainUseBusiness1White ⊔ MainUseBusiness2White))

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Table 1: *Entailed test cases used in debugging. (*continued*)*

Term	Axiom
DataFarmOrCentre	$\sqsubseteq$ (Ebusiness and allowedInUse $\forall$ (MainUseBusinessPark $\sqcup$ MainUseBusinessParkWhite $\sqcup$ MainUseBusiness1 $\sqcup$ MainUseBusiness2 $\sqcup$ MainUseBusiness1White $\sqcup$ MainUseBusiness2White))
BiotechLaboratory	$\sqsubseteq$ (TestLaboratory and allowedInUse $\forall$ (MainUseBusinessPark $\sqcup$ MainUseBusinessParkWhite))

A.4 OntoZoning zoning types and land uses

Table 2: *Description logic terms and axioms linking zoning types to land use types.*

Term	Axiom
Agriculture	$\sqsubseteq$ ZoningType $\sqcap$ $\forall$ allowsUse.(AgriculturalUse $\sqcup$ AncillaryAgriculturalUse)
Beach Area	$\sqsubseteq$ ZoningType $\sqcap$ $\forall$ allowsUse.CoastalRecreationUse
Business1	$\sqsubseteq$ ZoningType $\sqcap$ $\forall$ allowsUse.(MainUseBusiness1 $\sqcup$ AncillaryUseBusiness1 $\sqcup$ CommercialUseBusiness1)
Business1 White	$\sqsubseteq$ ZoningType $\sqcap$ $\forall$ allowsUse.(MainUseBusiness1White $\sqcup$ AncillaryUseBusiness1White $\sqcup$ PrivateMedicalClinicBusiness1White $\sqcup$ WhiteUseBusiness1White)
Business2	$\sqsubseteq$ ZoningType $\sqcap$ $\forall$ allowsUse.(MainUseBusiness2 $\sqcup$ AncillaryUseBusiness2)
Business2 White	$\sqsubseteq$ ZoningType $\sqcap$ $\forall$ allowsUse.(MainUseBusiness2White $\sqcup$ AncillaryUseBusiness2White $\sqcup$ PrivateMedicalClinicBusiness2White $\sqcup$ WhiteUseBusiness2White)
Business Park	$\sqsubseteq$ ZoningType $\sqcap$ $\forall$ allowsUse.(MainUseBusinessPark $\sqcup$ AncillaryUseBusinessPark $\sqcup$ PrivateMedicalClinicBusinessPark $\sqcup$ WhiteUseBusinessPark)
Business Park White	$\sqsubseteq$ ZoningType $\sqcap$ $\forall$ allowsUse.(MainUseBusinessParkWhite $\sqcup$ AncillaryUseBusinessParkWhite $\sqcup$ PrivateMedicalClinicBusinessParkWhite $\sqcup$ WhiteUseBusinessParkWhite)
Cemetery	$\sqsubseteq$ ZoningType $\sqcap$ $\forall$ allowsUse.CemeteryUse
Civic And Community Institution Zone	$\sqsubseteq$ ZoningType $\sqcap$ $\forall$ allowsUse.(CivicInstitutionUse $\sqcup$ CulturalInstitutionUse $\sqcup$ CommunityInstitutionUseCivicAnd-CommunityInstitutionZone)
Commercial	$\sqsubseteq$ ZoningType $\sqcap$ $\forall$ allowsUse.(CommercialUseCommercialZone $\sqcup$ PrivateMedicalClinicCommercialZone) $\sqcap$ $\forall$ mayAllowUse.CommercialUseCommercialZone
Commercial And Residential	$\sqsubseteq$ ZoningType $\sqcap$ $\forall$ allow-sUse.(CommercialOrHotelUseCommercialAndResidentialZone $\sqcup$ PrivateMedicalClinicCommercialAndResidentialZone $\sqcup$ FlatOrCondominiumUseCommercialAndResidentialZone)

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Table 2: *Description logic terms and axioms linking zoning types to land use types (*continued*)*

Term	Axiom
Commercial Or Institution	$\sqsubseteq$ ZoningType $\sqcap$ $\forall$ allowsUse.(CommercialUseCommercialOrInstitutionZone $\sqcup$ RecreationClubUseCommercialOrInstitutionZone $\sqcup$ CommunityInstitutionExcludingDormitoryAndFuneral) $\sqcap$ $\forall$ mayAllowUse.CommercialUseCommercialOrInstitutionZone $\sqcap$ $\forall$ mayAllowUse.CommercialUseCommercialOrInstitutionZone
Educational Institution	$\sqsubseteq$ ZoningType $\sqcap$ $\forall$ allowsUse.(EducationalInstitutionUse $\sqcup$ AncillarylUseEducationalInstitutionZone)
Health And Medical Care	$\sqsubseteq$ ZoningType $\sqcap$ $\forall$ allowsUse.(MedicalUse $\sqcup$ AncillaryVisitorHostel $\sqcup$ CommercialUseHealthAndMedicalCareZone $\sqcup$ OtherAncillaryUseHealthAndMedicalCareZone)
Hotel Zone	$\sqsubseteq$ ZoningType $\sqcap$ $\forall$ allowsUse.(HotelUseHotelZone $\sqcup$ CommercialUseHotelZone $\sqcup$ PrivateMedicalClinicHotelZone)
Open Space	$\sqsubseteq$ ZoningType $\sqcap$ $\forall$ allowsUse.(UnbuiltOpenSpace $\sqcup$ BuiltOpenSpace)
Park	$\sqsubseteq$ ZoningType $\sqcap$ $\forall$ allowsUse.(ParkUse $\sqcup$ GardenUse $\sqcup$ PedestrianLinkage)
Place Of Worship	$\sqsubseteq$ ZoningType $\sqcap$ $\forall$ allowsUse.(PredominantReligiousUse $\sqcup$ ColumbariumUse $\sqcup$ AncillaryReligiousUse $\sqcup$ AncillaryNonReligiousUse)
Port Or Airport	$\sqsubseteq$ ZoningType $\sqcap$ $\forall$ allowsUse.(AirportUse $\sqcup$ PortUse)
Rapid Transit	$\sqsubseteq$ ZoningType $\sqcap$ $\forall$ allowsUse.RapidTransitUse
Reserve Site	$\sqsubseteq$ ZoningType $\sqcap$ $\forall$ allowsUse.(UndeterminedUse $\sqcup$ InterimUse)
Residential	$\sqsubseteq$ ZoningType $\sqcap$ $\forall$ allowsUse.(FlatOrCondominiumUseResidentialZone $\sqcup$ FlatOrCondominiumAncillaryShopUseResidentialZone $\sqcup$ LandedHousingUse $\sqcup$ RetirementHousingUse $\sqcup$ StudentHostelUse $\sqcup$ ServicedApartmentUse $\sqcup$ ServicedApartmentAncillaryUse)

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Table 2: *Description logic terms and axioms linking zoning types to land use types (*continued*)*

Term	Axiom
Residential Or Institution	$\sqsubseteq$ ZoningType $\sqcap$ $\forall$ allowsUse.(FlatOrCondominiumUseResidentialOrInstitutionZone $\sqcup$ FlatOrCondominiumAncillaryUseResidentialOrInstitutionZone $\sqcup$ CommunityInstitutionResidentialOrInstitutionZone)
Residential With Commercial At First Storey	$\sqsubseteq$ ZoningType $\sqcap$ $\forall$ allowsUse.(FlatOrCondominiumUseInResidentialWithCommercialAtFirstStorey $\sqcup$ ShopHouseUseGeneral $\sqcup$ CommercialUseWithoutDisamenity $\sqcup$ PrivateMedicalClinicResidentialWithCommercialAtFirstStorey)
Road	$\sqsubseteq$ ZoningType $\sqcap$ $\forall$ allowsUse.(RoadUse $\sqcup$ OtherUseUnderElevatedRoad)
Special Use Zone	$\sqsubseteq$ ZoningType $\sqcap$ $\forall$ allowsUse.SpecialUse
Sports And Recreation	$\sqsubseteq$ ZoningType $\sqcap$ $\forall$ allowsUse.(SportsComplexUse $\sqcup$ WaterSportsCentreUse $\sqcup$ StadiumUse $\sqcup$ GolfUse $\sqcup$ RecreationClubUse $\sqcup$ ResortUse $\sqcup$ MarinaUse)
Transport Facilities	$\sqsubseteq$ ZoningType $\sqcap$ $\forall$ allowsUse.VehicleParkingUse
Utility	$\sqsubseteq$ ZoningType $\sqcap$ $\forall$ allowsUse.(PublicInstallationUse $\sqcup$ PublicUtilityUse $\sqcup$ InfrastructureUse $\sqcup$ TelecommunicationUse)
Waterbody	$\sqsubseteq$ ZoningType $\sqcap$ $\forall$ allowsUse.(DrainageUse $\sqcup$ WaterAreaUse)
White	$\sqsubseteq$ ZoningType $\sqcap$ $\forall$ allowsUse.(FlatOrCondominiumUseWhiteZone $\sqcup$ FlatOrCondominiumAncillaryShopUseWhiteZone $\sqcup$ ServicedApartmentUseWhiteZone $\sqcup$ ServicedApartmentAncillaryUseWhiteZone $\sqcup$ CommercialUseWhiteZone $\sqcup$ PrivateMedicalClinicWhiteZone $\sqcup$ HotelUseWhiteZone $\sqcup$ RecreationClubUseWhiteZone)

A.5 OntoZoning land use types and programme types

Table 3: *Description logic terms and axioms linking land use types to programme types (the top level of the programme type hierarchy).*

Term	Axiom
Agricultural Use	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(OpenAirAgriculture $\sqcup$ CoveredAgriculture) $\sqcap$ $\forall$ mayAllowProgramme.Farming,Tilling,Plowing,Harvesting,RelatedActivities
Airport Use	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(AirportTerminal $\sqcup$ AirportFacility $\sqcup$ LandingSite) $\sqcap$ $\forall$ mayAllowProgramme.AircraftTakeoff,Landing,Taxiing,Parking
Ancillary Agricultural Use	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(Office $\sqcup$ WorkersQuarters $\sqcup$ Restaurant $\sqcup$ Showroom $\sqcup$ Shop)
Ancillary Non Religious Use	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(Library $\sqcup$ ConferenceRoom $\sqcup$ ChildcareCentre $\sqcup$ Kindergarten $\sqcup$ MeetingRoom)
Ancillary Religious Use	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(ReligiousClassroom $\sqcup$ PriestRoom)
Ancillary Use Business1	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(Showroom $\sqcup$ ChildCareCentre $\sqcup$ IndustrialCanteen $\sqcup$ WorkersDormitory $\sqcup$ MeetingRoom $\sqcup$ AncillaryDisplayArea)
Ancillary Use Business1 White	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(Showroom $\sqcup$ ChildCareCentre $\sqcup$ IndustrialCanteen $\sqcup$ WorkersDormitory $\sqcup$ MeetingRoom $\sqcup$ AncillaryDisplayArea)
Ancillary Use Business2	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(Office $\sqcup$ MeetingRoom $\sqcup$ Showroom $\sqcup$ IndustrialCanteen $\sqcup$ DieselAndPumpPoint $\sqcup$ SickRoom $\sqcup$ M&EServices)
Ancillary Use Business2 White	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(AncillaryOffice $\sqcup$ MeetingRoom $\sqcup$ Showroom $\sqcup$ IndustrialCanteen $\sqcup$ DieselAndPumpPoint $\sqcup$ SickRoom $\sqcup$ M&EServices)
Ancillary Use Business Park	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(AncillaryOffice $\sqcup$ SickRoom $\sqcup$ IndustrialCanteen $\sqcup$ ChildcareCentre $\sqcup$ MeetingRoom $\sqcup$ Showroom)
Ancillary Use Business Park White	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(AncillaryOffice $\sqcup$ SickRoom $\sqcup$ IndustrialCanteen $\sqcup$ ChildcareCentre $\sqcup$ MeetingRoom $\sqcup$ Showroom)
Ancillary Visitor Hostel	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.HospitalVisitorsHostel

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Table 3: *Description logic terms and axioms linking land use types to programme types (*continued*)*

Term	Axiom
Ancillaryl Use Educational Institution Zone	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(Restaurant $\sqcup$ Cafe $\sqcup$ BookStore $\sqcup$ HairSalon $\sqcup$ MiniMart $\sqcup$ Bank $\sqcup$ TravelAgency $\sqcup$ Clinic $\sqcup$ StudentRunBusiness) $\sqcap$ $\forall$ mayAllowProgramme.(Restaurant-typeActivity $\sqcup$ Shopping $\sqcup$ GoodsOrientedShopping $\sqcup$ ServiceOrientedShopping $\sqcup$ Dentist $\sqcup$ Doctor $\sqcup$ Physiotherapist)
Built Open Space	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(PublicPromenade $\sqcup$ OutdoorPedestrianMall $\sqcup$ LandscapedPlaza) $\sqcap$ $\forall$ mayAllow-Programme.HistoricalOrCulturalCelebrations,Parades,Etc
Cemetery Use	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(Cemetery $\sqcup$ Crematory $\sqcup$ Columbaria) $\sqcap$ $\forall$ mayAllowPro-gramme.Interment,Cremation,GraveDiggingActivities
Civic Institution Use	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(Courts $\sqcup$ PoliceStation $\sqcup$ FireStation $\sqcup$ Prison $\sqcup$ DrugRehabilitationCentre) $\sqcap$ $\forall$ mayAllowProgramme.(EmergencyResponse,Public-safetyActivities $\sqcup$ FireAndRescueActivities $\sqcup$ Emergency,DisasterResponseActivities $\sqcup$ Police,Security,ProtectionActivities)
Coastal Recreation Use	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ mayAllowPro-gramme.(WaterSportsAndRelatedLeisureActivities $\sqcup$ CampingActivities $\sqcup$ PromenadingAndOtherActivitiesInParks $\sqcup$ Water-skiing $\sqcup$ Boating,Sailing,Etc $\sqcup$ Canoeing,Kayaking,Etc $\sqcup$ Fishing,Angling,Etc $\sqcup$ ScubaDiving,Snorkeling,Etc $\sqcup$ Swimming,Diving,Etc)
Columbarium Use	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.Columbarium
Commercial Or Hotel Use Commercial And Residential Zone	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(Shop $\sqcup$ Office $\sqcup$ Mall $\sqcup$ ConventionCentre $\sqcup$ ExhibitionCentre $\sqcup$ CommercialSchool $\sqcup$ Bank $\sqcup$ Market $\sqcup$ FoodCentre $\sqcup$ Restaurant $\sqcup$ Cinema $\sqcup$ Entertainment $\sqcup$ TradeMission $\sqcup$ HotelProgramme) $\sqcap$ $\forall$ mayAllowProgramme.(Store $\sqcup$ Nightclub $\sqcup$ KaraokeBar $\sqcup$ Bar $\sqcup$ BeautySalon $\sqcup$ HairCare $\sqcup$ Spa $\sqcup$ Dentist $\sqcup$ Doctor $\sqcup$ Physiotherapist $\sqcup$ PostOffice $\sqcup$ Cafe $\sqcup$ CarDealer $\sqcup$ CarRental $\sqcup$ CarRepair $\sqcup$ CarWash $\sqcup$ VeterinaryCare $\sqcup$ ArtGallery $\sqcup$ BowlingAlley $\sqcup$ Embassy $\sqcup$ Gym $\sqcup$ Laundry $\sqcup$ School $\sqcup$ Lodging $\sqcup$ OfficeActivities $\sqcup$ Restaurant-typeActivity $\sqcup$ Shopping $\sqcup$ GoodsOrientedShopping $\sqcup$ ServiceOrientedShopping)

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Table 3: *Description logic terms and axioms linking land use types to programme types (*continued*)*

Term	Axiom
Commercial Use Business1	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(Clinic $\sqcup$ Bank $\sqcup$ Minimart $\sqcup$ Gym $\sqcup$ FitnessCentre)
Commercial Use Commercial Or Institution Zone	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(Entertainment $\sqcup$ Office $\sqcup$ Bank $\sqcup$ Shop $\sqcup$ CommercialSchool $\sqcup$ FoodCentre $\sqcup$ Restaurant) $\sqcap$ $\forall$ mayAllowProgramme.(OfficeActivities $\sqcup$ Restaurant-typeActivity $\sqcup$ Shopping $\sqcup$ GoodsOrientedShopping $\sqcup$ ServiceOrientedShopping $\sqcup$ BeautySalon $\sqcup$ HairCare $\sqcup$ Spa $\sqcup$ Dentist $\sqcup$ Doctor $\sqcup$ Physiotherapist $\sqcup$ PostOffice $\sqcup$ Cafe $\sqcup$ CarDealer $\sqcup$ CarRental $\sqcup$ CarRepair $\sqcup$ CarWash $\sqcup$ VeterinaryCare $\sqcup$ ArtGallery $\sqcup$ BowlingAlley $\sqcup$ Embassy $\sqcup$ Gym $\sqcup$ Laundry $\sqcup$ School)
Commercial Use Commercial Zone	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(Shop $\sqcup$ Office $\sqcup$ Mall $\sqcup$ ConventionCentre $\sqcup$ ExhibitionCentre $\sqcup$ CommercialSchool $\sqcup$ Bank $\sqcup$ Market $\sqcup$ FoodCentre $\sqcup$ Restaurant $\sqcup$ Cinema $\sqcup$ Entertainment $\sqcup$ TradeMission) $\sqcap$ $\forall$ mayAllowProgramme.(Store $\sqcup$ Nightclub $\sqcup$ KaraokeBar $\sqcup$ Bar $\sqcup$ BeautySalon $\sqcup$ HairCare $\sqcup$ Spa $\sqcup$ Dentist $\sqcup$ Doctor $\sqcup$ Physiotherapist $\sqcup$ PostOffice $\sqcup$ Cafe $\sqcup$ CarDealer $\sqcup$ CarRental $\sqcup$ CarRepair $\sqcup$ CarWash $\sqcup$ VeterinaryCare $\sqcup$ ArtGallery $\sqcup$ BowlingAlley $\sqcup$ Embassy $\sqcup$ Gym $\sqcup$ Laundry $\sqcup$ School $\sqcup$ OfficeActivities $\sqcup$ Restaurant-typeActivity $\sqcup$ Shopping $\sqcup$ GoodsOrientedShopping $\sqcup$ ServiceOrientedShopping)
Commercial Use Health And Medical Care Zone	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(Pharmacy $\sqcup$ Shop $\sqcup$ Restaurant $\sqcup$ Cafe $\sqcup$ Bakery $\sqcup$ Bar $\sqcup$ Bank) $\sqcap$ $\forall$ mayAllowProgramme.(Store $\sqcup$ Restaurant-typeActivity $\sqcup$ Shopping $\sqcup$ GoodsOrientedShopping $\sqcup$ ServiceOrientedShopping)
Commercial Use Hotel Zone	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(Shop $\sqcup$ Restaurant $\sqcup$ Bar) $\sqcap$ $\forall$ mayAllowProgramme.(Store $\sqcup$ Nightclub $\sqcup$ BeautySalon $\sqcup$ HairCare $\sqcup$ Spa $\sqcup$ Dentist $\sqcup$ Doctor $\sqcup$ Physiotherapist $\sqcup$ PostOffice $\sqcup$ Cafe $\sqcup$ CarDealer $\sqcup$ CarRental $\sqcup$ CarRepair $\sqcup$ CarWash $\sqcup$ VeterinaryCare $\sqcup$ ArtGallery $\sqcup$ BowlingAlley $\sqcup$ Embassy $\sqcup$ Gym $\sqcup$ Laundry $\sqcup$ School $\sqcup$ OfficeActivities $\sqcup$ Restaurant-typeActivity $\sqcup$ Shopping $\sqcup$ GoodsOrientedShopping $\sqcup$ ServiceOrientedShopping)

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Table 3: *Description logic terms and axioms linking land use types to programme types (*continued*)*

Term	Axiom
Commercial Use White Zone	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(Shop $\sqcup$ Office $\sqcup$ Mall $\sqcup$ ConventionCentre $\sqcup$ ExhibitionCentre $\sqcup$ CommercialSchool $\sqcup$ Bank $\sqcup$ Market $\sqcup$ FoodCentre $\sqcup$ Restaurant $\sqcup$ Cinema $\sqcup$ Entertainment $\sqcup$ TradeMission $\sqcup$ HotelProgramme) $\sqcap$ $\forall$ mayAllowProgramme.(Store $\sqcup$ Nightclub $\sqcup$ KaraokeBar $\sqcup$ Bar $\sqcup$ BeautySalon $\sqcup$ HairCare $\sqcup$ Spa $\sqcup$ Dentist $\sqcup$ Doctor $\sqcup$ Physiotherapist $\sqcup$ PostOffice $\sqcup$ Cafe $\sqcup$ CarDealer $\sqcup$ CarRental $\sqcup$ CarRepair $\sqcup$ CarWash $\sqcup$ VeterinaryCare $\sqcup$ ArtGallery $\sqcup$ BowlingAlley $\sqcup$ Embassy $\sqcup$ Gym $\sqcup$ Laundry $\sqcup$ School $\sqcup$ OfficeActivities $\sqcup$ Restaurant-typeActivity $\sqcup$ Shopping $\sqcup$ GoodsOrientedShopping $\sqcup$ ServiceOrientedShopping)
Commercial Use Without Disamenity	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(Shop $\sqcup$ Mall $\sqcup$ ConventionCentre $\sqcup$ ExhibitionCentre $\sqcup$ CommercialSchool $\sqcup$ Bank $\sqcup$ Market $\sqcup$ FoodCentre $\sqcup$ Restaurant $\sqcup$ Cinema $\sqcup$ Entertainment $\sqcup$ TradeMission) $\sqcap$ $\forall$ mayAllowProgramme.(Office $\sqcup$ Store $\sqcup$ BeautySalon $\sqcup$ HairCare $\sqcup$ Spa $\sqcup$ Dentist $\sqcup$ Doctor $\sqcup$ Physiotherapist $\sqcup$ PostOffice $\sqcup$ Cafe $\sqcup$ CarDealer $\sqcup$ CarRental $\sqcup$ CarRepair $\sqcup$ CarWash $\sqcup$ VeterinaryCare $\sqcup$ ArtGallery $\sqcup$ BowlingAlley $\sqcup$ Embassy $\sqcup$ Gym $\sqcup$ Laundry $\sqcup$ School $\sqcup$ OfficeActivities $\sqcup$ Restaurant-typeActivity $\sqcup$ Shopping $\sqcup$ GoodsOrientedShopping $\sqcup$ ServiceOrientedShopping)
Community Institution Excluding Dormitory And Funeral	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(ChildCareCentre $\sqcup$ CommunityCentre $\sqcup$ CommunityHall $\sqcup$ WelfareHome $\sqcup$ HomeForTheAged $\sqcup$ HomeForTheDisabled $\sqcup$ AssociationPremise)
Community Institution Residential Or Institution Zone	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(AssociationPremise $\sqcup$ CommunityCentre $\sqcup$ CommunityHall $\sqcup$ WelfareHome $\sqcup$ ChildCareCentre $\sqcup$ HomeForTheAged $\sqcup$ HomeForTheDisabled)
Community Institution Use Civic And Community Institution Zone	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(ChildCareCentre $\sqcup$ CommunityCentre $\sqcup$ CommunityHall $\sqcup$ WelfareHome $\sqcup$ HomeForTheAged $\sqcup$ HomeForTheDisabled $\sqcup$ AssociationPremise $\sqcup$ FuneralParlour $\sqcup$ WorkersDormitory)

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Table 3: *Description logic terms and axioms linking land use types to programme types (*continued*)*

Term	Axiom
Cultural Institution Use	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(TelevisionOrFilmingStudioComplex $\sqcup$ PerformingArtsCentre $\sqcup$ Library $\sqcup$ Museum $\sqcup$ ArtsCentre $\sqcup$ ScienceCentre $\sqcup$ ConcertHall) $\sqcap$ $\forall$ mayAllowProgramme.(Movies,Concerts,EntertainmentShows $\sqcup$ GatheringsAtMuseums,Aquariums,ZoologicalParks,Etc $\sqcup$ Social,Cultural,ReligiousAssembly $\sqcup$ GatheringsAtFairsAndExhibitions)
Drainage Use	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(MajorDrain $\sqcup$ Canal) $\sqcap$ $\forall$ mayAllowProgramme.(FloodControl,Dams,OtherLargeIrrigationActivities $\sqcup$ IrrigationWaterStorageAndDistributionActivities)
Educational Institution Use	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(Kindergarten $\sqcup$ PrimarySchool $\sqcup$ SecondarySchool $\sqcup$ Polytechnic $\sqcup$ JuniorCollege $\sqcup$ InstituteOfTechnicalEducation $\sqcup$ TrainingInstitute $\sqcup$ University $\sqcup$ ForeignSchool $\sqcup$ SpecialEducationSchool) $\sqcap$ $\forall$ mayAllowProgramme.(SchoolOrLibraryActivities $\sqcup$ Classroom-typeActivities $\sqcup$ OtherInstructionalActivities $\sqcup$ TrainingOrInstructionalActivitiesOutsideClassrooms)
Flat Or Condominium Ancillary Shop Use Residential Zone	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(PersonalServiceTrade $\sqcup$ Laundromat $\sqcup$ Minimart)
Flat Or Condominium Ancillary Shop Use White Zone	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(PersonalServiceTrade $\sqcup$ Laundromat $\sqcup$ Minimart)
Flat Or Condominium Ancillary Use Residential Or Institution Zone	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(PersonalServiceTrade $\sqcup$ Laundromat $\sqcup$ Minimart)
Flat Or Condominium Use Commercial And Residential Zone	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(Flat $\sqcup$ Condominium) $\sqcap$ $\forall$ mayAllowProgramme.HouseholdActivities

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Table 3: *Description logic terms and axioms linking land use types to programme types (*continued*)*

Term	Axiom
Flat Or Condominium Use Commercial Or Institution	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(Flat $\sqcup$ Condominium)
Flat Or Condominium Use In Residential With Commercial At First Storey	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(Flat $\sqcup$ Condominium) $\sqcap$ $\forall$ mayAllowProgramme.HouseholdActivities
Flat Or Condominium Use Residential Or Institution Zone	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(Flat $\sqcup$ Condominium)
Flat Or Condominium Use Residential Zone	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(Flat $\sqcup$ Condominium) $\sqcap$ $\forall$ mayAllowProgramme.HouseholdActivities
Flat Or Condominium Use White Zone	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(Flat $\sqcup$ Condominium) $\sqcap$ $\forall$ mayAllowProgramme.HouseholdActivities
Garden Use	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(ZoologicalGarden $\sqcup$ BotanicGarden) $\sqcap$ $\forall$ mayAllowProgramme.PromenadingAndOtherActivitiesInParks
Golf Use	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(Golf $\sqcup$ Golf $\sqcup$ Restaurant $\sqcup$ Bar)
Hotel Use Commercial Or Institution Zone	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.HotelProgramme $\sqcap$ $\forall$ mayAllowProgramme.Lodging
Hotel Use Hotel Zone	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.HotelProgramme $\sqcap$ $\forall$ mayAllowProgramme.(TransientLiving $\sqcup$ Lodging)
Hotel Use White Zone	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.HotelProgramme $\sqcap$ $\forall$ mayAllowProgramme.(TransientLiving $\sqcup$ Lodging)

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Table 3: *Description logic terms and axioms linking land use types to programme types (*continued*)*

Term	Axiom
Infrastructure Use	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(WaterTreatmentPlant $\sqcup$ WaterReclamationPlant $\sqcup$ ServiceReservoir $\sqcup$ WaterPumpHouse $\sqcup$ SewagePumpingStation $\sqcup$ IncinerationPlant $\sqcup$ DesalinationPlant $\sqcup$ TransmittingStation) $\sqcap$ $\forall$ mayAllowProgramme.(SolidWasteManagementActivities $\sqcup$ LandfillingOrDumping $\sqcup$ SolidWasteCollectionAndStorage $\sqcup$ WasteProcessingOrRecycling $\sqcup$ WaterPurificationAndFiltrationActivities $\sqcup$ WaterStoring,Pumping,Piping $\sqcup$ Sewer-relatedControl,Monitor,DistributionActivities $\sqcup$ SewerTreatmentAndProcessing $\sqcup$ SewageStoring,Pumping,Piping $\sqcup$ TelecommunicationsControl,Monitor,DistributionActivities)
Interim Use	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.InterimProgramme
Landed Housing Use	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(Strata-LandedHousingUse $\sqcup$ BungalowUse $\sqcup$ TerraceHouseUse $\sqcup$ Semi-DetachedHousingUse $\sqcup$ Townhouse $\sqcup$ DetachedHouse) $\sqcap$ $\forall$ mayAllowProgramme.HouseholdActivities
Main Use Business1	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(LightIndustryUse $\sqcup$ FoodPackingUse $\sqcup$ PrintingOrPublishing $\sqcup$ IndustrialTrainingUse $\sqcup$ CoreMedia $\sqcup$ Ebusiness) $\sqcap$ $\forall$ mayAllowProgramme.(TelecommunicationsControl,Monitor,DistributionActivities $\sqcup$ PrimarilyGoodsStorageOrHandlingActivities)
Main Use Business1 White	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(LightIndustryUse $\sqcup$ FoodPackingUse $\sqcup$ PrintingOrPublishing $\sqcup$ IndustrialTrainingUse $\sqcup$ CoreMedia $\sqcup$ Ebusiness) $\sqcap$ $\forall$ mayAllowProgramme.(TelecommunicationsControl,Monitor,DistributionActivities $\sqcup$ PrimarilyGoodsStorageOrHandlingActivities)

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Table 3: *Description logic terms and axioms linking land use types to programme types (*continued*)*

Term	Axiom
Main Use Business2	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(ManufacturingGeneral $\sqcup$ RepairAndServicingUse $\sqcup$ ProductionUse $\sqcup$ StorageOfChemicalsOils $\sqcup$ AssemblyUse $\sqcup$ KnittingMill $\sqcup$ CoreMedia $\sqcup$ Ebusiness $\sqcup$ IndustrialTrainingUse) $\sqcap$ $\forall$ mayAllowProgramme.(TelecommunicationsControl,Monitor,DistributionActivities $\sqcup$ PrimarilyGoodsStorageOrHandlingActivities $\sqcup$ PrimarilyPlantOrFactoryActivities $\sqcup$ Plant,Factory,HeavyGoodsStorageOrHandlingActivities $\sqcup$ ConstructionActivities $\sqcup$ StorageOfChemical,Nuclear,OtherMaterials)
Main Use Business2 White	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(ManufacturingGeneral $\sqcup$ RepairAndServicingUse $\sqcup$ ProductionUse $\sqcup$ StorageOfChemicalsOils $\sqcup$ AssemblyProgramme $\sqcup$ KnittingMill $\sqcup$ CoreMedia $\sqcup$ Ebusiness $\sqcup$ IndustrialTrainingUse) $\sqcap$ $\forall$ mayAllowProgramme.(TelecommunicationsControl,Monitor,DistributionActivities $\sqcup$ PrimarilyGoodsStorageOrHandlingActivities $\sqcup$ PrimarilyPlantOrFactoryActivities $\sqcup$ Plant,Factory,HeavyGoodsStorageOrHandlingActivities $\sqcup$ ConstructionActivities $\sqcup$ StorageOfChemical,Nuclear,OtherMaterials)
Main Use Business Park	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(ResearchAndDevelopment $\sqcup$ DataProcessing $\sqcup$ CentralDistributionCentre $\sqcup$ TestLaboratory $\sqcup$ ProductDesignOrDevelopment $\sqcup$ HighTechManufacturing $\sqcup$ CoreMedia $\sqcup$ IndustrialTraining $\sqcup$ Ebusiness)
Main Use Business Park White	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(ResearchAndDevelopment $\sqcup$ DataProcessing $\sqcup$ CentralDistributionCentre $\sqcup$ TestLaboratory $\sqcup$ ProductDesignOrDevelopment $\sqcup$ HighTechManufacturing $\sqcup$ CoreMedia $\sqcup$ IndustrialTraining $\sqcup$ Ebusiness)

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Table 3: *Description logic terms and axioms linking land use types to programme types (*continued*)*

Term	Axiom
Marina Use	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.Marina $\sqcap$ $\forall$ mayAllowProgramme.(BoatMooring,Docking,Servicing $\sqcup$ Port,Ship-building,RelatedActivities $\sqcup$ Sailing,Boating,OtherPort,MarineAndWater-basedActivities $\sqcup$ Water-skiing $\sqcup$ Boating,Sailing,Etc $\sqcup$ Canoeing,Kayaking,Etc $\sqcup$ Fishing,Angling,Etc)
Medical Use	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(InpatientFacility $\sqcup$ NursingHome $\sqcup$ OutpatientFacility $\sqcup$ Clinic $\sqcup$ MedicalSuite $\sqcup$ DiagnosticFacility $\sqcup$ TratmentFacility $\sqcup$ NursingBedArea $\sqcup$ Dispensary $\sqcup$ ClinicalResearchFacility $\sqcup$ MedicalAdministrationSpace) $\sqcap$ $\forall$ mayAllowProgramme.(Dentist $\sqcup$ Doctor $\sqcup$ Physiotherapist $\sqcup$ HealthCare,Medical,TreatmentActivities)
Other Ancillary Use Health And Medical Care Zone	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(MedicalStaffFacility $\sqcup$ GeneralAdministrationSpace)
Other Use Under Elevated Road	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.OtherProgramme
Park Use	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(NationalPark $\sqcup$ RegionalPark $\sqcup$ CommunityPark $\sqcup$ NeighbourhoodPark) $\sqcap$ $\forall$ mayAllowProgramme.PromenadingAndOtherActivitiesInParks
Pedestrian Linkage	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.ParkConnector $\sqcap$ $\forall$ mayAllowProgramme.(PedestrianMovement $\sqcup$ HistoricalOrCulturalCelebrations,Parades,Etc $\sqcup$ PromenadingAndOtherActivitiesInParks)
Port Use	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(PortTerminal $\sqcup$ PortFacility $\sqcup$ CruiseCentre $\sqcup$ FishingPort) $\sqcap$ $\forall$ mayAllowProgramme.(BoatMooring,Docking,Servicing $\sqcup$ Port,Ship-building,RelatedActivities $\sqcup$ Sailing,Boating,OtherPort,MarineAndWater-basedActivities)
Predominant Religious Use	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.PrayingArea
Private Medical Clinic Business1 White	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.Clinic

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Table 3: *Description logic terms and axioms linking land use types to programme types (*continued*)*

Term	Axiom
Private Medical Clinic Business2 White	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.Clinic
Private Medical Clinic Business Park	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.Clinic
Private Medical Clinic Business Park White	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.Clinic
Private Medical Clinic Commercial And Residential Zone	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.Clinic
Private Medical Clinic Commercial Zone	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.Clinic
Private Medical Clinic Hotel Zone	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.Clinic
Private Medical Clinic Residential With Commercial At First Storey	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.Clinic
Private Medical Clinic White Zone	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.Clinic
Public Installation Use	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.ElectricalSubstation
Public Utility Use	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(PowerStation $\sqcup$ GasInstallation $\sqcup$ NaturalGasReceivingTerminal $\sqcup$ GasTakeoffStation) $\sqcap$ $\forall$ mayAllowProgramme.(PrimarilyPlantOrFactoryActivities $\sqcup$ PowerGeneration,Control,Monitor,DistributionActivities $\sqcup$ PowerTransmissionLinesOrControlActivities $\sqcup$ PowerGeneration,Control,Monitor,DistributionActivities $\sqcup$ NaturalGasOrFuelsControl,Monitor,DistributionActivities $\sqcup$ StorageOfNaturalGas,Fuels,Etc)

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Table 3: *Description logic terms and axioms linking land use types to programme types (*continued*)*

Term	Axiom
Rapid Transit Use	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.RapidTransitStation $\sqcap$ $\forall$ mayAllowProgramme.(PassengerAssembly $\sqcup$ TrainsOrOtherRailMovement)
Recreation Club Use	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.RecreationClub $\sqcap$ $\forall$ mayAllowProgramme.(BowlingAlley $\sqcup$ Gym $\sqcup$ Swimming,Diving,Etc $\sqcup$ Tennis $\sqcup$ Running,Jogging,Bicycling,Aerobics,Exercising,Etc)
Recreation Club Use Commercial Or Institution Zone	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.RecreationClub $\sqcap$ $\forall$ mayAllowProgramme.(BowlingAlley $\sqcup$ Gym $\sqcup$ Swimming,Diving,Etc $\sqcup$ Tennis $\sqcup$ Running,Jogging,Bicycling,Aerobics,Exercising,Etc)
Recreation Club Use Commercial Zone	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(RecreationClub $\sqcup$ RecreationClub) $\sqcap$ $\forall$ mayAllowProgramme.(BowlingAlley $\sqcup$ Gym $\sqcup$ Swimming,Diving,Etc $\sqcup$ Tennis $\sqcup$ Running,Jogging,Bicycling,Aerobics,Exercising,Etc)
Recreation Club Use White Zone	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.RecreationClub $\sqcap$ $\forall$ mayAllowProgramme.(BowlingAlley $\sqcup$ Gym $\sqcup$ Swimming,Diving,Etc $\sqcup$ Tennis $\sqcup$ Running,Jogging,Bicycling,Aerobics,Exercising,Etc)
Resort Use	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.Resort $\sqcap$ $\forall$ mayAllowProgramme.Flying,Air-relatedSports
Retirement Housing Use	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.RetirementHousing $\sqcap$ $\forall$ mayAllowProgramme.InstitutionalLiving
Road Use	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(Expressway $\sqcup$ Semi-Expressway $\sqcup$ MajorArterialRoad $\sqcup$ ArterialRoad $\sqcup$ PrimaryAccessRoad $\sqcup$ LocalAccessRoad $\sqcup$ ServiceRoadOrBacklane) $\sqcap$ $\forall$ mayAllowProgramme.(VehicularMovement $\sqcup$ Drive-in,DriveThrough,Stop-n-go,Etc $\sqcup$ VehicularParking,Storage,Etc $\sqcup$ HistoricalOrCulturalCelebrations,Parades,Etc)
Serviced Apartment Ancillary Use	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(Bar $\sqcup$ Lounge)

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Table 3: *Description logic terms and axioms linking land use types to programme types (*continued*)*

Term	Axiom
Serviced Apartment Ancillary Use White Zone	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(Bar $\sqcup$ Lounge)
Serviced Apartment Use	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.ServicedApartment $\sqcap$ $\forall$ mayAllowProgramme.(TransientLiving $\sqcup$ HouseholdActivities)
Serviced Apartment Use White Zone	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.ServicedApartment $\sqcap$ $\forall$ mayAllowProgramme.(HouseholdActivities $\sqcup$ TransientLiving)
Shop House Use General	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ mayAllowProgramme.(HouseholdActivities $\sqcup$ Store)
Special Use	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.SpecialProgramme
Sports Complex Use	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.SportsComplex $\sqcap$ $\forall$ mayAllowProgramme.(SpectatorSportsAssembly $\sqcup$ Tennis $\sqcup$ Hockey,IceSkating,Etc $\sqcup$ Running,Jogging,Bicycling,Aerobics,Exercising,Etc)
Stadium Use	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.Stadium $\sqcap$ $\forall$ mayAllowProgramme.(SpectatorSportsAssembly $\sqcup$ TrackAndField,TeamSports,OtherSports)
Student Hostel Use	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.StudentHostel $\sqcap$ $\forall$ mayAllowProgramme.(TransientLiving $\sqcup$ HouseholdActivities)
Telecommunication Use	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.EarthSatelliteStation
Unbuilt Open Space	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(WoodedArea $\sqcup$ SwampArea $\sqcup$ NaturalOpenSpace)
Undetermined Use	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.UndeterminedProgramme
Vehicle Parking Use	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(CarPark $\sqcup$ HeavyVehicleCarPark $\sqcup$ TrailerPark $\sqcup$ TransportDepot $\sqcup$ MRTDepotOrMarshallingYard $\sqcup$ LRTDepotOrMarshallingYard $\sqcup$ DrivingTestCentre)
Water Area Use	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(River $\sqcup$ Reservoir $\sqcup$ Pond) $\sqcap$ $\forall$ mayAllowProgramme.WaterStorage

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Table 3: *Description logic terms and axioms linking land use types to programme types (*continued*)*

Term	Axiom
Water Sports Centre Use	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.WaterSportsCentre $\sqcap$ $\forall$ mayAllowProgramme.(SpectatorSportsAssembly $\sqcup$ Swimming,Diving,Etc $\sqcup$ WaterSportsAndRelatedLeisureActivities $\sqcup$ Water-skiing $\sqcup$ Boating,Sailing,Etc $\sqcup$ Canoeing,Kayaking,Etc $\sqcup$ Fishing,Angling,Etc $\sqcup$ ScubaDiving,Snorkeling,Etc)
White Use Business1 White	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(Restaurant $\sqcup$ Shop $\sqcup$ Showroom $\sqcup$ AssociationUse $\sqcup$ Office $\sqcup$ Bank $\sqcup$ CommercialSchool $\sqcup$ ChildcareCentre $\sqcup$ Kindergarten $\sqcup$ SportsAndRecreationFacility $\sqcup$ FitnessCentre $\sqcup$ RecreationClub) $\sqcap$ $\forall$ mayAllowProgramme.(Store $\sqcup$ OfficeActivities $\sqcup$ Restaurant-typeActivity $\sqcup$ Shopping $\sqcup$ GoodsOrientedShopping $\sqcup$ ServiceOrientedShopping $\sqcup$ BeautySalon $\sqcup$ HairCare $\sqcup$ Spa $\sqcup$ Dentist $\sqcup$ Doctor $\sqcup$ Physiotherapist $\sqcup$ PostOffice $\sqcup$ Cafe $\sqcup$ CarDealer $\sqcup$ CarRental $\sqcup$ CarRepair $\sqcup$ CarWash $\sqcup$ VeterinaryCare $\sqcup$ ArtGallery $\sqcup$ Embassy $\sqcup$ Gym $\sqcup$ BowlingAlley $\sqcup$ Swimming,Diving,Etc $\sqcup$ Tennis $\sqcup$ Running,Jogging,Bicycling,Aerobics,Exercising,Etc $\sqcup$ Laundry $\sqcup$ School)
White Use Business2 White	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(Restaurant $\sqcup$ Shop $\sqcup$ Showroom $\sqcup$ AssociationUse $\sqcup$ Office $\sqcup$ Bank $\sqcup$ CommercialSchool $\sqcup$ SportsAndRecreationFacility $\sqcup$ FitnessCentre $\sqcup$ RecreationClub) $\sqcap$ $\forall$ mayAllowProgramme.(Store $\sqcup$ OfficeActivities $\sqcup$ Restaurant-typeActivity $\sqcup$ Shopping $\sqcup$ GoodsOrientedShopping $\sqcup$ ServiceOrientedShopping $\sqcup$ BeautySalon $\sqcup$ HairCare $\sqcup$ Spa $\sqcup$ Dentist $\sqcup$ Doctor $\sqcup$ Physiotherapist $\sqcup$ PostOffice $\sqcup$ Cafe $\sqcup$ CarDealer $\sqcup$ CarRental $\sqcup$ CarRepair $\sqcup$ CarWash $\sqcup$ VeterinaryCare $\sqcup$ ArtGallery $\sqcup$ Embassy $\sqcup$ Gym $\sqcup$ BowlingAlley $\sqcup$ Swimming,Diving,Etc $\sqcup$ Tennis $\sqcup$ Running,Jogging,Bicycling,Aerobics,Exercising,Etc $\sqcup$ Laundry $\sqcup$ School)

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Table 3: *Description logic terms and axioms linking land use types to programme types (*continued*)*

Term	Axiom
White Use Business Park	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(Restaurant $\sqcup$ Shop $\sqcup$ Showroom $\sqcup$ AssociationUse $\sqcup$ Office $\sqcup$ Bank $\sqcup$ CommercialSchool $\sqcup$ ChildcareCentre $\sqcup$ Kindergarten $\sqcup$ SportsAndRecreationFacility $\sqcup$ FitnessCentre $\sqcup$ MotorVehicleRenting $\sqcup$ RecreationClub $\sqcup$ HotelProgramme $\sqcup$ MotorVehicleTrading) $\sqcap$ $\forall$ mayAllowProgramme.(Store $\sqcup$ BeautySalon $\sqcup$ HairCare $\sqcup$ Spa $\sqcup$ Dentist $\sqcup$ Doctor $\sqcup$ Physiotherapist $\sqcup$ PostOffice $\sqcup$ Cafe $\sqcup$ CarDealer $\sqcup$ CarRental $\sqcup$ CarRepair $\sqcup$ CarWash $\sqcup$ VeterinaryCare $\sqcup$ ArtGallery $\sqcup$ Embassy $\sqcup$ Gym $\sqcup$ Laundry $\sqcup$ School $\sqcup$ BowlingAlley $\sqcup$ Swimming,Diving,Etc $\sqcup$ Tennis $\sqcup$ Running,Jogging,Bicycling,Aerobics,Exercising,Etc $\sqcup$ OfficeActivities $\sqcup$ Restaurant-typeActivity $\sqcup$ Shopping $\sqcup$ GoodsOrientedShopping $\sqcup$ ServiceOrientedShopping)
White Use Business Park White	$\sqsubseteq$ LandUse $\sqcap$ $\forall$ allowsProgramme.(Restaurant $\sqcup$ Shop $\sqcup$ Showroom $\sqcup$ AssociationUse $\sqcup$ Office $\sqcup$ Bank $\sqcup$ CommercialSchool $\sqcup$ ChildcareCentre $\sqcup$ Kindergarten $\sqcup$ SportsAndRecreationFacility $\sqcup$ HotelProgramme $\sqcup$ FitnessCentre $\sqcup$ MotorVehicleTrading $\sqcup$ RecreationClub) $\sqcap$ $\forall$ mayAllowProgramme.(BeautySalon $\sqcup$ HairCare $\sqcup$ Spa $\sqcup$ Dentist $\sqcup$ Doctor $\sqcup$ Physiotherapist $\sqcup$ PostOffice $\sqcup$ Cafe $\sqcup$ CarDealer $\sqcup$ CarRental $\sqcup$ CarRepair $\sqcup$ CarWash $\sqcup$ VeterinaryCare $\sqcup$ ArtGallery $\sqcup$ Embassy $\sqcup$ Laundry $\sqcup$ School $\sqcup$ Gym $\sqcup$ BowlingAlley $\sqcup$ Swimming,Diving,Etc $\sqcup$ Tennis $\sqcup$ Running,Jogging,Bicycling,Aerobics,Exercising,Etc $\sqcup$ OfficeActivities $\sqcup$ Restaurant-typeActivity $\sqcup$ Shopping $\sqcup$ GoodsOrientedShopping $\sqcup$ ServiceOrientedShopping)

A.6 OntoZoning programme hierarchy

Table 4: *Description logic representation of programme hierarchy.*

Term	Axiom
BicycleStore	$\sqsubseteq$ Store
BiotechLaboratory	$\sqsubseteq$ TestLaboratory

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Table 4: *Description logic representation of programme hierarchy.* *(*continued*)*

Term	Axiom
BookStore	$\sqsubseteq$ Store
CallCentre	$\sqsubseteq$ Ebusiness
Chalet	$\sqsubseteq$ Golf
ClothingStore	$\sqsubseteq$ Store
ClubHouse	$\sqsubseteq$ Golf
ComputerReservationSystems	$\sqsubseteq$ DataProcessing
ConvenienceStore	$\sqsubseteq$ Store
DataFarmOrCentre	$\sqsubseteq$ Ebusiness
DepartmentStore	$\sqsubseteq$ Store
DrivingRange	$\sqsubseteq$ Golf
ElectronicsStore	$\sqsubseteq$ Store
FinancialBackEndProcessingCentre	$\sqsubseteq$ DataProcessing
Florist	$\sqsubseteq$ Store
FoodLaboratory	$\sqsubseteq$ TestLaboratory
FurnitureStore	$\sqsubseteq$ Store
GeologyLaboratory	$\sqsubseteq$ TestLaboratory
GolfCourse	$\sqsubseteq$ Golf
Guesthouse	$\sqsubseteq$ Golf
HardwareStore	$\sqsubseteq$ Store
HomeGoodsStore	$\sqsubseteq$ Store
HotelAncillaryOffice	$\sqsubseteq$ HotelProgramme
HotelBusinessCentre	$\sqsubseteq$ HotelProgramme
HotelLibrary	$\sqsubseteq$ HotelProgramme
HotelRecreationalFacility	$\sqsubseteq$ HotelProgramme
HotelRooms	$\sqsubseteq$ HotelProgramme
HousekeepingRoom	$\sqsubseteq$ HotelProgramme
InternetServiceProvider	$\sqsubseteq$ Ebusiness
JewelryStore	$\sqsubseteq$ Store
LaboratoryTesting	$\sqsubseteq$ ResearchAndDevelopment

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Table 4: *Description logic representation of programme hierarchy. (*continued*)*

Term	Axiom
LinenAndLaundryRoom	$\sqsubseteq$ HotelProgramme
LiquorStore	$\sqsubseteq$ Store
Locksmith	$\sqsubseteq$ Store
Lounge	$\sqsubseteq$ Golf
ManufacturingBackEndProcessingCentre	$\sqsubseteq$ DataProcessing
MediaPostProductionAndDistribution	$\sqsubseteq$ CoreMedia
MediaPreProduction	$\sqsubseteq$ CoreMedia
MediaProduction	$\sqsubseteq$ CoreMedia
MovieRental	$\sqsubseteq$ Store
OnlineDirectory	$\sqsubseteq$ DataProcessing
PetStore	$\sqsubseteq$ Store
PharmaceuticalLaboratory	$\sqsubseteq$ TestLaboratory
Pharmacy	$\sqsubseteq$ Store
ProShop	$\sqsubseteq$ Golf
PrototypeProduction	$\sqsubseteq$ ResearchAndDevelopment
RegionalMarketingCentre	$\sqsubseteq$ DataProcessing
SeismicDataAnalysisCentre	$\sqsubseteq$ DataProcessing
ShoeStore	$\sqsubseteq$ Store
SoftwareDevelopment	$\sqsubseteq$ (ResearchAndDevelopment $\sqcup$ Ebusiness)
StaffCanteen	$\sqsubseteq$ HotelProgramme
StaffChangingRoom	$\sqsubseteq$ HotelProgramme
SupercomputingCentre	$\sqsubseteq$ DataProcessing
Supermarket	$\sqsubseteq$ Store
TVNetworkProgramming	$\sqsubseteq$ CoreMedia
Telecommunications	$\sqsubseteq$ Ebusiness
TextileLaboratory	$\sqsubseteq$ TestLaboratory
ValueAddedNetwork	$\sqsubseteq$ DataProcessing

A.7 OntoZoning programme types and sources

Table 5: *Description logic terms and axioms linking programme types to their sources.*

Term	Axiom
AircraftTakeoff,Landing,Taxiing,Parking	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
AirportFacility	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
AirportTerminal	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
AncillaryDisplayArea	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
AncillaryOffice	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
ArtGallery	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.Google
ArterialRoad	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
ArtsCentre	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
AssemblyProgramme	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
AssemblyUse	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
AssociationPremise	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
AssociationUse	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
Bakery	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.(URA $\sqcup$ Google)
Bank	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.(URA $\sqcup$ Google)
Bar	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.(URA $\sqcup$ Google)
BeautySalon	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.Google
BoatMooring,Docking,Servicing	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2

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Table 5: *Description logic terms and axioms linking programme types to their sources (*continued*)*

Term	Axiom
Boating,Sailing,Etc	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
BookStore	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
BotanicGarden	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
BowlingAlley	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.Google
BungalowUse	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
Cafe	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.(URA $\sqcup$ Google)
CampingActivities	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
Canal	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
Canoeing,Kayaking,Etc	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
CarDealer	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.Google
CarPark	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
CarRental	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.Google
CarRepair	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.Google
CarWash	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.Google
Cemetery	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
CentralDistributionCentre	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA

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Table 5: *Description logic terms and axioms linking programme types to their sources (*continued*)*

Term	Axiom
ChildCareCentre	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
ChildcareCentre	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
Cinema	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
Classroom-typeActivities	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
Clinic	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
ClinicalResearchFacility	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
Columbaria	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
Columbarium	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
CommercialSchool	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
CommunityCentre	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
CommunityHall	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
CommunityPark	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
ConcertHall	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
Condominium	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
ConferenceRoom	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
ConstructionActivities	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2

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Table 5: *Description logic terms and axioms linking programme types to their sources (*continued*)*

Term	Axiom
ConventionCentre	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
CoreMedia	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
Courts	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
CoveredAgriculture	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
Crematory	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
CruiseCentre	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
DataProcessing	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
Dentist	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.Google
DesalinationPlant	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
DetachedHouse	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
DiagnosticFacility	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
DieselAndPumpPoint	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
Dispensary	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
Doctor	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.Google
Drive-in,DriveThrough,Stop-n-go,Etc	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
DrivingTestCentre	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA

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Table 5: *Description logic terms and axioms linking programme types to their sources (*continued*)*

Term	Axiom
DrugRehabilitationCentre	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
EarthSatelliteStation	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
Ebusiness	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
ElectricalSubstation	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
Embassy	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.Google
Emergency,DisasterResponseActivities	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
EmergencyResponse,Public-safetyActivities	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
Entertainment	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
ExhibitionCentre	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
Expressway	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
Farming,Tilling,Plowing,Harvesting,RelatedActivities	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
FireAndRescueActivities	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
FireStation	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
Fishing,Angling,Etc	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
FishingPort	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
FitnessCentre	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA

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Table 5: *Description logic terms and axioms linking programme types to their sources (*continued*)*

Term	Axiom
Flat	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
FloodControl,Dams,OtherLargeIrrigationActivities	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
Flying,Air-relatedSports	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
FoodCentre	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
FoodPackingUse	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
ForeignSchool	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
FuneralParlour	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
GasInstallation	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
GasTakeoffStation	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
GatheringsAtFairsAndExhibitions	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
GatheringsAtMuseums,Aquariums, ZoologicalParks,Etc	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
GeneralAdministrationSpace	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
Golf	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.(URA $\sqcup$ LBCSv2)
GoodsOrientedShopping	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
Gym	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.(URA $\sqcup$ Google)
HairCare	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.Google

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Table 5: *Description logic terms and axioms linking programme types to their sources (*continued*)*

Term	Axiom
HairSalon	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
HealthCare,Medical,TreatmentActivities	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
HeavyVehicleCarPark	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
HighTechManufacturing	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
HistoricalOrCulturalCelebrations,Parades,Etc	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
Hockey,IceSkating,Etc	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
HomeForTheAged	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
HomeForTheDisabled	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
HospitalVisitorsHostel	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
HotelProgramme	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
HouseholdActivities	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
IncinerationPlant	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
IndustrialCanteen	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
IndustrialTraining	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
IndustrialTrainingUse	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
InpatientFacility	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA

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Table 5: *Description logic terms and axioms linking programme types to their sources (*continued*)*

Term	Axiom
InstituteOfTechnicalEducation	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
InstitutionalLiving	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
InterimProgramme	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
Interment,Cremation,GraveDiggingActivities	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
IrrigationWaterStorageAndDistributionActivities	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
JuniorCollege	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
KaraokeBar	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
Kindergarten	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
KnittingMill	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
LRTDepotOrMarshallingYard	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
LandfillingOrDumping	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
LandingSite	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
LandscapedPlaza	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
Laundromat	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
Laundry	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.Google
Library	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.(URA $\sqcup$ Google)

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Table 5: *Description logic terms and axioms linking programme types to their sources (*continued*)*

Term	Axiom
LightIndustryUse	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
LocalAccessRoad	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
Lodging	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.Google
Lounge	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
M&EServices	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
MRTDepotOrMarshallingYard	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
MajorArterialRoad	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
MajorDrain	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
Mall	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
ManufacturingGeneral	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
Marina	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
Market	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
MedicalAdministrationSpace	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
MedicalStaffFacility	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
MedicalSuite	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
MeetingRoom	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA

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Table 5: *Description logic terms and axioms linking programme types to their sources (*continued*)*

Term	Axiom
MiniMart	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
Minimart	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
MotorVehicleRenting	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
MotorVehicleTrading	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
Movies,Concerts,EntertainmentShows	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
Museum	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.(URA $\sqcup$ Google)
NationalPark	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
NaturalGasOrFuelsControl,Monitor, DistributionActivities	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
NaturalGasReceivingTerminal	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
NaturalOpenSpace	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
NeighbourhoodPark	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
Nightclub	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.(URA $\sqcup$ Google)
NursingBedArea	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
NursingHome	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
Office	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
OfficeActivities	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2

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Table 5: *Description logic terms and axioms linking programme types to their sources (*continued*)*

Term	Axiom
OpenAirAgriculture	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
OtherInstructionalActivities	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
OtherProgramme	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
OutdoorPedestrianMall	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
OutpatientFacility	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
ParkConnector	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
PassengerAssembly	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
PedestrianMovement	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
PerformingArtsCentre	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
PersonalServiceTrade	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
Pharmacy	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
Physiotherapist	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.Google
Plant,Factory,HeavyGoodsStorageOr HandlingActivities	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
Police,Security,ProtectionActivities	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
PoliceStation	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
Polytechnic	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA

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Table 5: *Description logic terms and axioms linking programme types to their sources (*continued*)*

Term	Axiom
Pond	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
Port,Ship-building,RelatedActivities	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
PortFacility	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
PortTerminal	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
PostOffice	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.Google
PowerGeneration,Control,Monitor, DistributionActivities	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
PowerStation	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
PowerTransmissionLinesOrControl Activities	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
PrayingArea	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
PriestRoom	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
PrimarilyGoodsStorageOrHandling Activities	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
PrimarilyPlantOrFactoryActivities	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
PrimaryAccessRoad	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
PrimarySchool	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
PrintingOrPublishing	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
Prison	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA

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Table 5: *Description logic terms and axioms linking programme types to their sources (*continued*)*

Term	Axiom
ProductDesignOrDevelopment	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
ProductionUse	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
PromenadingAndOtherActivitiesInParks	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
PublicPromenade	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
RapidTransitStation	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
RecreationClub	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
RegionalPark	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
ReligiousClassroom	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
RepairAndServicingUse	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
ResearchAndDevelopment	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
Reservoir	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
Resort	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
Restaurant	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.(URA $\sqcup$ Google)
Restaurant-typeActivity	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
RetirementHousing	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
River	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA

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Table 5: *Description logic terms and axioms linking programme types to their sources (*continued*)*

Term	Axiom
Running,Jogging,Bicycling,Aerobics, Exercising,Etc	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
Sailing,Boating,OtherPort,MarineAndWater-basedActivities	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
School	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.Google
SchoolOrLibraryActivities	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
ScienceCentre	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
ScubaDiving,Snorkeling,Etc	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
SecondarySchool	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
Semi-DetachedHousingUse	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
Semi-Expressway	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
ServiceOrientedShopping	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
ServiceReservoir	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
ServiceRoadOrBacklane	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
ServicedApartment	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
SewagePumpingStation	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
SewageStoring,Pumping,Piping	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
Sewer-relatedControl,Monitor,Distribution Activities	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2

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Table 5: *Description logic terms and axioms linking programme types to their sources (*continued*)*

Term	Axiom
SewerTreatmentAndProcessing	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
Shop	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
Shopping	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
Showroom	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
SickRoom	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
Social,Cultural,ReligiousAssembly	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
SolidWasteCollectionAndStorage	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
SolidWasteManagementActivities	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
Spa	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.Google
SpecialEducationSchool	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
SpecialProgramme	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
SpectatorSportsAssembly	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
SportsAndRecreationFacility	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
SportsComplex	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
Stadium	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
StorageOfChemical,Nuclear,OtherMaterials	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2

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Table 5: *Description logic terms and axioms linking programme types to their sources (*continued*)*

Term	Axiom
StorageOfChemicalsOils	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
StorageOfNaturalGas,Fuels,Etc	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
Store	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.General
Strata-LandedHousingUse	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
StudentHostel	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
StudentRunBusiness	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
SwampArea	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
Swimming,Diving,Etc	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
TelecommunicationsControl,Monitor, DistributionActivities	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
TelevisionOrFilmingStudioComplex	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
Tennis	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
TerraceHouseUse	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
TestLaboratory	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
Townhouse	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
TrackAndField,TeamSports,OtherSports	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
TradeMission	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA

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Table 5: *Description logic terms and axioms linking programme types to their sources (*continued*)*

Term	Axiom
TrailerPark	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
TrainingInstitute	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
TrainingOrInstructionalActivitiesOutsideClassrooms	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
TrainsOrOtherRailMovement	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
TransientLiving	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
TransmittingStation	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
TransportDepot	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
TratmentFacility	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
TravelAgency	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
UndeterminedProgramme	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
University	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
VehicularMovement	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
VehicularParking,Storage,Etc	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
VeterinaryCare	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.Google
WasteProcessingOrRecycling	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
Water-skiing	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2

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Table 5: *Description logic terms and axioms linking programme types to their sources (*continued*)*

Term	Axiom
WaterPumpHouse	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
WaterPurificationAndFiltrationActivities	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
WaterReclamationPlant	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
WaterSportsAndRelatedLeisureActivities	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
WaterSportsCentre	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
WaterStorage	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
WaterStoring,Pumping,Piping	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.LBCSv2
WaterTreatmentPlant	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
WelfareHome	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
WoodedArea	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
WorkersDormitory	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
WorkersQuarters	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA
ZoologicalGarden	$\sqsubseteq$ ProgrammeType $\sqcap$ $\forall$ hasSource.URA

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