# Geospatial Ontology to support the Documentation of **Minor Historical Centres**

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# Geospatial Ontology to support the Documentation of Minor Historical Centres

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I hereby declare that the contents and organisation of this dissertation constitute my own original work and does not compromise in any way the rights of third parties, including those relating to the security of personal data.

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Elisabetta Colucci
Turin, February 2022

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# Abstract

The research presented in this work encompasses two main research fields: geomatics, focusing on geographical information (GI) and Artificial Intelligence (AI), studying and applying ontologies.

The core of this research methodology focuses on the study and the design of ontologies for spatial data: ***geospatial ontologies.*** Ontologies can be considered as conceptual structures able to formalise the explicit knowledge of a domain. They are of particular usefulness to create a unique and standard thesaurus and to ensure semantic interoperability. In the ontology engineering process, classes are semantically expressed and connected by relations. In geographic sciences, this formalisation of concepts allows digital information control between different operating systems by communicating with geographic tools. This thesis is targeted to fill various gaps in the current scenario of GI.

The main research topic of this thesis focuses on the possibility to standardise spatial information in the domain of ***minor historical centres (MHC)*** and the related *architectural, built and landscape heritage.* Nevertheless, the notions of the urban centre, historical city, and ancient urban area are not consolidated overall, took different meanings, and evolved over the centuries. Historical centres (HC) are intended as a historical part of cities, villages and hamlets (urban, rural, minor or abandoned) with cultural, social and economic values. They need to be preserved, documented and safeguarded due to their intrinsic values, connected with their functions and evolution. The documentation is a fundamental tool for increasing the resilience of CH. Therefore, the study, the communication and the protection of this heritage are supported by many processes and require specific data to be collected, stored, and post-processed. In addition, these activities involve many disciplines, actors, and stakeholders, leading to sharing common knowledge and using a unique language. For this purpose, the use of ontology is of relevant interest and usability.

There is no defined ontology containing helpful information to manage, share and collect data on historical and minor rural centres. Moreover, an interoperable structure is lacking to semantic formalises cultural built, urban, architectural heritage. The research developed a spatial ontology integrating existing knowledge (ontologies, vocabularies and standards) representing geographical objects of built and territorial heritage.

The domain of this study is identified in historical centres, and the ontology scope is their ***spatial and temporal documentation***. The design of this ontological structure can help various actors involved in the decision-making process of small urban and rural areas in different scenarios (such as rural villages, alpine hamlets,

historical city centres needing restoration actions, urban planning or rehinabitation activities). For this purpose, the methodology is validated, enriching and populating (adding classes and instances) the ontology with structured and unstructured data of real data case studies (a Dutch fortified village and an Italian alpine hamlet). Concepts from existing urban regulation plans, historical documents, regional landscape plans, data models, datasets and data from 3D integrated metric surveys have been collected, harmonised and inserted into the ontology.

Finally, this thesis wants to produce an accurate representation of reality through a ***multi-scale approach considering different levels of detail***. This final aim regards the publication of the GIS (Geographic Information System/Science) projects of the case studies. For each use case, a geodatabase was published in a ***WebGIS*** application in which it is possible to query geometries and directly open the related semantic classes of the ontology.

*"Every ontology is a treaty – a social agreement –*
*among people with some common motive in sharing"*

Tom Gruber, 1994

# Acknowledgement

I would like to acknowledge the Laboratories of Geomatics of Politecnico of Turin (DAD and DIATI) and all my colleagues and friends for supporting me during these years with coffee breaks, aperitifs and lunch breaks (especially at the B-side). A special thanks go to my supervisors for believing in me and my research (sometimes more than I did). A particular thanks also to the NTUA Cartography Lab and my Greek tutor for following me during the challenging period of COVID and transmitting to me her passion for spatial ontologies. I also thank the 3D Geoinformation TU Delft group for their feedbacks. I want to thank my close PhD colleagues and friends, who shared special moments of PhD life. Thank you to my friends and loved ones, who support and believe in me. Finally, thank you to my loving family, who can now explain what geomatics and ontologies are …

maybe.

*I would like to dedicate*
*this thesis to my granny Maria.*

# Contents

# I. Declaration of originality

*I Hereby declare that,*

this PhD thesis entitled "***Geospatial Ontology to support the Documentation of Minor Historical Centres***" was carried out by me for the degree of Doctor of Philosophy in Urban and Regional Development (34° cycle), under the guidance and supervision of Professors *Andrea Maria Lingua*, *Antonia Teresa Spanò* (Politecnico di Torino, Italy) and *Margarita Kokla* (National Technical University of Athens, Greece).

The interpretations put forth are based on my reading and understanding of the original texts, and they are not published in this form of books or monographs. The other books, articles, and websites I have used are acknowledged at the respective place in the text. For the present thesis, which I am submitting to the University, no degree or diploma or distinction has been conferred on me before, either in this or any other University.

# II. List of Tables

# III. List of Figures

# IV. List of abbreviations

The following abbreviations and acronyms are used in this dissertation:

AI: Artificial Intelligence
ARPA: Agenzia Regionale per la Protezione dell'Ambiente
BAG: Basisregistratie Adressen en Gebouwen/ Key Register Addresses and Buildings
BBA: Bundle Block Adjustment
BDTRE: Base Dati Territoriale di Riferimento degli Enti
BGT: Basisregistratie Grootschalige Topografie/ Key Register Large-Scale Topography
BIM: Building Information Modelling
CAI: Club Alpino Italiano
CH: Cultural Heritage
CIDOC-CRM: CIDOC Conceptual Reference Model
CRM: Conceptual Reference Model
CPs: Check Points
CRP: Close-Range Photogrammetry
CS: Computer Science
DB: Database
DBMS: Database Management System
DEM: Digital Elevation Model
DiRECT Team: Disaster Recovery Team
DSLR: Digital Single-lens Reflex
DSM: Digital Surface Model
DTM: Digital Terrain Model
EPOCH: European Research Network on Excellence in Processing Open Cultural Heritage
GCPs: Ground Control Points
GDB: Geographic Database
GeoSPARQL: Geographic Query Language for RDF Data
GI: Geospatial/Geographic Information
GIS: Geographic Information System and Science
GK: Geographic Knowledge
GKB: Geographic Knowledge Base
GML: Geography Markup Language
GPS/GNSS: Global Positioning System/Global Navigation Satellite System
GRDF: Geospatial Resource Description Framework
GSD: Ground Sample Distance
HBIM: Historical or Heritage BIM
HC: Historical Centre
HUL: Historic Urban Landscape
ICCD: Istituto Centrale per il Catalogo e la Documentazione
ICOMOS: International Council on Monuments and Sites
ICT: Information and Communication Technologies
ICP: Iterative Closest Point
ISCS: International Scientific Committee for Stone
IFC: Industry Foundation Classes
IGM: Istituto Geografico Militare
INSPIRE: Infrastructure for Spatial Information in the European Community
IRI: Internationalized Resource Identifier
ISO: International Organization for Standardization
IFC: Industry Foundation Classes
KG: Knowledge Graph
LiDAR: Light Detection and Ranging
LoD: Levels of Detail
MHC: Minor Historical Centre
MMS: Mobile Mapping System

MIBACT: Ministry of Cultural Heritage and Activities and Tourism
MONDIS: Monument Damage Information System
NLUD: National Land Use Database
OGC: Open Geospatial Consortium
ODIS: Ontology-Driven Information System
ODGIS: Ontology-Driven Geographic Information System
ORDBMS: Object-Relational Database Management System
OS: Open-Source
OSM: Open Stress Map
OWL: Web Ontology Language
PC: Point Cloud
PdC: Permesso di Costruire/Bulding Permit
PDOK: Publieke Dienstverlening Op de Kaart/ Public Services on the Map
PPR: Piano Paesaggistico Regional/Landscape Regional Plan
PR: Piano Regolatore/Technical City Plan
PRGCM: Piano Regolatore Generale della Comunità Montana Valli Chisone e Germanasca/General Plan of the Mountain Community of the Chisone and Germanasca Valleys
PRGI: Piano Regionale Generale Intercomunale/ Interregional Regional Plan
PT: Piano Territoriale/Territorial Plan
PTC: Piano Territoriale di Coordinamento/Territorial Coordination Plan
PURL: Persistent Uniform Resource Locator
RF: Reference System
RDBMS: Relational Database Management System
RDF: Resource Description Framework
RMSE: Root-Mean-Square Error
RTK: Real-Time Kinematic
SDI: Spatial Data Infrastructure
SfM: Structure from Motion
SIFT: Scale-invariant Feature Transform
SIT: Sistema Informative Territoriale
SQL: Structured Query Language
SW: Software
TLS: Terrestrial Laser Scanning
TPs: Tie Points
TS: Total Station
UAVs: Unmanned Aerial Vehicles
UML: Unified Modeling Language
URI: Uniform Resource Identifier
URL: Uniform Resource Locator
UTM: Universal Transverse Mercator
XML: Extensible Markup Language
WebGIS: Web Geographic Information System
WCS: Web Coverage Service
WFS: Web Feature Service
WMS: Web Map Service
WPS: Web Processing Service
WGS: World Geodetic System

# INTROD

UCTION

# 1

Chapter 1

# Introduction

## 1.1 Research topic

***Historical centres (HC)*** express both cultural heritage values and urban characteristics. For this reason, numerous historians, architects, urban planners, and restorers have recognised the great importance of the documentation and the preservation of these centres. They are expressions of identity and intangible cultural values for both the local and further societies. The notion of HC takes different meanings depending on the context and the period in which it is applied. The concept of HC evolved over the years, including in its semantic and spatial definitions also minor and small centres such as historic urban core and part of cities, rural villages and semi-abandoned hamlets.

Rural or inner areas and minor centres have experienced an increased interest in recent years. A real new opportunity is provided by the necessity for sustainable environmental opportunities, such as decentralisation, revitalisation, development and re-inhabitation of the countryside and minor historical centres in hinterlands. This scenario has been reinforced by the recent pandemic crisis of COVID-19 (Boeri, 2020; Istituto di Architettura Montana, 2020; Koolhaas, 2020). Together with climate change issues in cities (Cassar & Pender, 2003; Mercalli, 2020; Rosenzweig et al., 2011), the pandemic has temporarily led city dwellers to move to rural areas. All these phenomena involve multidisciplinary knowledge and include a variety of actors and stakeholders from different disciplines, application areas and domains. Using a standard, unique, and shared language could be an excellent utility for the development of an interdisciplinary knowledge of historical centres. Such language would make it possible to reuse and integrate information and data. Ontologies are considered an effective solution for the formal conceptualisation of a domain. In Computer Science, an ontology is an information object or a computational artefact; it is a "formal, explicit specification of a shared

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APA6th Style Referencing is used in this dissertation.
References of books, articles and newspapers are reported in the text; website links are in footnotes.

conceptualisation" (Studer et al., 1998). They facilitate knowledge representation and semantic description of concepts with their attributes and relations. Sharing a common understanding and exchanging information among different users is one of the central goals of an ontology (Gruber, 1993; Musen, 1992).

Spatial Ontology

This thesis aims to lay the foundation for creating a common structure for sharing knowledge about historical centres in rural or urban areas. Hence, this work proposes a ***spatial ontology*** in the domain of ***minor historical centres (MHC)***. The ontology structure formalises the knowledge of HC semantically defining its objects (classes such as buildings, roads, etc.), characteristics (properties) and relations. Urban and territorial aspects have been considered to apply the workflow to an upper level. The methodology focuses on defining and clarifying notions of minor historical centres and spatial ontologies. Ontology design or engineering approaches have been applied to harmonise and reuse existing knowledge of architectural and built heritage and geographic information (GI).

The final purpose is to develop a multi-scale application in which exemplary case studies are spatially represented in a GIS (Geographical Information System) environment. In these maps, objects published on the Web (WebGIS) can be visualised and queried, gathering information linked to the semantic classes and definitions published in the ontology. Thanks to digitalisation, the semantic acquired value and the approach results are innovative and replicable.

## 1.2 Methodological framework

A list of the primary *motivations* for investigating this dissertation topic of spatial ontologies in the domain of historical centres is presented to clarify the needs and gaps that this research wants to fill in:

- Needs to document and valorise rural areas and minor historical centres to re-habit abandoned places, as underlined by the pandemic situation and climate changes in cities.
- Historical centres are more and more interesting for cultural heritage, landscape communities, and land planners.
- Geomatics techniques and methods support the research in different disciplines and areas of study.
- Problems of interaction between foreign and complementary information about historical centres can find support in the definition of digital systems thanks to the development of formal and conceptual representations such as ontologies.
- Ontologies help create a common language to ensure semantic interoperability, building a unique standard thesaurus that lets different disciplines and stakeholders interact together.
- Sharing a common understanding among citizens, scientists, researchers, policymakers, and other stakeholders will allow urban planning, restoration activities, reinhabitations actions, landscape plans and building permits processes in countryside areas.

- Allowing multiscale analysis and spatial visualisation of HC and the related territory, landscape, buildings, roads, etc.
- Linking spatial data objects to a unique ontology structure through their semantic classes, describing properties and relations.

### 1.2.1 Specific research questions

Research questions

After the above-listed motivations, there are some questions that this dissertation will attempt to answer. They are the following:

- Are Historical Centres adequately spatial and temporal documented and described? How is it possible to semantically identify objects and characteristics of minor historical centres to avoid repetition?
- How can the various parties involved in MHC activities work together, sharing a unique structure? How to spread knowledge of HC and allow their reuse?
- Which is the adequate method to design a spatial ontology for MHC?
- Which are the main limitations of nowadays existing ontologies and vocabularies in the domain of GI? Does the literature address these limits? Is there a solution to bridge these gaps?

To answer these questions, an overview of the literature and an explanation of the objectives of this research is carried out in the following section (1.2.2 and 1.2.3).

### 1.2.2 Overview of the academic literature, needs and lacks, and contribution of this PhD research

Over the years, some research have tried to define ontologies in the historic built heritage domain. The main ontology for managing cultural heritage information is the CIDOC core Conceptual Reference Model[2] (CRM), standard ISO (International Organization for Standardization). It structures high-level concepts, so it is mainly used to underline interoperability in the cultural heritage domain (including architectural and landscape heritage). This ontology is based on several studies (Häyrinen, 2010; Kokla et al., 2019; Moraitou et al., 2019). Besides, it is essential to mention the research methods and tools made in geospatial information and in GIS for managing and documenting cultural and architectural heritage. In this case, some extensions of the Open Geospatial Consortium (OGC) CityGML[3] standard were proposed (Egusquiza et al., 2018; Mohd et al., 2017; Noardo, 2018), as well as of the INSPIRE (Infrastructure for Spatial Information in Europe)[4] data model (Chiabrando et al., 2018; Fernández Freire et al., 2013). Moreover, existing ontologies for towns and cities (Berdier & Roussey, 2007; Teller et al., 2007) and

[2] http://www.cidoc-crm.org/
[3] https://www.ogc.org/standards/citygml
[4] https://inspire.ec.europa.eu/

some studies on historical heritage ontology (Acierno, 2019; Fiorani, 2019; Kokla et al., 2019) have been made. Moreover, in recent times, Building Information Modeling (BIM) and Historical/Heritage BIM (HBIM) technology were recommended to boost cultural heritage interoperability in management and preservation activities. Some examples are a cloud-based platform to enhance semantic-based search to retrieve open data (Brumana et al., 2019) and applications of ontologies-based approaches to represent buildings their components (Niknam & Karshenas, 2017; Previtali et al., 2020).

Despite these consolidated methodologies and standards, there are still some gaps and shortcomings. At first, there is a lack of ontology in computer science, containing helpful information to manage, share and collect data on historical centres. Moreover, there are many interoperability problems and geometries incompatibilities (for example, between GIS and BIM or HBIM data) (Fosu et al., 2015; Tobiáš, 2016). Another inconsistency is that geographical and spatial data standards and data models are not adopted as a unique base at the national and international levels.

The research wants to demonstrate the necessity of semantic formalising historical centres and buildings by investigating the existing studies and standards. The thesis would like to fill the lack of a proper standard structure to represent historical centres as built heritage. Furthermore, the thesis wants to solve the current impossibility of communication among different stakeholders involved in urban and monitoring planning, actions of conservation, local and regional policies, and so on.

### 1.2.3 Objectives and Goals

The present thesis aims to investigate the different and already-known definitions of the concepts of HC and ontologies in the geographical and spatial domain. This clarification allows the development of the second step of research: the meaning and the choice of the ontology domain and scope to define why it is necessary to create the ontology and for who it could be helpful. The main aim is to ***temporal, spatial and geographical document*** minor historical centres. It is crucial to consider innovative and new technologies to describe these places and launch the resettlement and recovery of cultural values and legacy. In this framework, the territorial and spatial dimension of historical centres plays a key role. In the ontology engineering methodological part, objects (concepts), characteristics (properties and attributes) and relations have been defined comparing existing knowledge (such as ontologies, conceptualisations, regulations, documents, and so on). The methodology has been validated by selecting an explicative case study. The final objective regards the connection of the semantic ontological structure developed with the spatial data. For this purpose, the last part of the methodology aims to create a WebGIS App in which spatial objects are linked to their semantic definition through Linked Data technologies. The definition of a knowledge base representing HC information

*Aims of the thesis*

will help various recovery plans for internal, mountain and marginal regions excluded for a long time from national policies.

#### 1.2.3.1 Sustainable Development Goals contributions

*SDGs contribution*

This dissertation falls within some of the Sustainable Developments Goals (SDGs)[5] (Figure 1), the core topic of the 2030 Agenda for Sustainable Development (UNITED NATIONS, 2016), defined by the United Nations General Assembly and adopted by all United Nations Member States in 2015. The document "provides a shared blueprint for peace and prosperity for people and the planet, now and into the future". Moreover, the United Nations Member States, UN-GGIM[6], in the document "The Role of Geospatial Information in the Sustainable Development Goals", listed and explained the main goals in which GI technologies and methods can effectively help. This thesis aims are related to SDSs 9, 11 and 13. These are:

- *9*, "Build resilient infrastructure, promote inclusive and sustainable industrialisation and foster innovation". Mainly, target *9.1*[7] and *9.1.1* are linked to developing sustainable and resilient infrastructure, including rural areas and their population. This research tries to define a new innovative tool to document and manage knowledge of historical centres for future and sustainable planning.
- *11*, "Make cities and human settlements inclusive, safe, resilient and sustainable"[8]. In this case, target *11a* aims to support environmental, economic, and social values by linking urban and rural areas. The proposed ontology structure wants to set the basis for promoting the future development of hinterland areas and minor historical centres. Moreover, target *11.3* seeks to enhance participatory and integrated human settlement planning and management. This point falls exactly with the ontology objective of creating a joint base to share a unique knowledge among different actors.
- Finally, SDS *13*, "Take urgent action to combat climate change and its impacts", and its target 13.2, "Integrate climate change measures into national policies, strategies and planning"[9]. As explained before, after the COVID-19 pandemic, many people changed their idea of life in cities for more sustainable and "slow" behaviours. These changes could be noticeable in upgrading services in foothills or mountains small centres. These changes are also related to the decrease in greenhouse emissions during the COVID-19 period. Developing such infrastructures as a common ontology to share minor settlements information could help re-inhabit marginal areas with more sustainable

[5] https://sdgs.un.org/goals
[6] https://ggim.un.org/
[7] https://sdgs.un.org/goals/goal9
[8] https://sdgs.un.org/goals/goal11
[9] https://sdgs.un.org/goals/goal13

planning and activities. The return of a "slow-life" could meet the need of adopting sustainable choices and strategies.


Figure 1. Sustainable Development Goals (SDGs), (UNITED NATIONS, 2016).

## 1.3 Structure of the dissertation

This research presents a literature review about the topic of geographical ontologies and a study of the definition and evolution of historical centres (*Chapters 2 and 3*). After that, the research intends to focus on the lack of architectural, landscape and geographical informative standards trying to bridge and overcome them. These gaps will be investigated in-depth, covering different scientific theoretical literature backgrounds to provide an exhaustive overview of the topic (*Chapter 4*). The analysis will cover geographical information and architectural conventions, historical notions on urbanism and historical centres, the literature of national and international spatial standards, consolidated methods of semantic formalization, information extraction, automatic identification, geometries classification, etc. This thesis purposes to contribute in an operative and practise way, through an application ontology, in different scenarios and activities in which buildings, parts of cities, hamlets are involved at varying levels of detail. The core of the methodology consists of ontology design and validation (*Chapter 5*). The first available approach that will be used to create the ontology is the top-down one. It will start from existing knowledge (both formal and informal) of landscape, territory and urban scenarios to define the semantic formalization of buildings and historical centres. The bottom-up approach will be considered in the second phase of this PhD research. It regards ontology enrichment with instances using the case studies (*Chapter 6*). Hence, combining the two methods (the knowledge-based ontology and the experience-based ontology) makes it possible to ensure the completeness of the structure and validate it. Finally, this thesis will develop a geodatabase (GDB) with the data mapped from the datasets of the case studies. Furthermore, after the ontology web publication, to share data information and open data and to link spatial data to the semantics of the ontology, the geodatabase is published through a WebGIS. In this step, some semantic, technical, and geometric interoperability tests will be performed to visualise data in a WebGIS map and query them, retrieving information and semantic descriptions stored in the ontology structure (*Chapter 7*). *Chapters 8 and 9* present discussions, critical reflections, conclusions and possible future developments.

Figure 2 shows the workflow of the thesis and the three different parts in which it is subdivided.

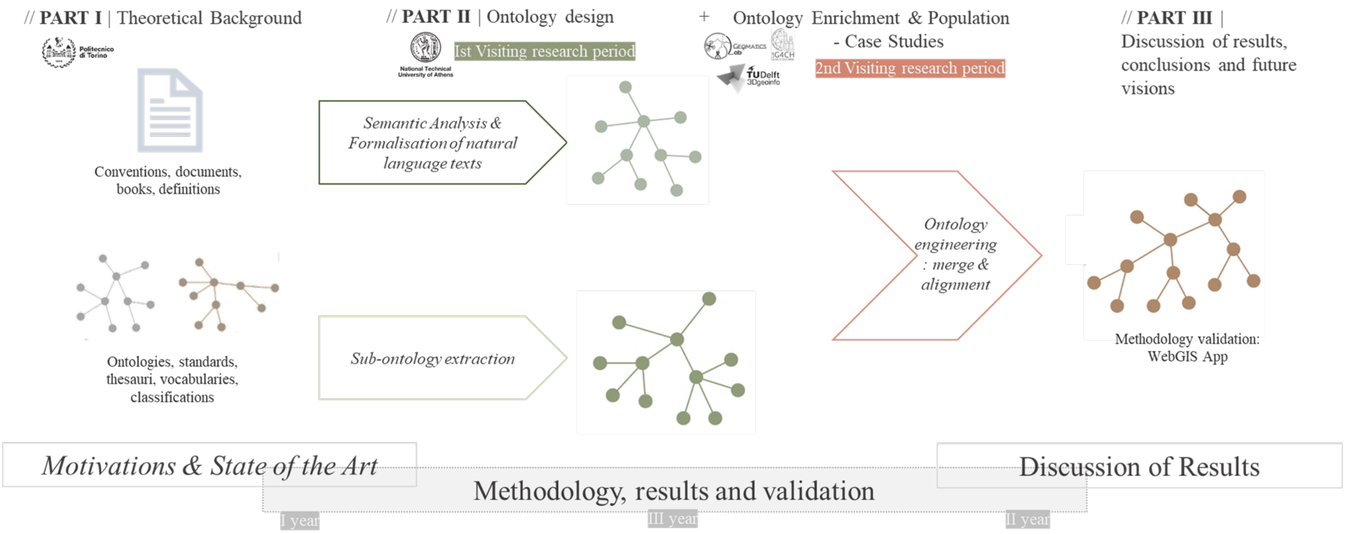



Figure 2. Workflow of the present thesis and Parts of the document.

## 1.4 Keywords

- Geospatial Information (GI)
- Artificial Intelligence
- Geospatial ontology
- Minor Historical Centres (MHC)
- Cultural Architectural Built and Landscape Heritage
- Spatial and Temporal Documentation
- Geographic Information System and Science (GIS)
- Semantics Formalisation
- WebGIS
- Linked Data
- Multiscale representation
- Level of Details

***Part of the work described in next chapters has been published previously in Colucci & Spanò, (2020).***

→ Colucci, E. & Spanò, A. (2020). Ontologie geografiche nel dominio spaziale urbano e del patrimonio costruito. *Bollettino Società Italiana di Topografia e Fotogrammetria, SIFET*.

# Theoretical background

Trying to explain what an ontology is to friends and family, I soon met great difficulty defining the concept in simple words. I investigated the variety of meanings of ontologies and studied applications and domains of this method. As a result of this research, I am now able to define and explain ontologies to non-experts. This section presents the object of my research: ***minor historical centres***. The review of the state of the art clarifies the definition of ontology. Finally, the section discusses the application area of built heritage and historical centres that need a formal and organised semantic language. The standards for interoperability are presented in this context.

For Chapter 2 writing, I would like to thank Professor Cristina Cuneo of Politecnico di Torino for her precious suggestions on the bibliography on the evolution of historical centres.

# PART I

# 2

Chapter 2

# Historical centres in the literature

Notions and evolution of historical centres

Historical centres are part of built cultural heritage from which they inherit historical, cultural and social values. Before investigating the different typologies of ontologies and standards for geographical information and architectural heritage representation, it is necessary to clarify the meanings and the evolution of the ***notion of historical centre***. To this purpose, some questions that can guide this exploration for a definition are: what are historical centres? How can we define them? How has the notion of HC evolved and developed over the years? A literature investigation extensively studies historical books and descriptions of architecture and urbanism on the topic to define the ontology domain adequately. In this literature, urban cores, parts of cities and small villages or hamlets are all considered HC. The different semantic definitions of HC have changed over time, and therefore it is necessary to understand the evolution of the concept in the last 50 years. This chapter presents the definition of cultural heritage, with its classification. It describes the evolution of the concepts of city and HC over the different historical periods and clarifies the different meanings of historical centres in the urban environment, in landscape plans, and in rural scenarios.

## 2.1 The notions of Cultural, Built, Urban, Landscape and Architectural heritage

The concept of HC lies inside the domain of *built, urban and architectural heritage* due to its characteristics and social, historical and cultural values. Therefore, this thesis must deal with the notion of *cultural heritage.* Before clarifying the different facets of the historic centre, this section presents the framework and evolution of the different concepts of heritage:

- ***Cultural Heritage (CH)***
  The UNESCO definition of cultural heritage is expressed in the "Convention Concerning the protection of the World Cultural and Natural Heritage: The General Conference of the United Nations Educational, Scientific and Cultural Organization" meeting in Paris from 17 October to 21 November 1972, at its seventeenth session, (…) (Labadi, 2018; UNESCO, 1972).
  In the first article, we can find the definition of the Cultural and Heritage.
  Art.1: "For the purposes of this Convention, the following shall be considered as cultural heritage:

  - monuments,
  - groups of buildings,
  - sites".

  The more recent definitions of CH items in the UNESCO documents include:

  - ***Landscape cultural heritage*** (Cultural Landscape definition of 1992), combined works of nature and humankind (UNESCO, 1992);
  - ***Intangible cultural heritage,*** which is the more recent definition of CH (UNESCO, 2003);
  - ***Digital heritage.*** "Born-digital heritage available online, including electronic journals, World Wide Web pages or on-line databases, is now part of the world's cultural heritage" (UNESCO, 2009).

- ***Architectural heritage***
  A good survey on definitions in the 900 can be found in Jokilehto (2005). "In the modern theory by Brandi, cultural heritage qualities are the historical and aesthetic values. A historical building is a complex system of spaces, volumes, materials, surfaces, constructive aspects, actual and past functions and configurations, degradation, etc. The whole is the result of a continuous historical process of modification and transformation. An architectural heritage can be interpreted as an artefact, where its elements are witnesses of the cultures, actors, and of events occurred during the life of the building" (Brusaporci, 2020).

- ***Built heritage***
  Built heritage represents another crucial cultural asset; it is the historical layers of our built environment in places.
  The term cultural built heritage is, therefore, a broad concept.
  "According to the UNESCO Universal Declaration on Cultural Diversity (UNESCO, 2002), culture is the set of distinctive spiritual, material, intellectual and emotional features of a society or a social group that encompasses art and literature, lifestyles, ways of living together, value systems, traditions and beliefs. Thus, urban culture covers the notions of culture within an urban setting from both a functional and anthropological perspective"[10].

- ***Historic urban landscape***
  It is "an urban area understood as the result of a historic layering of cultural and natural values and attributes extending beyond the notion of historic centre or ensemble to include the broader urban context and its geographical setting: sites' topography, geomorphology, hydrology and natural features, built environment, both historic and contemporary, infrastructures above and below ground, open spaces and gardens, land use patterns and spatial organization, perceptions and visual relationships, other urban structure elements. It also includes social and cultural practices and values, economic processes and the intangible dimensions of heritage related to diversity and identity" (UNESCO, 2011).

The "Operational Guidelines on the Implementation of the World Heritage Convention" (UNESCO, 2005) reported the definition of "groups of buildings", including ***historic towns***.

- ***Urban heritage***
  "As a concept, urban heritage is global and has a worldwide scope, but at the same time, it harbours several notions and must be seen with the different and specific contexts with which it deals. Urban heritage issues engage heritage managers and archaeologists and geographers, landscape and urban planners, engineers, architects, anthropologists, and historians. As cultural heritage issues in general, those concerning the urban heritage are interdisciplinary and multifaceted" (Karlström, 2014).

[10] https://www.heritage21.com.au/heritage-practice/cultural-built-heritage/

### 2.1.1 Cultural Heritage classifications for documentation

*CH classifications*

The necessity to *document* cultural heritage is well known and acknowledged internationally. For this reason, several cataloguing systems are developed at both national and international levels for inventorying cultural heritage items. The targets of documentation consist mainly of preservation. Some specific kinds of documentation also aim at supporting detailed studies and analysis on cultural heritage. Moreover, in the last years, the concept of the resilience of cultural heritage, included in the broad concept of urban resilience (Meerow et al., 2016; Sharifi & Yamagata, 2016), was spread.

The documentation is a fundamental tool for increasing it. This section presents International and National Classifications, starting from the UNESCO definition of CH (Table 1).

Table 1. UNESCO CH classifications.

| | | | |
|---|---|---|---|
| UNESCO | 1972 | *Monuments* | architectural works |
| | | | works of monumental sculpture and painting |
| | | | elements or structures of an archaeological nature |
| | | | inscriptions, cave dwellings |
| | | *Groups of buildings* | groups of separate or connected buildings |
| | | *Sites* | works of man or the combined works of nature and man |
| | | | areas including archaeological sites |
| | 1992 | *Cultural landscape* | combined works of nature and humankind |
| | 2003 | *Intangible Cultural Heritage* | oral traditions |
| | | | performing arts |
| | | | social practice |
| | | | rituals |
| | | | festive events |
| | | | knowledge and skills to produce traditional crafts |
| | | | knowledge and practices concerning nature and the universe |

In Italy the cataloguing entities belonging to the MIBACT[11] (Ministero per i Beni e le Attività Culturali e del Turismo, Ministry of cultural heritage and activities and tourism) and its ICCD (Istituto Centrale per il Catalogo e la Documentazione, Italian Central Institute for Cataloguing and Documentation). Several different inventory organizations exist (see § 4.1). The more recent ones are often based on the previous ones so that they are already included in the most recent classification that ICCD employs. This classification consists of classes and values defined by further Italian classifications. It is implemented in the SIGECweb[12] platform, and some efforts to map it to the standard CIDOC-CRM ontology[13] are in progress. Table 2 shows the different classification and cataloguing bodies of CH in Italy.

[11] https://www.beniculturali.it/
[12] http://www.iccd.beniculturali.it/
[13] http://www.cidoc-crm.org/

Table 2. MIBACT classification of CH.

| MIBACT Classification | | | | Previous Mibact Classification integrated into the ICCD one | | | | |
|---|---|---|---|---|---|---|---|---|
| ICCD | MOVABLE, IMMOVABLE, MATERIAL, IMMATERIAL | Archaeological | anthropological finds | ISCR | Archaeological | site | | |
| | | | archaeological sites | | | monuments | | |
| | | | archaeological monuments | | | | | |
| | | | archaeological finds | | | | | |
| | | | stratigraphic tests | | | | | |
| | | | archaeological materials | | | | | |
| | | Architectural and Landscape | architecture | | Architectural | | PaBAAC | Architectural Protected |
| | | | historical nuclei | | | | | not protected |
| | | | parks/ gardens | | | | | |
| | | Photographic | photos | | | | | |
| | | | photo collections | | | | | |
| | | Musical | musical instruments | | | | | |
| | | | musical instruments - organ | | | | | |
| | | Naturalistic | botany | | | | | |
| | | | mineralogy | | | | | |
| | | | palaeontology | | | | | |
| | | | petrology | | | | | |
| | | | planetology | | | | | |
| | | | zoology | | | | | |
| | | Scientific e Technological | | | | | | |
| | | Historic e Artistic | drawings | BeAP - SITAP | Historic and Ethno-anthropological | | | |
| | | | engraved matrices | | | | | |
| | | | works of art / contemporary art | | | | | |
| | | | prints | | | | | |
| | | | antique/contemporary costumes | | | | | |
| | | Demo-ethno-anthropological | | | | | | |

## 2.2 Evolution of the concepts of city and historical centre

The notion of the *historical centre* in the *urban area*, namely *historical urban centres*, appears after the second world war due to the need for reconstruction and preservation actions and planning in cities. In Italy, for example, the city planning tool of national legislation aims to recover the historical values of the urban landscape. In this scenario, the evolution of the concept of historical centres concept was spread from studies and research carried out by Giovanni Astengo and Augusto Cavallari Murat. They explored the history of the planning and representation method (Bravo & Mingucci, 2008). It is important to clarify the whole process that led to these urban planning actions before analysing the increase of the interest in the reconstruction, definition and plans of historical urban centres.

Fano (1974) reports the entire development of the evolution of historical centres. He describes the first people who became aware of the dynamic and cared about conservation and enhancement. It is possible to mention John Ruskin, William Morris, Stuart Mill, T.H. Huxley in Great Britain; Viollet-Le-Duc, Victor Hugo in France and Camillo Boito and Gustavo Giovannoni in Italy. In "The Stone of Venice 1846", John Ruskin presents the idea of beauty and cultural value of historical centre. In 1875, William Morris promoted arguments against the industrialization that destroyed the cities by tampering with their historical-environmental values and compromising the future of the cities themselves and the countryside. He says: "to contain the decline of the urban and rural environment; there is no other option than to monitor and preserve the set-up of the landscape and to try to pass on to posterity a cultural heritage no less than that which has been re-inherited" (Morris, 1875). In the same years in Great Britain, the "*Commons Preservation Society"* and the "*Society for the protection of ancient buildings"* were founded in 1865 and 1877. The same ideas also spread in France, where the debate between Violet-Le-Duc and Victor Hugo on the study and preservation of ancient and Middle Ages Architecture took place. Le-Duc claimed the reinterpretation of historic architecture and integration with new parts. On the other side, Hugo aimed to preserve and conserve the authenticity of historical monuments. In Italy, in the second half of the 19th century, some studies considered a historical re-examination of the architecture of the Middle Ages. A critical acceptance of the cultural content of monuments and historic centres through valorisation and restoration practices was spread.

Camillo Boito dealt with restoration and study of ancient Middle Age buildings (1880-1890), and Gustavo Giovannoni, in 1913, defined the first urban concepts in his work "Old cities and new buildings" (*Vecchie città ed edilizia Nuova in Nuova Antologia*). The book of Fano (1974) deals with the process of historic centres creation, their development and their evolution over time. Firstly, he differenced *urban centre* with the *historical value* from the *new city*. Historical centres are defined as the "old part" of cities, distinguishing new from old. Moreover, it is also important to analyse the social, political, and economic transformations in a society's history dynamic. Every historical fact is linked to a specific period, and it finds its environment in part or a construction phase of the city. It is possible to say that historical centres are part of the city related to the recent past. Despite this, such definition needs a study of the history of cities.

*History of cities*

New theories and related urban actions started to occur from the end of '700 and the beginning of '800 centuries (with the Industrial Revolution, 1760 – 1840). With the revolution, new urban planning policies have been spread involving historical centres and transforming their values. Therefore, the structures and the appearance of the architecture changed, giving a new face to the city and creating a "fracture" between the pre-existing nucleus and the unique neighbourhoods (not only for the different urban-architectural aspects but also for the diversity of the socio-economic environment). Historical urban core or centres are part of cities; therefore, it is fundamental to investigate the city concept from a historiographic perspective looking at the cities' development from Greek POLIS to today's municipality (Figure 3). After the diffusion of *Etruscan cities* in the past, the connotation of public and community life (with politic, social, cultural and economic activities) begin to 'take roots' with the *Greek POLIS* (πόλις) concept. This view has been considered and developed after the Greek empire in the Hellenistic culture (historically after the Great invasions of Alexander). After this event, social and cultural values also spread in Africa and Asia. Afterwards, the *CIVITAS Romana* (meaning centres of culture) were urban centres composed of walls, arches, temples, homes, streets, theatre, arena, urban services, and administrative organizations. They represented the organizational structure expressed in the architectural forms. From civitas derived the *URBS*, they had a religious value and represented a fortified structure with sacral boundaries named "pomeridium". Europe was significantly influenced by the development of cities and the succession of different Mediterranean cultures. *Middle Ages cities* were structured based on roman ones. In Italy, in 1110 AC, the central municipalities of the north were established.

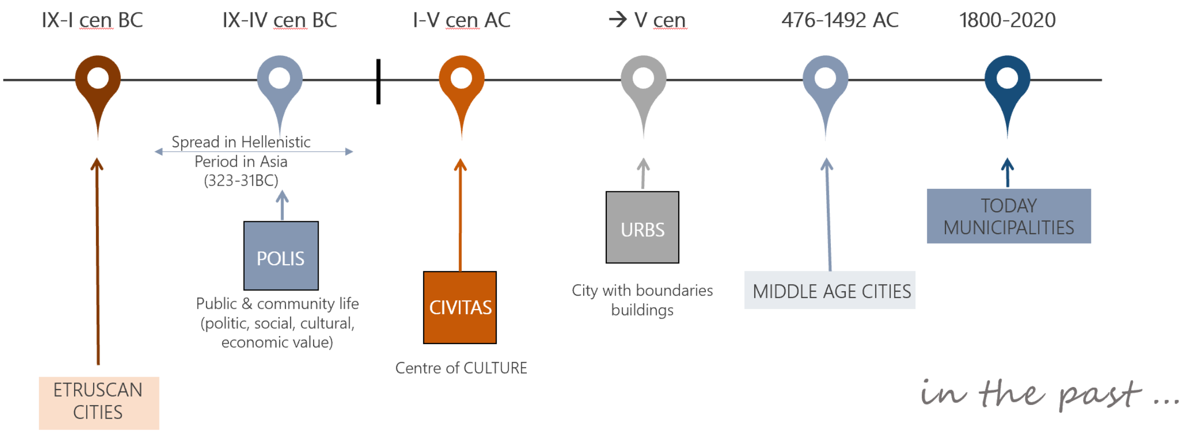



Figure 3. Evolution of cities during centuries.

Despite the term "historical centre" was born in 1950-1970, the study of historical centres issues starts from '50 years of XIX century and considers historical centres from the cultural point of view and includes them into the territory's dynamics (urban planning). The most meaningful events and dates that contributed to the definition of the notion of historical centres are reported below (Figure 4). The conventions, charter, and declarations listed deal with cultural and historical heritage domains, restoration and conservation actions, and urban (recovery) planning:

- 1931→ *Athens Charter for the Restoration* and Conservation of Cultural and Historical Heritage (CIAM, Congresso internazionale di architettura moderna, Le Corbusier).

- 1939 → *Bottai Laws (no. 1089 and no. 1497 of 1939*) “for the protection of heritage with artistic and historical interest”, in which for the first time in the Italian legislation, the attention focused on the preservation and protection of cultural heritage.
- 1954 → *UNESCO Aja declaration.* Article 1 was devoted to centres comprising a considerable number of cultural heritages called "monumental centres”.
- 1960 → *the Gubbio Charter* (Convegno Nazionale per la Salvaguardia e il Risanamento dei Centri Storici), in which for the first time it is stated that “the necessity of an urgent recognition and a preliminary classification of historical centres with the identification of the areas that should be protected and rehabilitated”.
- 1964 → *Venice Charter,* for the Conservation and Restoration of Monuments and Sites[14].

*1St definition of historical centres*

- 1967 → *Commissione Franceschini titolo IV (“Dei beni ambientali”), dichiarazione XL (“centri storici e loro tutela”)* – Coord. Astengo. For the first time, the definition of historical urban centre appeared as "urban settlement structures that constitute cultural unity or the original and authentic part of settlements and testify the characteristics of a lively urban culture. (...) For operational purposes, the protection of historic centres will have to be implemented through preventive measures (such as the temporary suspension of construction activities related to them), and definitive through regulatory plans".

In these years, the attention shifted from the architectural composition of the urban area to the conservation of the monuments with social, political, economic and legislative values. Following are listed the main changes:

- 1969 → The word ***historical centres*** appeared in the *Dizionario Enciclopedico di Architettura e Urbanistica (Encyclopaedic Urban and Architecture Dictionary)*. They are defined as: “core of a city that constitutes a complex linked to particular historical moments due to formal, typological and urban characteristics. Sometimes the concept of the historic centre is extended to the whole city when it represents a living testimony of other eras. The term was spread by the most recent town planning legislation, which dealt with the problem of the conservation, rehabilitation and enhancement of the historical centre”.
- 1972 → The *Italian Restoration Charter* (Ministero della pubblica istruzione) - in which the role of Cesare Brandi was fundamental - is the first official document containing the notion of historical centre.

[14] https://www.icomos.org/charters/venice_e.pdf

- 1978 → The *Italian Law no*. 457 reserves – for the first time - significant financial resources to recover "the historic built heritage and introduces a new and specific type of plan", the *Recovery Plan*.

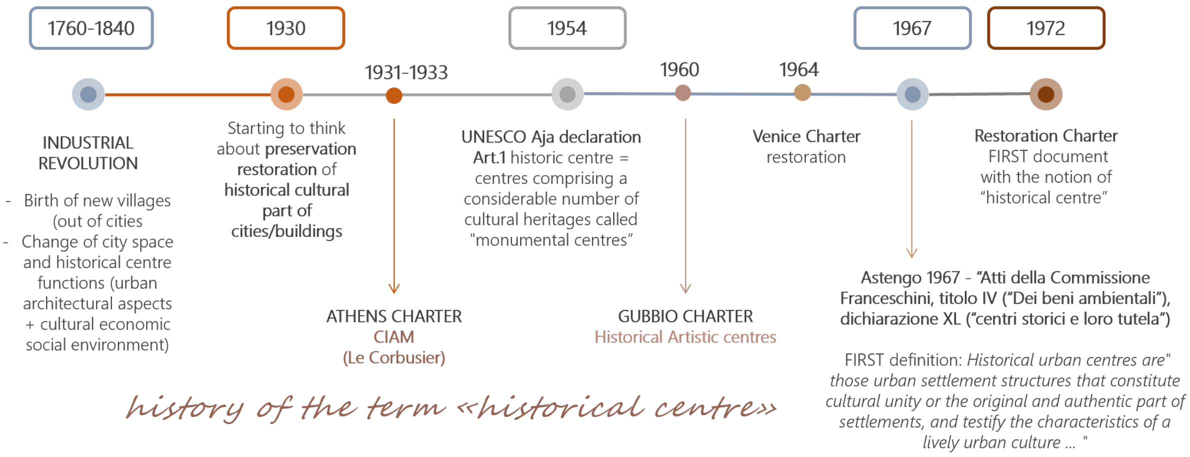



Figure 4. Declarations, charters and actions that led to the definition of the term "historical centre".

## 2.3 Definitions and meanings of historical centres in the literature

In the above paragraph, it has been highlighted that the meaning of historic centre is a long controversial and discussed theme at various levels (technical, economic, social, and legal). Although the only working definition for Benevolo is the historical one, "a historical centre is the pre-industrial city in that it survives, isolated or confused, in the system of current settlements" (Cervellati et al., 1977); it becomes univocal and persuasive only in the context of urban planning management. Moreover, before the industrial revolution and urbanism, the relationship between the city and the *countryside* or *rural areas* remains constant in the different phases of urban history. In 1980 years, the historical city becomes part or central area of the new one. The city and the historic centre were a single entity that could identify places with a specific role (for example, fortified cities were strategically located to defend and defend themselves; cities could have a commercial role and so on). There were different cities with different functions. Hence, after a rich literature investigation (Cervellati et al., 1977; Cervellati & Miliari, 1977; Cialdini & Falini, 1978; Cutolo & Pace, 2016; Volpiano, 2017; Yadav, 1986), the most known definitions and meanings of historical centres and related concepts are here presented. This list of concepts is fundamental to define the different definitions and semantics of HC and historical city, comparing and merging them (see section 5.2.2) to integrate various classes into the ontology structure.

- An ***urban centre***, old or new, represents an entity with life (in the broadest sense that can be attributed to this expression).
- A ***historic city*** reflects the historical, anthropological, cultural and artistic evolutionary process due to the stratification of its monuments (Dezzi Bardeschi, 1998).
- An ***architectural ruin*** or a "dead monument" belongs to archaeology. Therefore, it represents one of the most valid testimonies of tradition, but remains detached, by its nature, from contemporary social, economic, and political life.
- In Pane (1965), the differences between "historical centre" and "ancient-old centre" are explained. "The ***ancient centre*** corresponds to the area of archaeological stratification. The ***historical centre*** is the city itself as a whole, including its modern agglomerations. What is ancient is historical, but not all that is historical is ancient".
- A ***historical centre*** and the neighbourhoods of the new city connected to it continue to live. Its population often carries out its work activities within the centre itself, maintains social and political relationships and cultural exchanges. It has its face validly expressed through the architectures and their environment. HC is the place of people traditions and culture (Fano, 1974). It also represents the oldest part of an urban settlement, generally the richest in historical evidence, in urban planning (Treccani, lexicon of XXI century, 2012). A historical centre is "a place configurable within a boundary, where citizens carried out the main activities, and the most representative offices for these functions have long since consolidated" (Di Gioia, 1975). Nowadays, after a long debate, a historical centre could be defined as a combination of "cultural, economic and social assets with a specific urban identity and a high historical value and testimonial" (Cerasoli, 2010). These values are linked both in the urban context and cultural heritage elements.

## 2.4 Concepts of minor and abandoned historical centres

This section presents a literature investigation (Cerasoli & Biere Arenas, 2016; Coletta, 2005; Lauria, 2009; Rolli, 2005) carried out in the domain of minor and abandoned historical centres. These other concepts have been integrated into the semantics of the ontology to express different connotations around the domain of HC.

Carci (1980) reported that, at the end of the 1970s, the concept of the historical centre changed: "we can refer not only to the ***ancient part of a city*** subject to the dynamics of development (...) but also to an ***ancient nucleus*** coinciding with the urban one". The conversion of the post-industrial settlement models and the related globalisation causes different situations such as abandonment. In other conditions, it is possible to observe the presence of new social classes composed of immigrants.

In addition, 'gentrification' could occur or reuse (partial or total) only for touristic-commercial goals. The debate about the recovery and valorisation of the historical centres, especially the *small ones,* represents a significant challenge. Minor historical centres are extremely vulnerable territories with high historical and social values. For these reasons, they need to be documented and protected (Cerasoli & Biere Arenas, 2016). Coletta (2005) reported the difficulty of defining historical and minor historical centres. She states that it is impossible to identify an "unitary conceptual category" where the various ancient urban agglomerations and internal elements coexist.

As shown in the previous sections, the concept of the HC has evolved over the years, changing its physical identification and meaning, including the one of MHC. It has included social and economic aspects from a simple urban-architectural reality with artistic and cultural quality. The concept of ***minor historical centres*** is introduced by *Alberto Predieri,* in his report for the *"VI Convegno A.N.C.S.A."- Bergamo, 1971* (Predieri, 1971). He classified historical centres into three different categories:

*1st concept of MINOR historical centres*

- ***Historical centres in cities***.
- ***Minor historical centres.*** Those included in developing cities (or even stationary ones) originally were the core of essential political-cultural and economic functions, now lapsed, but with great historical-artistic-environmental value and cultural and touristic interest. According to the Venice Charter of 1964 and Disegno di Legge n. 1942 in Italy, minor historical centres are municipalities with fewer than 5,000 inhabitants.
- ***Abandoned Minor historical centres.*** These are those in which buildings' physical and technological deterioration finds its origin in the demographic exodus. In 1975 the European Charter of Architectural Heritage defined "abandoned places".

It is also possible to distinguish different typologies of MHC (Coletta, 2005):

- The "centres in the gravitational sphere of the capital cities".
- The "coastal centres affected by seasonal residential phenomena and tourism".
- The "agricultural centres of rural internal areas".
- The "centres with a highly distinctive historical reality".

Rolli (2005) includes in the definition of minor historical centres also ***small villages*** and ***hamlets***. He tries to define the different parts and elements to represent historical centres in his work. These are buildings, building units, urban furniture, boundaries features and roads. His work carried out also a spaces classification. It identified:

- Margin: natural and artificial boundaries (walls, fortified structures, wall-houses, etc.);
- Connections and Morphological Characteristics: core points (Acropolis, Rocca, Castle, archaeological sites, etc.) and lines (paths, roads, transport networks, etc.);
- Open Spaces: nodes, squares, architectural discoveries, etc;
- Urban/Architectural Structure or context: architectural and suburbs elements.

Rolli classified historical centres based on their shape in site, boundaries, networks, accesses, nodes and patterns.

Finally, it is essential to mention the concept of "*abandonment*" of spaces, cities, and historical places. In the framework of transformation area, among the different behaviour of evolution of cities, it is possible to notice the "state of abandonment". Moreover, urban regeneration processes start from this situation to restore the balance of places (Caramia, 2016).

## 2.5 Initiatives to document and promote HC, villages and hamlets

For the present research aim of recovering and reinhabiting HC, it is essential to analyse the existing associations, projects and recent articles related to HC, MHC and villages dynamics, transformation and preservation. An investigation of existing ideas, discussions and proposals was carried out to support the documentation of these places. This paragraph presents a list of some initiatives aimed to document, preserve and promote HC. Below, some Italian examples of "groups and associations", "events", and "paper from newspapers and websites" are presented subdivided into different classes of typology.

Associations and Administrative Bodies:

- In Italy, one of the oldest and most influential associations for historical and artistic centres is the *ANCSA*[15] (Associazione Nazionale Centri Storico-Artistici - National Association of Historic-Artistic Centers). From 1960 it works for the conservation, protection, safeguard and regeneration with many research, studies and publication (such as the Gubbio Charter of 1960. Among its founders, it is possible to find Giovanni Astengo, Antonio Cederna and Giuseppe Samonà, mentioned in the previous paragraphs.

[15] https://www.ancsa.org/

- The "*Associazione Nazionale Piccoli Comuni di Italia*"[16] (National Association of Small Municipalities of Italy) was born in 1997. It groups all the municipalities with less than 5000 inhabitants. The association was created to protect small cities and collect their cultural, programmatic and ideological heritage values. The primary purposes are: to carry out actions to promote and preserve local autonomy; to encourage the study of the problems and propose the relative solutions to help responsible bodies, to carry out information actions for associated bodies through the dissemination of news, analyses, proposals and to promote the economic and social development and the competitiveness of small municipalities.

Projects and groups:

- In the framework of Alpine hamlets and villages, the "*BorghiAlpini.it*"[17] (Alpine Villages) represents a project realised by the Unione Nazionale Comuni Comunità e Enti Montani, Piemonte (National Union of Municipalities, Communities and Mountain Bodies, Piedmont Region). The project underlines the possibility of growth and development of these areas. These centres are an essential resource for new businesses and new job opportunities. On the other hand, they would like to promote the recovery as a factor of enhancement and protection of the territory, according to architectural and urban planning criteria capable of reconciling modern styles and the great legacy of the past.

- *Planet B?,* a research group that acts on cities, landscapes and civil economy, proposes the report "*Borghi Abbandonati - Censimento di un'Italia che scompare*"[18] (Abandoned Villages - Census of a disappearing Italy). The article wants to underline the number of abandoned historical centres, the causes that led them to this situation, and a study to re-evaluate these villages and economic terms.

- *Montagne in Rete*[19] was born as a project for the mountain of the Trentino School of Management of Trento. They wanted to research, enhance and group common characteristics into a unique system. The project "Riabitare le Alpi" (Re-inhabiting the Alps) was born in 1990, and it collects information on different forms of living and working in the mountain. On their website, they reported that: "the current deep structural crisis of the industrial economy has called into question the

[16] http://www.anpci.it/
[17] http://www.borghialpini.it/
[18] http://planetb.it/borghi-abbandonati-censimento-di-unitalia-che-sta-scomparendo/
[19] https://www.montagneinrete.it/https://www.montagneinrete.it/riabitare-le-alpi

choice of possible development models to rebuild good and sustainable productive relations with human environments. Rural contexts are called to face a new and significant challenge for the future, and, from marginal places, they can return to assume a central function (…). The awareness of living in a regenerative phase of rural society is growing, and virtuous initiatives are spreading in the Alps to enhance artefacts, places and productions" (Carminati, 2017). The present study collected some recent papers on the valorisation, spatial documentation and regeneration of villages and rural abandoned areas.

- "*Montagne In Movimento - MIM*" is an informal research group born within the Department of Philosophy and Educational Sciences of the University of Turin that deals with public anthropology in mountain communities throughout the Italian territory. They want to promote a new sustainable way of living in the Alps[20].

Journals, Books and Research:

- *ARCHALP*, the *International Journal of Alpine Architecture and Landscape*[21] created by the Istituto di Architettura Montana (IAM – Institute of Mountain Architecture) of Politecnico of Turin, reported different papers in the framework of mountain design, urban planning and strategies, project and so on. In particular, one of the last numbers published by the journal, ArchAlp n.4 "For a new inhabitability of the Alps. Architectures for welfare and regeneration" (Istituto di Architettura Montana, 2020), reports many hints for the reinhabitation of hinterlands and the valorisation of small historical centres located in rural areas.

- Regarding the spatial documentation of villages and historical centres, it is possible to mention the work "*Ripopolare borghi e montagne*"[22] (Re-inhabit villages and mountains). The article presents an initiative launched by UNCEM (Unione Nazionale Comuni Comunità Enti Montani). It regards the first "national mapping of Alpine and Apennine villages" involving citizens, administrations and businesses to identify new proposals and solutions to restore and valorise semi-abandoned centres.

[20] https://www.facebook.com/MIM-Montagne-in-Movimento-102118241369620/?ref=page_internal
[21] https://archalp.it/
[22] https://www.italiachecambia.org/2020/09/italia-mappano-borghi-vivere-lavorare-montagna/?fbclid=IwAR3IUPLZWoXFbC3cNWw_9T7EbxJzF_cXqijv_a6JhlmWyqDPcEihpu6t3mI

- Another significant contribution to the studies of Climate Changes is the numerous research of Luca Mercalli, climatologist, director of Nimbus magazine, chair the Italian Meteorological Society (Mercalli, 2020). In two different interviews, "*Salire in montagna contro la modernità*"[23] (Climbing to the mountains against modernity) and "*Cambia il clima cambia la montagna: scenari di vita futura sulle terre alte*"[24] (Change the climate change the mountain: scenarios of future life on the highlands), he reported that, in the following years, many people would escape from the heat and un-livability of cities. The reasons are both the effects of climate change and the fact that many jobs are becoming "smart", as it is possible to notice by COVID-19 pandemic effects.

- The content of the article "*Recuperare i borghi d'Italia può valere 2 miliardi*"[25] (Recovering the villages of Italy can be worth 2 billion) underlines the economic point of view re-valorisation of villages. In fact, after the lockdown of COVID-19, the related "smart working" and the resulted revitalisation of small towns, an agreement between the Order of Architects and the Union of Mountain Communities and Bodies aims to revalue them thanks to private projects and European Union funds.

Announcements and Calls:

- Finally, another important recent initiative is represented by the Italian Call for regions to move and live in the mountains (November 2021), such as the Piedmont Region[26]. The initiative aims to support the revitalization and repopulation of mountain areas due to the growing social needs caused by the current health emergency of COVID-19. Anyone who resides in an urban centre in Italy and intends to buy or recover property in a mountain municipality with less than 5,000 inhabitants can join the call.

All these initiatives show how it is crucial to spatial and historical document HC such as villages or hamlets to promote the territory and new sustainable plans. Moreover, this list of associations represents the multitude of stakeholders involved in MHC tasks needing a common language and structure to share knowledge.

[23] https://www.ladige.it/eventi/cultura/2020/08/12/salire-montagna-contro-modernit-oggi-mercalli-comano
[24] https://ilpostodelleparole.it/luca-mercalli/luca-mercalli-cambia-clima-cambia-la-montagna-scenari-vita-futura-sulle-terre-alte/
[25] https://www.ilsole24ore.com/art/recuperare-borghi-d-italia-puo-valere-2-miliardi-ADq10Dm?utm_term=Autofeed&utm_medium=LISole24Ore&utm_source=LinkedIn#Echobox=1598940322&refresh_ce=1
[26] https://bandi.regione.piemonte.it/contributi-finanziamenti/residenzialita-montagna

# 3

Chapter 3

# A review of ontologies

Researches have changed the way they interact with information content as a result of the massive increase of information and communication technologies that were developed from the beginning of the 2000s. Parallelly, this increase of technologies brought about a revolution in the interdisciplinary use of information: “to be understandable and reusable, these models need to combine the precision of formal semantics with the efficacy of cognitive transparency, as they incorporate increasingly sophisticated and heterogeneous modelling paradigms” (Guarino & Musen, 2005). The great interest in ontologies underlines this trend. The significant claim in ontologies arose from the consolidation of the Semantic Web (§ 3.1.3), the web of Linked Data (principles to share a machine-readable interconnected data on the Web). Ontologies in Computer Science play a crucial role in enabling content-based access, interoperability and communication across the Web, equipping it with new services. Ontologies are considered conceptual structures that formalise the explicit knowledge of a domain. The definition of ontologies can help solve problems of interaction between different and complementary information in the domain of spatial information, one of the frameworks of this thesis. Ontologies make it possible to express semantic concepts and relations of a specific domain, such as historical built and cultural heritage objects. They can allow digital control of information and integration of urban and rural protection and management activities and are helpful to share a common understanding of the structure of information among citizens, scientists, researchers, policymakers and other stakeholders.

This chapter illustrates the different meanings and applications of digital ontologies to clarify the context in which the methodology of the thesis is set.

## 3.1 Defining ontology

The word "ontology" has different meanings depending on the context where it is applied. The differences are greatest between the philosophical context and how it is used in computer and information sciences (Guarino, 1998). In Philosophy, "Ontologies" is used without an article and with a capital "o", whereas an "ontology", with an article and a lowercase "o", is used in computer science. Before investigating the areas of application and the many meanings of ontologies in-depth, it is necessary to explain the term briefly. It is used at an interdisciplinary level, in different scientific communities and with multiple senses. In (Guarino, 1998), two main definitions and two sub-definitions are given:

*Ontology meaning*

1. "*Ontology*" refers to Philosophy (explained in greater detail in section 3.1.1);
2. "*ontology*" can be applied in two different senses:
- in a philosophical sense as a "conceptualisation", a system of categories accounting for a vision of the world without depending on a language;
- in Artificial Intelligence (AI), "ontology" is an engineering artefact with a defined vocabulary and language. This definition includes "domain ontologies" and "applied ontologies". In this thesis, I will consider this last meaning of "ontology".

Further meanings of the term ontology can be seen in Table 3.

Table 3. Possible interpretations of the term "ontology" by (Guarino & Giaretta, 1995).

| |
|---|
| 1. Ontology as a philosophical discipline |
| 2. Ontology as an informal conceptual system |
| 3. Ontology as a formal semantic account |
| 4. Ontology as a specification of a "conceptualisation" |
| 5. Ontology as a representation of a conceptual system via a logical theory<br>- characterized by specific formal properties<br>- characterized only by its specific purposes |
| 6. Ontology as the vocabulary used by a logical theory |
| 7. Ontology as a (meta-level) specification of a logical theory |

### 3.1.1 Ontologies in Philosophy

It is essential to distinguish the first *Ontology* (1, Table 3) interpretation from the others (2-7, Table 3). The significant distinction concerns their application in Philosophy and Aristotle's definition. From the etymological point of view, the compound term "Ontology" derives from the Ancient Greek ὄντος, òntos which means "being; that which is" and from λόγος, lògos, "logical discourse", so it signifies "study of being". Quine (1948) reported that the word Ontology was born with Aristotle in the study of nature and reality in his *Metaphysics* work. Philosophers often use it as a synonym of the concept of metaphysics. Aristotle defined Ontology as the "science of being" and "science of the whole of the reality", moving from the sensible world to transcend it for finding the universal

*Ontology in philosophy*

fundamentals (Masolo et al., 2003). The core of that work is the theory of "all the species of *being qua being* and the attributes which belong to it *qua being*" (Aristotle, Metaphysics, IV, 1). Ontology is the concept that regards the structures of real objects with their properties, events, processes, and relations. It seeks to provide a classification of entities in all spheres of beings (Smith, 2003). This idea of Aristotle is related to the newer concept of General or Formal Ontology for which there are different and controversial points of view (Poli, 1995). In Cocchiarella (1991), a Formal Ontology is "the systematic, formal, axiomatic development of the logic of all forms and modes of being", it concerns the description of "forms of being", i.e. the structural features. In practice, Formal Ontology can be identified in the distinctions among the entities of the world (as well as physical objects or events) or among the categories of the world (concept, property, characteristic, …). The discipline of Ontology could be related both to Knowledge Representation and Knowledge Acquisition (Guarino, 1998). Opposite to the Aristotle conception of Ontology, in which it describes the intrinsic nature of the world, there is another study in which the entities are "filtered" by the perception and the thought of human's mental activity. This last idea consisted of the research of conceptualisations and was promoted by Immanuel Kant in his "Critique of Pure Reason" (*Kritik Der Reinen Vernunft*, 1781). This ontology could provide a catalogue of the entities of the "world of experience" that is determined by the innate (*a priori*) forms of perception and reason (Masolo et al., 2003). Finally, Ontology in philosophy focuses on the "nature and structure of things *per se*, independently of any further considerations, and even independently of their actual existence" (Staab & Studer, 2009). Moreover, a philosophical Ontology, such as the Aristotle conception, does not depend on a specific language. It is always the same, independently of the language used to define it (Guarino, 1998).

### 3.1.2 Ontologies in Computer Sciences and Artificial Intelligence

During the last ten years, ontologies have grown in the field of the computer science community, knowledge representation and engineering, information integration, retrieval and extraction. It is possible to refer to an *ontology* in knowledge communities, especially in Computer Science (CS), to identify "a kind of information object or computational artefact" (Guarino et al., 2009). For Gruber (1993), what "exists" in reality can be represented. He defines an ontology as a "specification of a representational vocabulary for a shared domain of discourse - definitions of classes, relations, functions, and other objects". "Entities (the most general being) are analysed and organized into concepts and relations. The core of an ontology is the generalization/specialisation hierarchy of concepts, that is, a *taxonomy*. It already makes clear the necessity of the employment of systems that implement hierarchies and inheritance in the final application phases" (Guarino et al., 2009).

*Ontologies in CS and AI*

The most cited definitions of ontology are here reported:

- "Explicit specification of a conceptualisation" (Gruber, 1993);
- "Formal specification of a shared conceptualisation" (Borst, 1997);
- "Formal, explicit specification of a shared conceptualisation" (Studer et al., 1998).

The first one from Gruber is the most cited. This definition of the required conceptualisation should express a "shared" view between many parties, a consensus rather than an individual view (Guarino et al., 2009). The one of Studer et al. (1998) merges the others. The first definition defines ontology in a knowledge-based system intending that what "exists" is precisely that which can be represented. Gruber said that "when the knowledge of a domain is represented in a declarative formalism, the set of objects that can be represented is called the universe of discourse. This set of objects, and the formalized relations among them, are reflected in the representational vocabulary with which a knowledge-based program represents knowledge. Thus, we can describe the ontology of a program by defining a set of representational terms. Definitions associate the names of entities in the universe of discourse (e.g. classes, relations, functions, or other objects) with human-readable text describing what the names are meant" (Gruber, 1993). He defines ontologies such as objects, properties, and entities existing in some area of interest. In the definition of Gruber (1995) an ontology was defined and specified as the concepts, relations, and other distinctions that are relevant to model a *domain*. "The specification takes the form of the definitions of representational vocabulary (classes, relations, and so forth), which provide meanings for the vocabulary and formal constraints on its coherent use" (Gruber, 1995). Ontologies generally consist of a vocabulary of terms and their definitions (a specification of their between-relations). These relations could be classified into two typologies (Stevens et al., 2000):

- "Taxonomical relations, which relate concepts according to subsumption hierarchies; the most common taxonomical relations are the specialization relations (is a kind of) and the partitive relations (is a part of)" (Kavouras & Kokla, 2007);
- "Associative relations, relating concepts across hierarchical structures and describing properties, functions, and processes of a concept" (Kavouras & Kokla, 2007).

### 3.1.3 Ontologies in the Semantic Web

The term ontology is spread and applied in many scientific disciplines, such as Computer Science, Artificial Intelligence, Semantic Web, Systems Engineering, Software Engineering, Biomedical Informatics, Library Science, Enterprise Bookmarking, and Information Architecture. In this section, we consider ontologies used as components in the fields of information science. In the field of *Artificial Intelligence* and *Semantic Web* they were initially used to conceptualize some parts of the real world. The first objective was to allow the software system to "reason" about real-world entities. One of the first examples is represented by the CYC (Cycorp) ontology (Lenat, 1995). The project aims to assemble a comprehensive ontology and knowledge base. Among the tasks listed in (Smith, 2003) and created for the use of ontologies for many purposes in different fields, the CYC project is relevant for Semantic Web development. The Semantic Web is the web composed of Linked Data. "It will bring structure to the meaningful content of Web pages, creating an environment where software agents roaming from page to page can readily carry out sophisticated tasks for users" (Berners-Lee et al., 2001). The main aim of the web of data is to allow computers to work hard to develop systems supporting many interactions over the net. Semantic Web technologies help users archive data on the web, design vocabularies, and define rules to handle data. The Semantic Web can realise a Web of Data using standard technologies and with a common model. This model must be provided for machines to describe and query the data and their connections and properly classify the terms for specific knowledge areas. In this framework are located ontologies in Semantic Web (Figure 5). Ontologies are part of the W3C27 standards, and they help to exchange data among different systems, provide queries tools, and publish open knowledge. Moreover, they offer services to facilitate interoperability across multiple, heterogeneous systems and databases (DB).

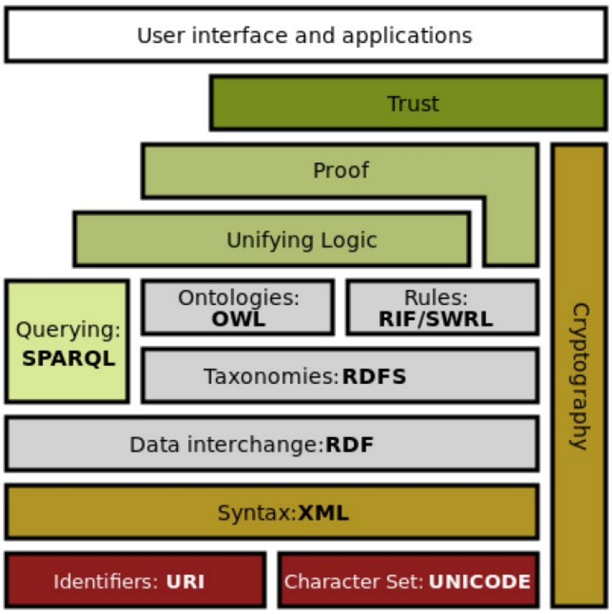



Figure 5. Semantic Web components (W3C.org).

In the last decades, there has been a rapid increase in the number of publicly available ontologies in the *engineering* field. These ontologies are not all high quality, and some have a minimal scope (Falquet et al., 2011). However, this shows that the development of ontologies is no longer a reserve of big projects. It is

[27] https://www.w3.org/standards/

probably due to several factors such as the spread of the Semantic Web, the availability of methodologies for engineering ontologies, the presentation of books, courses and tutorials, etc. Although the concept of ontology is today widespread, the practical implementation of ontologies in a specific application context remains an open challenge. In this framework, ontologies embody the results of academic research and offer an operational method to put theory to practice in database systems. Since 2005, critical domain-specific ontologies have emerged in multiple fields, becoming official or de facto standards, with a massive impact on the communities they serve. Guarino & Musen (2015) give a great list of applied ontologies. Many types of research of applied ontologies are presented and published in the *Applied Ontology Journal, an Interdisciplinary Journal of Ontological Analysis and Conceptual Modelling*[28].

OWL

The Web Ontology Language (OWL) is a knowledge representation language designed to formulate, exchange and reason with knowledge about a domain of interest. It is one of the W3C standards, and it includes RDF, RDF(S) and SPARQL languages[29] (Figure 6). RDF (Resource Description Framework) is a standard model for data interchange on the Web. It represents a graph data format to represent information on the Web. SPARQL[30] is the query language for OWL ontologies. OWL 2 is the current version of OWL[31]. RDF is a data model built on edge-node "graphs." Each link in a graph consists of three parts: subject, predicate, object (Figure 7).

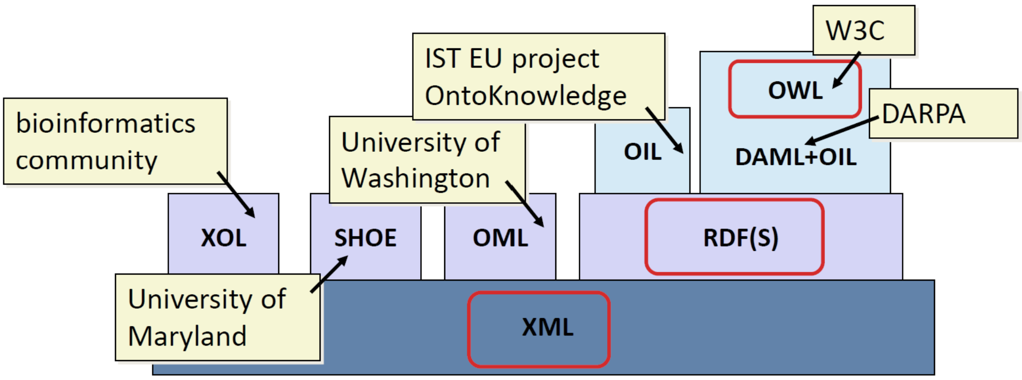



Figure 6. Web Ontology Language (OWL) among different languages.

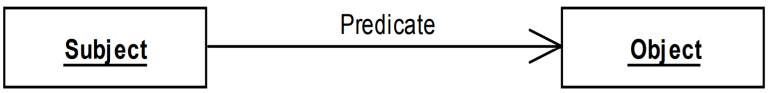



Figure 7. RDF Triple ((Perry & Herring, 2012).

[28] https://www.iospress.nl/journal/applied-ontology
[29] https://www.w3.org/2007/03/VLDB/
[30] https://www.w3.org/TR/rdf-sparql-query/
[31] W3C. OWL – Semantic Web Standards. http://www.w3.org/2004/OWL/, 2004.

OWL is more expressive than RDFS because it can provide identity equivalence or difference (sameAs, differentFrom, equivalent Class/Property) and has more expressive class definitions such as class intersection, union, complement disjoints and cardinality restrictions. Statements in OWL commonly refer to objects of the world and describe them by putting them into categories or saying something about their relations. All atomic constituents of statements, objects, categories or relations are called entities. In OWL 2, Figure 8, objects are called "individuals", categories are called "classes", relations are called "properties". Properties in OWL 2 are further subdivided into "object properties"; they relate objects to objects and "data properties" assign data values to objects. Annotation properties encode information about *parts of* the ontology itself instead of the domain of interest. The ontology developed for this thesis refers to the OWL language and follows the OWL2 syntax and semantics.

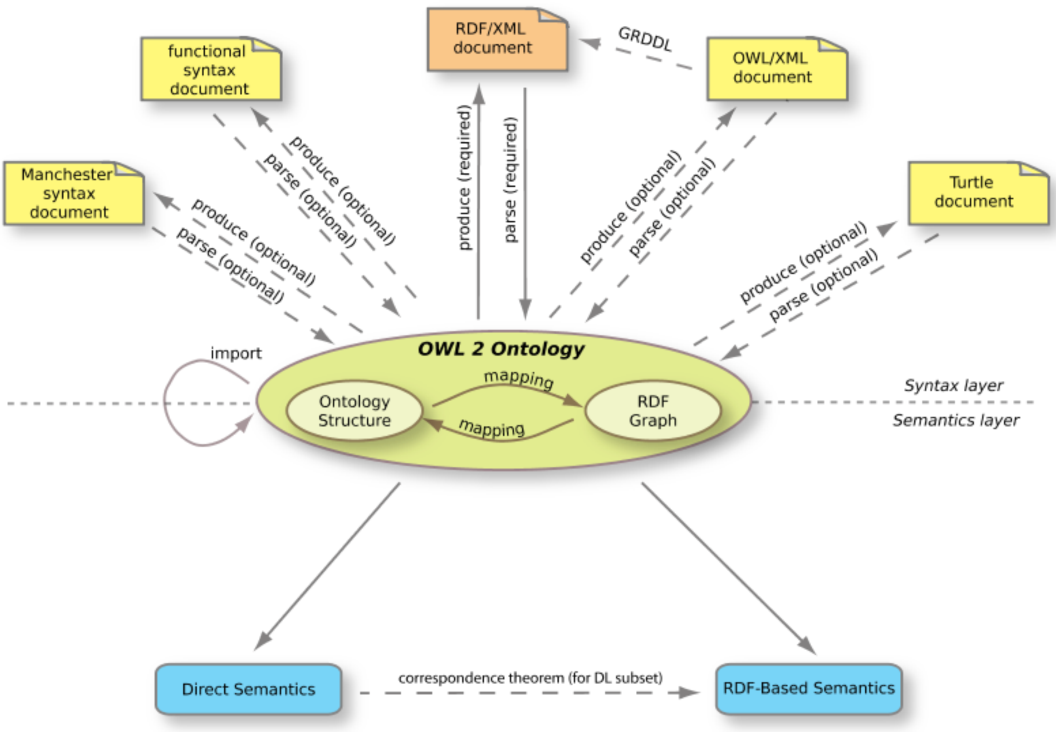



Figure 8. OWL2 syntax and semantic.

### 3.1.4 Ontologies in the Built and Urban Domain

As explained in Falquet et al. (2011), the interest in ontologies applied to the built heritage and urban domain was initially triggered by the technological challenges linked to the interoperability of urban and territorial databases and the need to interconnect the different databases. GIS spread has characterized many urban and city databases even among urban planning experts. A further update of these databases to make them more readily available and link them to other data sources couldn't be possible without restructuring their content. Given the scale and complexity of the activity, ontological engineering was selected as a necessary step to manage the continuity with previous database versions. This DBs integration is crucial in developing an urban ontology and standardising all databases with international standards such as INSPIRE[32] (see § 4.2). The planning of urban ontologies is seen as a stimulating conceptual challenge as it would force a clarification of the means of communication and purpose between the different actors involved in urban development: engineers, urban planners, builders, architects, citizens, etc. As it is possible to see in § 4.4, some attempts to build urban spatial ontologies have been made.

## 3.2 Ontology classifications

*Ontologies classifications in literature*

In the last decades, ontologies have been used for different activities, such as improving communication between agents (human or software) or re-using data models or knowledge schemes. All these activities concern interoperability problems and can be applied in different domains. As a result, ontologies have evolved, and various ontologies have been proposed. Some clear subdivision of ontologies has been outlined in Kavouras & Kokla (2007) and in (Kokla & Guilbert, 2020). They reported that Uschold & Gruninger (1996) identifies three dimensions along which ontologies diverge: *formality, purpose, and subject matter*.

- According to the *degree of formality*, it is possible to classify ontologies in different levels: *highly informal*, with definitions of terms expressed in natural language; *structurally informal*, with meanings in a structured natural language; semiformal, in an artificial formal language; and *rigorously formal*, when the meaning is expressed in a formal language with formal semantics, theorems, and proofs (Gruber, 2004);
- Regarding the *purpose*, we can identify *communication* between people, *system' interoperability* and *system engineering benefits* (reusability, knowledge acquisition, reliability, and specification) (Uschold, 1996);
- Based on the *subject matter*, there are *top-level ontologies*, *domain ontologies, task ontologies* and *representation ontologies*.

In Van Heijst et al. (1997), ontologies have been classified according to:

- the *amount and type of structure* of the conceptualisation in:
  - *terminological ontologies*, defining the terms of a domain;
  - *information ontologies*, describing the structure of database;
  - *knowledge modelling ontologies*, representing the conceptualisation of knowledge.
- the *conceptualisation* in:
  - *generic ontologies* such as entity, property, relation, domain ontologies);

[32] https://inspire.ec.europa.eu/

- *application ontologies*;
- *representation ontologies*, describing reality without any assertions about reality themselves.

Guarino (1998) distinguishes ontologies according to their level of generality:

- *Top-level ontologies*, to define general concepts, independent of any particular domain or task;
- Domain and task ontologies, to define concepts of a specific domain and task;
- *Application ontologies* to explain concepts relative to a particular domain and task.

Gruber (2003; 2004) also classifies ontologies according to the level of specification' formality as (1) informal, (2) semiformal, and (3) formal. "The term *Semiformal Ontology* refers to an ontology with a few bits of formality but is largely informal. A semiformal ontology could support technology to process its formal parts but leaves it to the reader to make sense of the informal parts".

Falquet et al. (2011) presented an ontology classification based on languages or aims; the category is reported below. It is possible to group them into four categories, from the less formal to the more formal, to classify ontologies on *language and semantics*:

- *Ontologies of information* are schemes and diagrams used by humans to spread projects and ideas. They are synthetic, schematic, easily editable, focused on concepts, characterised by examples and relations.
- *Linguistic or terminological ontologies* include glossaries, dictionaries, vocabularies, taxonomies, thesauri and lexical databases (focused on terms, relations and hierarchies). They are used to define what term has to be used to represent a concept avoiding ambiguity. Linguistic ontologies contain hierarchical links, related links and synonym links between terms. This kind of ontologies could use a language as well as RDF. RDF is implemented in XML (Extensible Markup Language), and it is composed of Triples (subject, property or predicate and object). An example is the HEREIN[33] Thesaurus, the European Heritage Network, which gathers governmental services in charge of heritage protection within the Council of Europe. The goal of linguistic ontologies in this type of system is to normalize the vocabulary used in the document to avoid lexical ambiguity.
- *Software ontologies* (or software implementation driven ontologies) provide a conceptual schema for data storage or data manipulation operation. In software development activities, they are applied to

[33] http://www.european-heritage.net/sdx/herein/index.xsp

guarantee data consistency. An example of language for this type is the UML class diagram (Unified Modeling Language) (3.3.4). UML is a standardized modelling language consisting of an integrated set of graphs developed to help system and software developers specify, visualise, construct, and document the artefacts of software systems. An example of software ontology is represented by the IFC standard (Industry Foundation Classes) (see § 4.2.4). It aims to guarantee interoperability among software applications in the building and construction market sector, such as BIM, which is applied as the standard data format to share and exchange information about a project.

- *Formal Ontologies* are "specified by a collection of names for concept and relation types organized in a partial ordering by the type-subtype relation" (Sowa, 2009). They require precise semantics for the language used and clear reasons for distinguishing concepts. In the Semantic Web, they have been defined with ontology editor software such as Protégé[34] , and they could be expressed in OWL.

Another classification is based on the scope of the object described by the ontology. Falquet (2009) shows how it is possible to connect the different typologies based on domain scope:

- *Local or application ontologies* are specializations of domain ontologies in which there could be no knowledge sharing. This type of ontology represents the model of a domain based on a single point of view of a user or developer. Fonseca et al. (2000) presented local or application ontologies such as combining domain ontologies and task ontologies. The task ontology contains the knowledge to carry out an activity; the domain ontology describes the knowledge in which the activity is applied.
- *Domain ontologies* are relevant for a domain with a specific point of view (defining how a circumscribed group of users conceptualizes and visualizes a particular phenomenon). They have more specific concepts than core reference ontologies.
- *Core reference ontologies* is "a standard used by different groups of users. It is therefore connected to a domain but integrates other points of view of the group. It is the result of the integration between other ontologies" (Fonseca et al., 2002). A representative example of this ontology is CityGML (explained later in § 4.2.2). It is standard for the representation, storage and exchange of virtual 3D city and landscape models.

[34] https://protege.stanford.edu/

- *General ontologies* are not referred to a specific domain but describe a significant area of knowledge. Thus its concepts can be as general as those of core reference ontologies-
- *Foundation, Top-Level, or Upper-Level Ontologies* are generic ontologies suitable for different target domains. Foundational ontologies can be considered meta ontologies describing the top-level concepts or primitives used to define other ontologies. They could be compared to the meta-model of a conceptual schema (Fonseca et al., 2003). The advantage in information science applications regards the design and structuring of databases.
  They can be calibrated in terms of one common ontology specifying highly general categories (time, space, inherence, instantiation, identity, measure, quantity, process, event, attribute, etc.). This is a solution to the problem of the trade-off between the fact that an ontology must be neutral to be maximally accepted. Still, it also needs to be expressively powerful and wide-ranging (containing, therefore, the most significant possible number of terms) (Smith, 2003). An example is the Geography Markup Language (GML), an OpenGIS Encoding Standard for representing, storing, and exchanging geographical features.

## 3.3 Approaches and methodologies for building ontologies

It is essential to clarify the meaning of some concepts as *conceptualisation* and *specification* in the framework of ontologies creation. This clarification helps to describe the different approaches and activities to build an ontology, later reported. Genesereth & Nilsson (2012) described conceptualisation as "a body of formally represented knowledge based on a conceptualisation: the objects, concepts, and other entities that are assumed to exist in some area of interest the relationships that hold among them".

*conceptualisation*

Guarino (1998) claimed that the notion of Genesereth and Nilsson is referred to ordinary mathematical relations, and there is the necessity to speak of intentional relations, named conceptual relations. After defining the typology of relations, it is possible to clarify the role of ontology. According to Guarino, it involves a set of logical axioms designed to account for the intended meaning of a vocabulary. After having defined a language (L) with an ontological commitment (K), the ontology is a set of axioms designed in a way such that "the set of its models approximates as best as possible the set of intended models of L according to K" (Figure 9).

The relationships between vocabulary, conceptualisation, ontological commitment and ontology are illustrated in Figure 9. It is important to stress that an ontology is *language-dependent*, while a conceptualisation is *language-independent*.

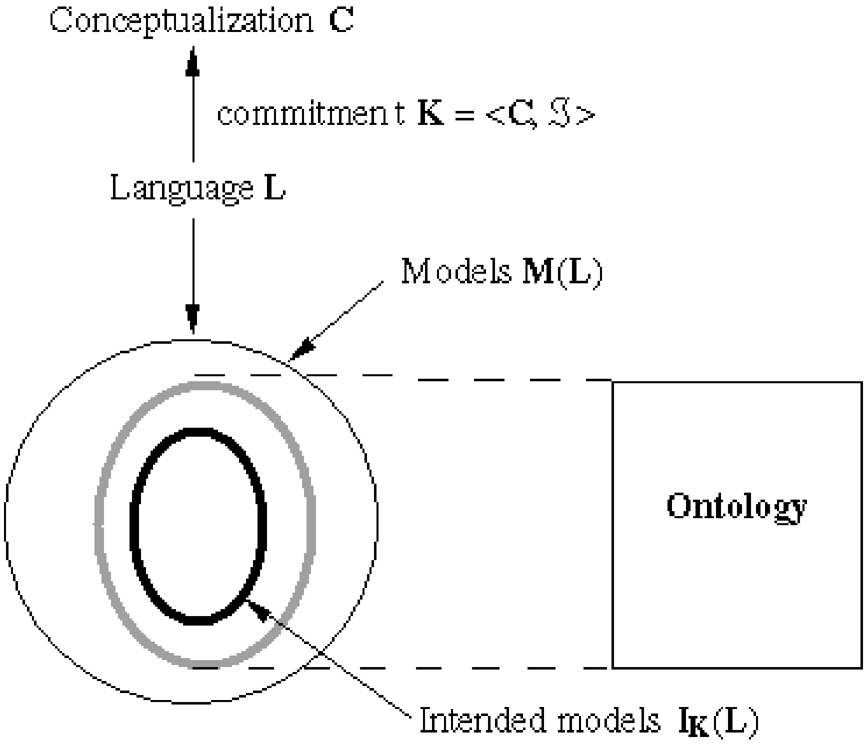



Figure 9. The intended models of a logical language reflect its commitment to a conceptualisation (Guarino, 1998).

Guarino et al. (2009) provided many definitions of the term conceptualisation. The more significant is the one related to the *Extensional relational structure* in which a conceptualisation (an extensional structure) is a mathematical representation, a *tuple* (D, R). D is a set called the universe of discourse, and R is a set of relations on D. Each element of R is a relation that indicates a domain in the world.

*specification*

The explanation of ontologies in AI regards the explicit specification of the conceptualisation. *The explicit specification* is related to conceptualisation, and for this reason, it is vital to define a correct interpretation of the world correctly. In real human situations, we must adopt a language to refer to the elements of the conceptualisation. For this last case, a language must be fixed, and the constraints of interpretations are defined in that language using axioms (meaning postulates).

The ontology is the set of these axioms to capture the intended models corresponding to a certain conceptualisation. The result is "an approximate specification of a conceptualisation: the better-intended models will be captured, and non-intended models will be excluded" (Figure 10, Guarino et al., 2009).

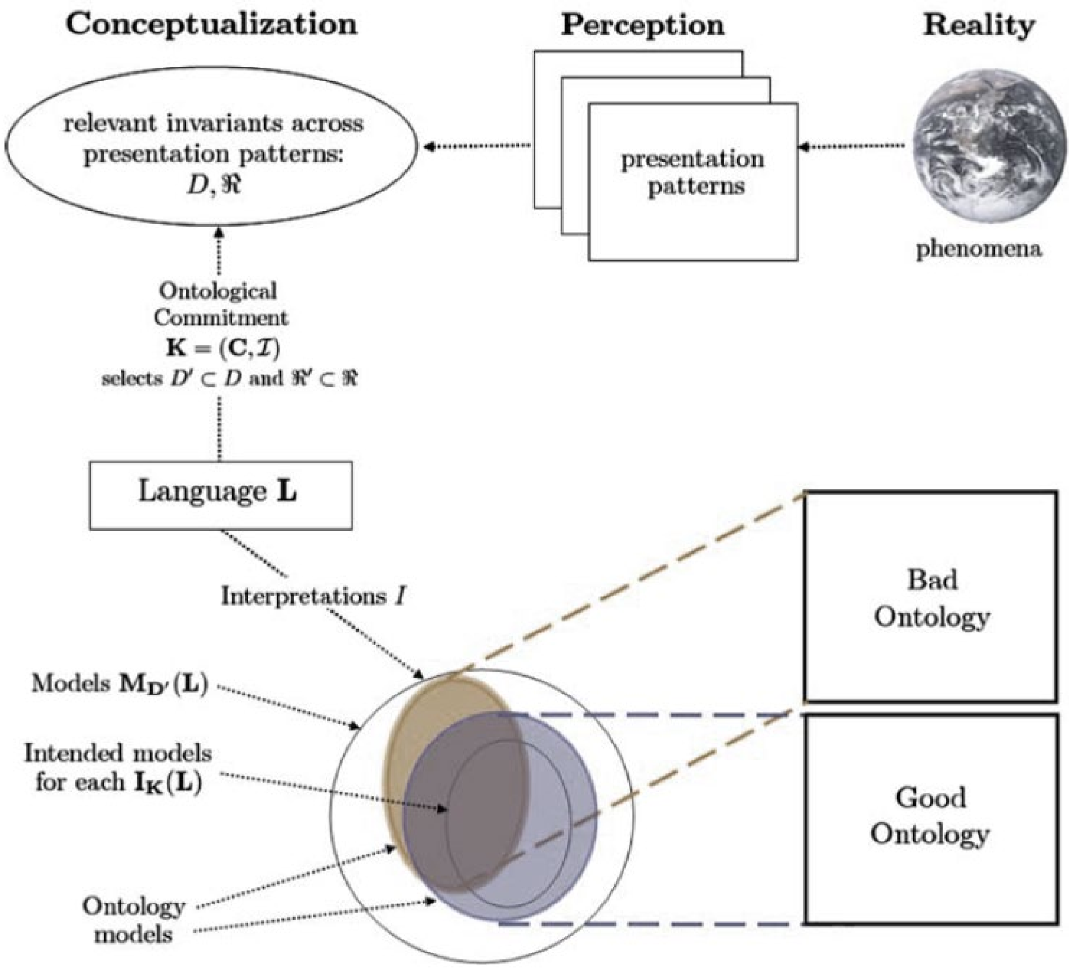



Figure 10. "The relationships between phenomena occurring in reality, their perception, their abstracted conceptualisation, the language used to talk about such conceptualisation, its intended models, and an ontology" (Guarino et al., 2009).

The axioms for conceptualisation can be expressed in informal or formal language (L). On one side, there are informal approaches for the language that allow knowing only the definitions of words, without specification of meaning, application or use. On the other side, formal approaches with logical languages allow specifying rigorously formalized logical theories. Language is essential to define and communicate the description of the real world. It can be informal (natural language, graphical language, icons, etc) or formal (logical language, mathematical language, programming language, etc).

Figure 11 shows the different approaches to the language with increasing formalization levels (Guarino et al., 2009).

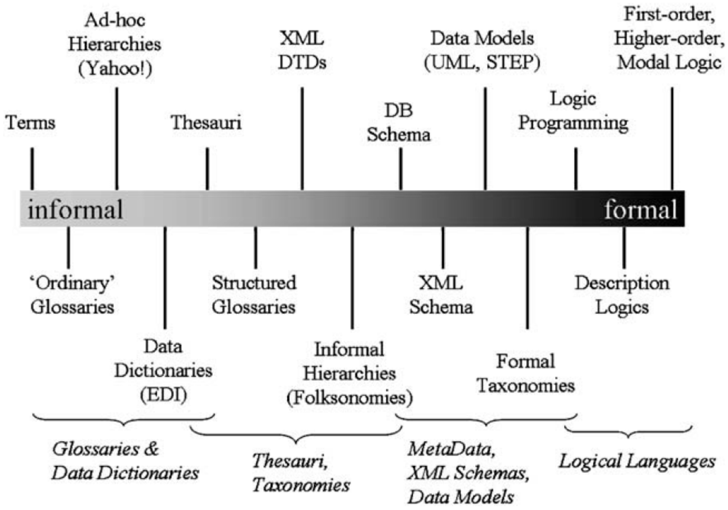



Figure 11. Different approaches to the language L. Typically, logical languages are eligible for the formal, explicit specification and, thus, ontologies (Guarino et al., 2009).

### 3.3.1 Approaches to design an ontology

*Methontology*

Many methodological approaches are proposed to design an ontology. Investigating in depth the literature, the most known are *Methontology* (Fernandez et al., 1997; Gómez-Pérez, 2004) and *On-to-knowledge* (Sure et al., 2004, 2003). Methontology emphasizes the re-use of the existing domain and upper-level ontologies and proposes to use, for formalization, a series of intermediate representations that can be subsequently automatically transformed into different formal languages. This structured method to build ontologies is based on many steps that must include additional information as well as the domain, the use and the users of the ontology, the formality level and the scope to achieve (Figure 12).

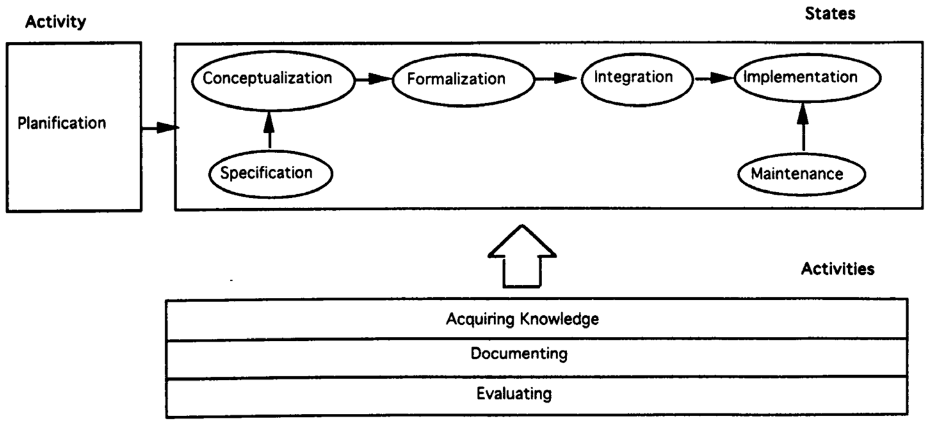



Figure 12. States and activities (Gómez-Pérez, 2004).

The phases of building an ontology are: ontology specification, knowledge acquisition, conceptualisation (creating a glossary term, and group terms as concepts and verbs using dictionaries) for designing a conceptual model (Figure 13), formalization and integration, implementation in a formal language, evaluation of the ontology, creation of documentation and guidelines (document for each phase to make re-usable the ontology) and maintenance.

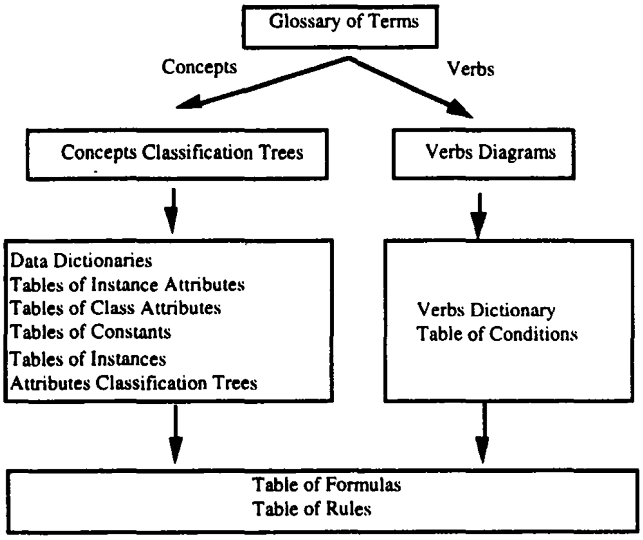



Figure 13. Conceptualisation phase (Gomez-Perz et al., 2004).

*On-to-knowledge methodology*

The On-to-knowledge methodology (OTKM) was developed for an EU project "to introduce and maintain ontology-based knowledge management applications into enterprises, focusing on Knowledge Processes and Knowledge Meta Processes" [35]. In particular, the Knowledge Meta Process consists of five different phases: Feasibility Study, Kickoff, Refinement, Evaluation and Application and Evolution (Figure 14).

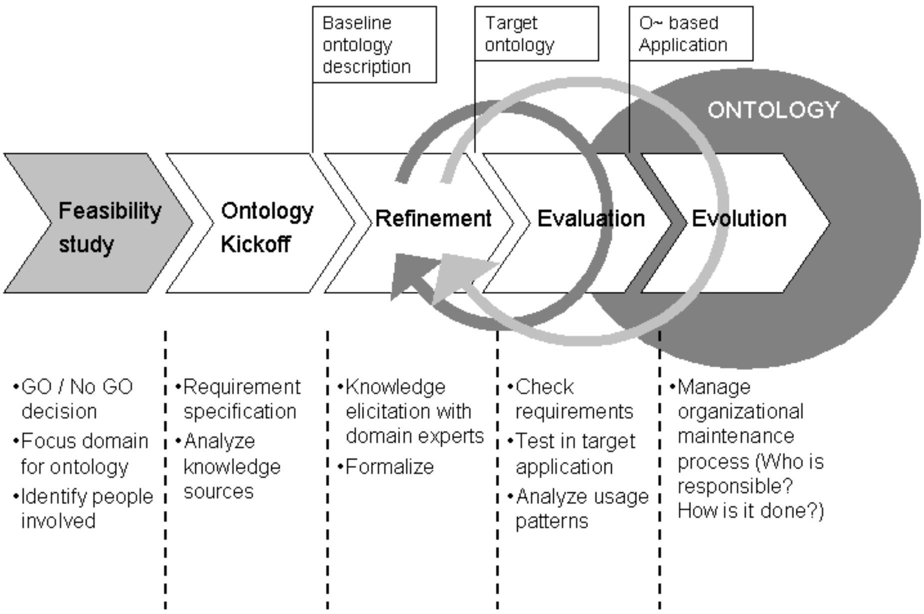



Figure 14. The Knowledge Meta Process knowledge (Sure et al. 2003; Staab et al., 2002).

[35] http://www.ontoknowledge.org

### 3.3.2 Approaches for the taxonomy creation

As reported below, the *conceptualisation* phase is composed of several tasks. One of them is the taxonomy construction, in which it is possible to adopt different approaches: the top-down, the bottom-up and the middle-out (Gandon, 2002).

The *Top-Down approach* starts from the most generic concept and builds a structure by specialization. It aims to use existing knowledge (formal as well as standards, ontologies, conceptual models and dictionaries and informal as well as documents), considering the reuse of existing ontologies, to define the semantic formalization of more specific concepts. A top-down approach may be "*applied to extend the ontology by integrating knowledge from existing ontologies*" (Kokla et al., 2018). Moreover, it aims to develop the knowledge representation, enrich the semantics, use open standards and ensure interoperability.

The *Bottom-Up approach* starts from the most specific concepts and builds a structure by generalization; the ontology is developed by determining first the low taxonomic level and then generalizing them. This method allows to create specific ontologies with refined detail grain concepts (Gandon, 2002). It regards the ontology enrichment with instances using the case studies data. A bottom-up approach may be "*applied to enrich and populate the geospatial ontology with concepts and instances extracted from domain-specific web content*" (Kokla et al., 2018). It is close to the application, captures experience, is dynamic and competitive and is designed with a simple structure.

The *Middle-Out approaches* identify central concepts in each area/domain identified; core concepts are identified and then generalized and specialized to complete the ontology (Gandon, 2002).

### 3.3.3 Ontology development 101

*Ontology development 101*

In the current scenario, it is important to mention a very prominent methodology for developing an ontology in the field of the semantic web, reported by Noy & McGuinness (2001). The paper states that the development of an ontology regards the definition of classes and their taxonomy or hierarchy (with subclass and superclass); the description of terms and their values must be filled in with instances. It is also stated that there is no one "correct" way or methodology for developing ontologies to model a domain— there are always viable alternatives. The best solution almost always depends on the imagined application and the anticipated extensions. It is possible to follow an iterative approach to ontology development. Concepts have to be similar to objects (physical or logical), and relations should be close to the domain of interest. The process could be summarised in some steps for the present thesis methodology:

- Step 1. Determine the domain and scope of the ontology
- Step 2. Consider reusing existing ontologies
- Step 3. Enumerate important terms in the ontology

- Step 4. Define the classes and the class hierarchy (top-down, bottom-up, mixed)
- Step 5. Define the properties of classes
- Step 6. Define the facets of the slots – define constraints
- Step 7. Create instances

### 3.3.4 Ontology merging and alignment

The most used method for building ontologies and the built heritage domain is "ontology matching" (Euzenat & Shvaiko, 2013). It allows finding semantic correspondences between different ontologies. For the geospatial domain, semantic integration consists of a complex process because of the intricate semantics of geographic categories (Kokla & Kavouras, 2005). The Integration Process aims to define, step by step, a good mapping among different domain ontologies. Various ontologies have to be compared by adopting reasoning, syntactic and semantic functions, or structural analysis (Buccella et al., 2010). Moreover, the "ontology alignment", or a multi-matching, identifies correspondences between multiple ontologies. Application examples are shown in (An et al., 2005; F. Fonseca et al., 2003; McGuinness et al., 2000).

In this framework, *ontology mapping* represents another method that includes ontology alignment, finding correspondences, semantic integration, interrelating information between different conceptualisations, and semantic matching. Ontology mapping was defined by (Su, 2002). He stated that "given two ontologies A and B, mapping one ontology with another means that for each concept (node) in ontology A, we try to find a corresponding concept (node), which has the same or similar semantics, in ontology B and vice versa" (Ehrig & Sure, 2004).

Much research reported the *ontology alignment* methods. It is often necessary to align various ontologies developed by different users and communities. This process aims to support data integration (Buccella et al., 2010; Cruz et al., 2004; Hess et al., 2007). Kavouras et al. (2006) states that "integration" is used in the literature (Kavouras, 2005; Klein, 2001; Kokla & Kavouras, 2005; Sowa, 2000; Uschold & Gruninger, 2002) to group many linked concepts such as "association, coordination, combining, matching, mapping, translation, merging, partial compatibility, alignment, unification, fusion, mediation, true integration".

### 3.3.5 Ontology enrichment and documentation

During the ontology design process the task of adding new classes, properties and instances is called ontology enrichment and population (Petasis et al., 2011). The first one is "the task of extending an existing ontology with additional concepts and semantic relations and placing them at the correct position in the ontology" (Petasis et al., 2011). Ontology population "is the task of adding new instances of concepts to the ontology" (Kokla et al., 2018; Petasis et al., 2011).

## 3.4 Ontology in the Geospatial Domain

The present section wants to introduce the domain of geographic and spatial information in ontologies. Some basic notions of Geographical Knowledge (GK), GIS and spatial data models and geographic/geodatabases (GDB) are here presented.

### 3.4.1 Elements for Spatial and Geographical Knowledge

GK is related to spatial and geographical ontologies regarding architectural, territorial and urban knowledge. It includes the representation of 3D heritage model and its elements. The work of Laurini (2014) reports a conceptual framework for geographic knowledge engineering. The management of geographic knowledge is essential for many urban and environmental planning or territorial intelligence applications. The passage from a simple geographic representation to a complex geographic knowledge includes the reasoning and geographic information retrieval. It is composed of some elements: facts (data or instance), concepts (classes of items), processes (flows of events), and rules (that allow to make inferences or draw implications). Laurini also underlines the difficulties to construct geographic knowledge repositories. These issues regard geographic semantics, toponyms, scale of representation, accuracy, moving objects, multiple-representation and multi-scale. Hence, to define a conceptual framework for GK, it is important to define some prolegomena - preliminary considerations - for the origin of geographic data, data transformation, update data, and structure objects and information. These 12 *Prolegomena* contained in Laurini (2014) are:

1) "3D objects: all existing objects are three-dimensional and can have temporal evolution; lower dimensions (0D, 1D and 2D) are only used for modelling (in databases) and visualization (in cartography).
2) Acquisition by measurements: all basic attributes (spatial or non-spatial) are obtained using measuring apparatuses having some limited accuracy. In the nowadays scenario of technologies development, the word "apparatus" must be taken very wide, from sensors to census, etc.
3) Continuous fields: since it is not possible to store the infinite number of value points in a continuous field, some sampling points will be used to generate the whole field by interpolation.
4) Raster-vector and vector-raster transformations: procedures transforming vector to raster data and raster to vector data must be implemented with losing less accuracy as possible.
5) From Popper's falsifiability principle: when a new apparatus delivers measures with higher accuracy, these measures supersede the previous ones.
6) Permanent updating: since objects are evolving either continuously (sea, continental drift) or event-based (removing building), updating should be done permanently respectively in real-time and as soon as possible.
7) Geographic metadata: all geographic databases or repositories must be accompanied with meta-data.

8) Cartographic object: in cartography, it is common to eliminate objects, to displace or to simplify that.
9) One storing, several visualizations: a good practice should be to store all geographic objects with the highest possible accuracy and to generate other shapes by means of generalization.
10) Place names and gazetteers: relationships between places and place names are many-to-many.
11) Geographic ontologies: all geographic object types are linked to concepts organized into a geographic ontology based on topological relations.
12) Tobler's law: everything is related to everything else, but near things are more related than distant things."

Finally, in the research of Laurini (2014), there are also reported principles of conceptual framework based on guidelines and rules and allow to make predictions and draw implications and are the bases of theoretical models.

### 3.4.2 Spatial and Geographic Ontologies

*Spatial and geographic ontologies*

A spatial ontology defines the general concepts of spatial objects and their relations for spatial application domains. "Etymologically, geography means the description of the Earth, while ontology refers to the discourse about existing things. Hence, geographic ontology means the description of things existing on Earth, i.e., geographic features. For decades, ontologies have been used in information technologies to describe knowledge in a domain as a kind of semantic networks, especially for the interoperability of databases and for knowledge description in artificial intelligence" (Laurini & Kazar, 2016). It is possible to consider the ontologies applied in GIScience as domain ontologies. These "are often called geographic ontologies or geo-ontologies" (Fonseca et al., 2006; Tomai & Kavouras, 2004). Geospatial ontologies are also defined by the W3C standards[36].

Many years ago, geographic ontologies were based on the organisation of spatial concepts employing conventional relations. That was insufficient to describe the space; then, it was necessary to specify geometry type, features with a common language. Nowadays, geo-ontologies represent space by integrating their relations among objects. It structures geographic entities and links them through spatial relations (topological relations). The issue of language is still current. In the past ten years, the European Towntology project aimed to design ontologies in the domain of urban planning (Teller et al., 2007). The project focused on the discussion of "designing a complete ontology in English and translating it into various other languages or making several ontologies in different languages and then fusing them into an English ontology". This problem is not at all solved. For this reason, for the present thesis, spatial ontology is chosen to supply a solution in terms of semantics. It is possible to say that a geo-ontology is "a set of concepts expressed as a vocabulary of the terms used, a specification of the term meaning (commonly expressed by definition), their properties, and the relations among

[36] https://www.w3.org/2005/Incubator/geo/XGR-geo-ont-20071023/#glossary

concepts or concepts' properties. Instances, accompanied by an ontology, constitute what is known as a *knowledge base*" (Kavouras & Kokla, 2007). Moreover, ontological research in geographic information is characterised by both philosophical and computer science meanings. A geo-ontology could refer to space, spatial relations, spatial entities, position, geographic boundaries, etc. Among the semantic relations, in spatial and geographical ontologies, it is possible to consider IS-A relations that are hierarchies, and PART-OF relations or Mereology (from greek *mero*s: part), "a notion from logic, mathematics, and metaphysics, known as the theveral work on spatial and geographical ontologies are published. In Fonseca et al. (2002), the use of ontologies for GIS integration is proposed. The work aimed to find a GIS architecture able to integrate geographic information based on the semantics value of its representation. To this end, it is necessary to develop a conceptual model for geographic data and its digital representation. As stated by Yeung and Hall (2007) and widely discussed by Fonseca et al. (2002, 2003), the process of designing and documentation of ontology is similar to the modelling of conceptual data model in the database design. Both methods aim to identify and define the characteristics of the real world and the relationships among entities. However, although this similarity, the final products are not the same. The purpose of a conceptual scheme is to describe the database structure with a high level of abstraction; an ontology represents a consensual agreement on the meanings and relationships between the vocabulary of terms used to represent data. There is not necessarily a direct correspondence between the structure of an ontology and the structure of the database as a conceptual database model represents it. In the research special emphasis was given to use the ontological structure for semantic information integration between GIS and remote sensing systems (RSS). The solution adopted was an ontology-driven geographic information system (ODGIS) in which an ontology is a component, such as a database, cooperating to fulfil the system's objectives. Tomai & Kavouras (2004, 2005) and Tomai & Spanaki (2005) presented different methodologies for designing and implementing geographic ontologies. The research of 2004 investigated the elements of ontologies as concepts, lexicon, relations and axioms and the existing geo-ontologies to create a systematic approach to design geographic ontologies. After this first method to develop ontology, they moved their effort on the study of ontology implementation, creating a web-based tool using the OWL language and schema. Finally, in the other selected work, they examined how the notion of formalized context can be incorporated into a geographic ontology, proving that the methodology is beneficial in choosing a diversity of sources of knowledge and information to generate a geographic ontology. Kavouras et al. (2005) tried to introduce a methodology to compare categories in geographic ontologies. After that, many studies have attempted to create a common framework to classify the different types of ontologies in the geographic and spatial field. The research aims to identify semantic information from definitions and enrich the representation of categories with semantic properties and relations to disambiguate geographic types. The methodology explored and extracted semantic information from the different definitions to identify and formalize similarities and heterogeneities. Another example of an investigation of ontologies in GI field is represented by the thesis of Lutz & Klien (2006). It is a literature review on works that "address the question of how to enhance the discovery of geographic data and geographic information services in spatial data infrastructures by means of ontologies". Moreover, the study of Chaves et al. (2007) described a new version of the Geographic Knowledge Base (GKB), an environment to integrate geographic data and generate ontologies to avoid the duplication of data and allow the reuse of knowledge. Finally, in many research (Chaves et al., 2007; Fonseca et al., 2002; Kavouras et al., 2005; Kokla et al., 2018; Lutz & Klien, 2006; Tomai & Kavouras, 2004; Tomai & Spanaki, 2005), different methodologies to enrich and populate a geospatial ontology to enable semantic information formalisation have been presented.

As it is possible to understand from the previous literature examples, geographical applied ontologies are helpful and suitable in many field and application areas of geo-information science, with different purposes. This scenario includes the possibility to consider ontologies to guarantee the exchange and use of data in the GI field. They can be a tool to enable decision-making and resource management in different areas (for example, natural resources, structures, cadastre, agriculture, urban planning) of the governmental or private sectors. From the evolution of GIS to the broader concept of Spatial Data Infrastructure (SDI) the use of ontologies has been considered urgent and fundamental. It represents an open question for the use and dissemination of SDI (such as in the project Towntology above mentioned). Therefore, according to the Global Spatial Data Infrastructure Association Cookbook (Nebert, 2004), "the term Spatial Data Infrastructure is often used to indicate the collection of technologies, policies and institutional provisions that facilitate the availability and access to spatial data". In this regard, ontologies are needed to integrate and harmonise cartographic data from regional, national, and international sources. The issues in applying and adopting ontologies in the GI field and sharing spatial information using SDI are related to the many different data formats in which data are distributed and the lack of documentation of data and metadata. The big obstacle to interoperability is the lack of homogeneity in terms of semantics, syntax, topology and geometry. To solve these interoperability problems some geographical and spatial standards were born. They are presented in the following Chapter (4).

### 3.4.3 GIS (Geographic Information System and Science)

*Meanings of GIS*

The best tool to manage data in digital cartography is GIS, a working method to design a multi-dimensional model to represent the real world with the final aim to create a project by the user. Geographic Information Science is the discipline studying acquisition, management, processing, analysis, visualization and storage tasks of geographic data. Geographic Information Systems are intended as all the computer software packages created to perform these activities (Goodchild, 2003). GISs are computer-based system that enables capture, modelling, storage, retrieval, sharing, manipulation, analysis, and presentation of geographically referenced data. GIS emerged in geography, cartography, remote sensing, image processing, environmental sciences, and computing science (Worboys & Duckham, 2004) (Figure 15).

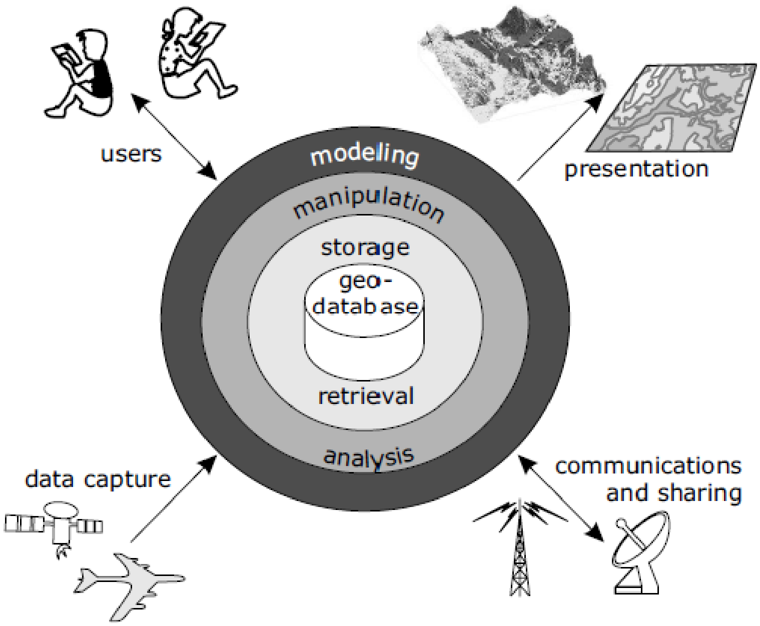



Figure 15. Schematic of a GIS (Worboys & Duckham, 2004).

The main components of an Information System are:

- the hardware, programs which do the actions in an informative system in the machine;
- the software, electronic tools which gather input and output information;
- application procedures;
- data banks, geographical information in the database;
- people.

Acquired data inserted in GIS software to be georeferenced, are territorial information on historical, geographical, social, economic, cultural aspects. In a GIS, maps, images, digital and textual data, lists and GPS/GNSS can be added. Data detected and downloaded from geoportals are of different type:

- *geometric data*, to describe characteristic and shape of real entity. They could be *vector data* (points, lines, polygons), characterised by topological relations and *raster data*, symbolised by pixels, in the form of regular-shaped cells. There are different types of raster images: physical, classified, cartographic and photographic.
- *alphanumeric/ descriptive data* that are attributes and values of entities. The characteristics define the qualitative and quantitative information of spatial objects and are linked by relationships. Attributes can also be part of multiple systems and be updated by many applications; they are generally stored in relational databases and can be queried using SQL

(Structured Query Language) languages. A carefully designed relational database structure makes it possible to carry out various analyses of spatial data.

In the last years, GIS has evolved, including 3D GIS, in which it is possible to visualise, relate, and query 3D geometries into a geographical environment. The present research will propose a method to integrate different kinds of 3D models (such as metric point clouds, BIM models, CityGML models, etc.) into a geographic database (ontologically designed). The functions to be provided by a GIS, according to (Laurini & Thompson, 1992) are the following:

- provide tools for the digital representation of spatial phenomena (data acquisition and data encoding);
- handle and secure the encodings efficiently by providing tools for editing, updating, managing and storing and for converting, verifying and validating those data;
- foster the easy development of additional insight into theoretical or applied problems by providing tools for information browsing, querying summarizing;
- provide facilities for analysis, simulation and synthesis;
- assist the task of spatial reasoning by providing efficient retrieval of data for complex queries;
- create compatible output in various forms;
- share data information.

A WebGIS (a GIS published on the web) inherits all its fusions from the GIS concept (above listed). The WebGIS intends to transmit the previously mentioned tools, making them flexible through a client-server architecture based on an Open-Source (OS) platform. The combination of geographic information and "abstract" information is the GIS extension to the Web environment. It concerns, therefore, all the products and services that allow a user to access the different aspects of geographic information using web technology. Accordingly, the WebGIS responds to the spirit of sharing, use, and easy consultation of data for common users. In recent years, WebGIS has been used by public administration to communicate and share their spatial data (through the Geoportals). A practical solution to share information on the web includes using some standards. Open Geospatial Consortium (OGC) web services are available: Web Map Service (WMS), Web Feature Service (WFS), Web Coverage Service (WCS) for data export, or Web Processing Service (WPS) for processing and analysis. A list of these and further similar OGC standards that enable these possibilities are listed on the website of OG standards[37].

[37] http://www.opengeospatial.org/standards/

### 3.4.4 Database Modelling Process

The core part of a GIS is the database (DB). It is a group of organised data in a schema to be stored and retrieved by a computer. A DB is a data repository where information is logically related and accessible by many applications and users. For Worboys & Duckham (2004), a DB is valid when it is:

- reliable (able to offer a continual, uninterrupted service);
- correct and consistent (data should be accurate and consistent with each other);
- technology proof (it should evolve with each new technology development);
- secure (it must allow different levels of authorized access)

A good database project, which is the preliminary phase for a GIS building, must keep them in mind to develop application-independent schemas and explicitly provide all the helpful information in future implementations or data interpretation. Databases offer several tools to retrieve information from the archived data and to present it for communication purposes. The same abilities are transposed to geodatabases introducing the spatial aspect for added potentialities. A database of geographical data is defined by the presence of geographic attributes of the managed objects in space. One of the main information that have to be stored and managed in the database is the position of the objects in a specified geographical space, independently from how this information is formalized. Although the structuring of complex databases and the linked information systems is achievable only by informatic experts in the database field, the structuring of simple territorial informatics systems is requested some introductive notions. It is imperative to define a conceptual data model. There are two types of geographical data:

- relational database;
- objects database.

The first one are the Relational Database Management System (RDBMS), and they are based on the relational model introduced by Edgar F. Codd. The logical relational model is based on the mathematical notion of relationship. It is used for the structuration of data regarding precisely their value; so, data are represented as relations. The second one is the ODBMS (Object Database Management System), in which the information is an object, as in the informatic object language. Moreover, the Object-Relational Database Management System (ORDBMS) uses a data model that adds extended functionalities for objects. Information are still in the lists, but data can have a more complex structure. Object databases are placed in a niche market compared to the relational model (RDBMS). They were considered starting from the Eighties and the Nineties, but they had a weak commercial impact and were used only in few fields.

Furthermore, there are Database Management System (DBMS), software used to manage databases. DBMS is a collection of data linked with each other, and also a management software that updates the maintenance and the consultation of a collection of registrations in a mass memory device.

Choosing an appropriate data model (database modelling) is the first and most crucial phase of designing a DB able to manage data about a specific application domain. The data model is the key to the database idea. The purpose of the model is to simplify and abstract away from the source domain. According to Worboys & Duckham (2004) "the process of developing a database, or indeed any information system, is essentially a process of model building. At the highest level is the application domain model, which describes the core requirements of users in a particular application domain based on an initial study. At the next level, the conceptual computational model provides a means of communication between the user and the system that is independent of the details of the implementation" (Nižnanský, 2009).

The successive modelling phases have been defined by the ANSI/X3/SPARC standard since 1975 (Laurini & Thompson, 1992) and consist in:

- *external model* (application domain model description): it uses the natural language (high-level language) and is an analysis of the interested part of reality to be managed in the database;
- *conceptual model*: implementation-independent, it formalizes the previous model by identifying the concepts (entities or class of entities) and the relationships among them;
- *logical model*: it is tailored to an implementation. It focuses on how the system will implement the conceptual model (system design);
- *internal model* (also called physical model): it describes the actual software and hardware application in a low-level language (system implementation). The final implementation will contain the self-description of the system (encoding both data and structure of the data).

It would be possible to deduce the modelling process phases.

The progression of the phases are represented in two different but equally meaningful schemas: the work of Laurini & Thompson (1992) effectively illustrates the modelling process, emphasizing the research of a consensus in the early abstraction phases (Figure 16). In the meantime, the so-called "system life-cycle" in (Worboys & Duckham, 2004) emphasizes the evolutionary and iterative nature of the development (Figure 17).

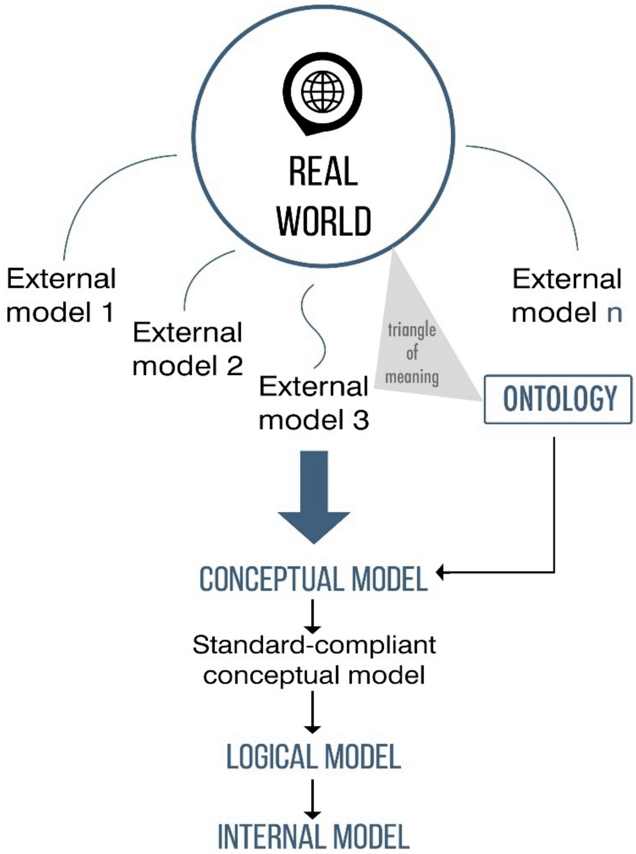



Figure 16. A framework for designing an information system adapted from Laurini & Thompson, (1992).

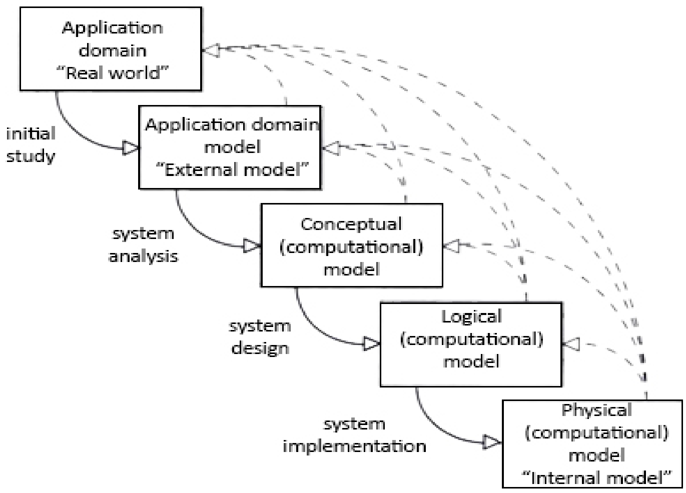



Figure 17. Modelling processes and the stages of system development underlying their iterative nature (Worboys & Duckham, 2004).

### 3.4.4.1 The Conceptual Model & the Unified Modelling Language (UML)

In conceptual models, entities to be managed in the database, their attributes and their associations are defined in a formal language. An entity is a phenomenon that cannot be subdivided into similar units (Laurini & Thompson, 1992). The conceptual model focuses on system analysis. It is the primary disambiguation tool for the system and aims to store and query the data efficiently. A dynamic component is often added to this static component, which is related to its behaviour in operations (Worboys & Duckham, 2004).

UML

Usually, some standard notations are used to design the database, such as the entity-relationship (E-R) model or extensions of it. The UML is used in the definition of standard data models, and therefore it is also employed in the application part of this thesis. "The UML is the most-used specification, and the way the world models, not only application structure, behaviour, and architecture, but also business process and data structure*"*[38]. UML is a modelling language based on the object-oriented paradigm. However, it is used for conceptual modelling independently from the following translation to a chosen logical model. It was defined in 1996 by *Grady Booch, Jim Rumbaugh and Ivan Jabson* at the Object Management Group (OMG)[39]. The aim was to develop a unique language that could become a standard, as it happened later. It is now considered an industrial standard, and it has spread in the informatics programming community and conceptual modelling activities. Many kinds of schemas can be built using UML for programming projects, business management, and modelling issues. For conceptual modelling, the UML class diagram is typically used. As reported in France et al. (1998), entities in the *UML notation* are represented by a rectangle; relationships are shown as lines with cardinality specified at the ends of the lines; generalizations are represented by an empty arrow; aggregations are shown as binary association with a diamond at the end of the association lines. Moreover, compositions are drawn as binary associations with a black diamond at the end of the line. Figure 18 reports the different symbologies of the UML notation.

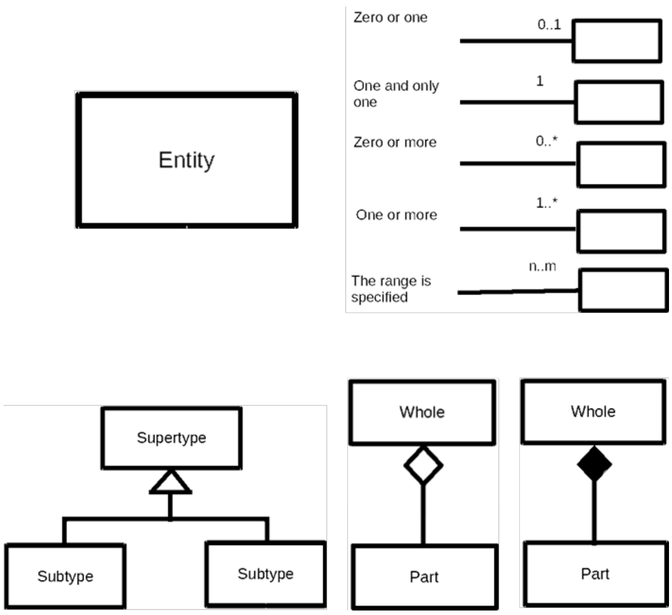



Figure 18. UML notation (image adapted from https://vertabelo.com/blog/uml-notation/).

[38] http://www.omg.org/gettingstarted/what_is_uml.htm
[39] https://www.omg.org/

# 4

Chapter 4

# Standards for interoperability

Interoperability is a fundamental aspect of applying ontologies. An ontology that should support interoperability has to be structured being understandable by every actor using it (Guarino et al., 2009). During the years, there have been numerous attempts to deal with the problem of ontology integration and interoperability (both semantics and geometrics) (Kokla & Kavouras, 2001; Uitermark, 2001; Vckovski, 1999; Wache et al., 2001). This section presents a review of the primary standards used in spatial information and cultural heritage, taking into account the broad meaning and definition of built and urban heritage and the multi-scale approach adopted to represent them. Some of these standards, conceptualisations and ontologies have been integrated and considered a starting point to design the MHC ontology with the scope of reusing existing knowledge.

## 4.1 Existing standards for architectural heritage

The existing standards and vocabularies to represent information concurring in built, urban and architectural heritage knowledge come from various fields. Some of the most critical ones are those available for the digital mapping, which is essential to represent the architecture in its context, and the cultural heritage, describing data about history, cultural value, artistic characteristics and further relevant connected issues (Colucci et al., 2020). The following sub-sections present the most used and spread standards in the framework of built heritage. Some have been selected and analysed for ontology creation, considering their concepts, relations and semantic definition.

### 4.1.1 CIDOC Conceptual Reference Model (CIDOC-CRM)

The core ontology to represent heritage is the CIDOC Conceptual Reference Model (CIDOC-CRM)[40], developed by the *International Committee for Documentation* (CIDOC) of the *International Council of Monuments* (ICOM), now standard ISO 21127 (Doerr, 2003; Doerr et al., 2007). This standard aims to enable the exchange and integration of data information between heterogeneous data sources. It was born to represent the knowledge of museum objects; therefore, it is applied in architecture, archaeological heritage, and so on, it had to be adapted or expanded (De Roo et al., 2013). More specifically, “it defines and is restricted to the underlying semantics of database schemata and document structures used in cultural heritage and museum documentation in terms of a formal ontology”. The CIDOC CRM model declares no “attributes” at all (except implicitly in its “scope notes” for classes) but regards any information element as a “property” (or “relationship”) between two classes.

The CORE ontology has been considered for the present thesis, and particular attention has been paid to spatial representation and documentation purposes. In Figure 19, Figure 20 and Figure 21, the concepts, the properties and the hierarchies of the core ontologies are listed:

| | |
|---|---|
| E1 | CRM Entity |
| E2 | - Temporal Entity |
| E4 | - - Period |
| E5 | - - - Event |
| E7 | - - - - Activity |
| E11 | - - - - - Modification |
| E12 | - - - - - - Production |
| E13 | - - - - - Attribute Assignment |
| E65 | - - - - - Creation |
| E63 | - - - - Beginning of Existence |
| *E12* | - - - - - *Production* |
| E65 | - - - - - Creation |
| E64 | - - - - End of Existence |
| E77 | - Persistent Item |
| E70 | - - Thing |
| E72 | - - - Legal Object |
| E18 | - - - - Physical Thing |
| E24 | - - - - - Physical Man-Made Thing |
| E90 | - - - - Symbolic Object |
| E71 | - - - Man-Made Thing |
| *E24* | - - - - *Physical Man-Made Thing* |
| E28 | - - - - Conceptual Object |
| E89 | - - - - - Propositional Object |
| E30 | - - - - - - Right |
| E73 | - - - - - - Information Object |
| *E90* | - - - - - *Symbolic Object* |
| E41 | - - - - - - Appellation |
| *E73* | - - - - - - *Information Object* |
| E55 | - - - - - Type |
| E39 | - - Actor |
| E74 | - - - Group |
| E52 | - Time-Span |
| E53 | - Place |
| E54 | - Dimension |
| E59 | Primitive Value |
| E61 | - Time Primitive |
| E62 | - String |

Figure 19. Concepts of CIDOC-CRM core ontologies.

[40] http://www.cidoc-crm.org/

| **Property id** | **Property Name** | **Entity – Domain** | **Entity - Range** |
|---|---|---|---|
| P1 | is identified by (identifies) | E1 CRM Entity | E41 Appellation |
| P2 | has type (is type of) | E1 CRM Entity | E55 Type |
| P3 | has note | E1 CRM Entity | E62 String |
| P4 | has time-span (is time-span of) | E2 Temporal Entity | E52 Time-Span |
| P7 | took place at (witnessed) | E4 Period | E53 Place |
| P10 | falls within (contains) | E92 Spacetime Volume | E92 Spacetime Volume |
| P12 | occurred in the presence of (was present at) | E5 Event | E77 Persistent Item |
| P11 | - had participant (participated in) | E5 Event | E39 Actor |
| P14 | - - carried out by (performed) | E7 Activity | E39 Actor |
| P16 | - used specific object (was used for) | E7 Activity | E70 Thing |
| P31 | - has modified (was modified by) | E11 Modification | E18 Physical Thing |
| P108 | - - has produced (was produced by) | E12 Production | E24 Physical Man-Made Thing |
| P92 | - brought into existence (was brought into existence by) | E63 Beginning of Existence | E77 Persistent Item |
| *P108* | *- - has produced (was produced by)* | *E12 Production* | *E24 Physical Man-Made Thing* |
| P94 | - - has created (was created by) | E65 Creation | E28 Conceptual Object |
| P93 | - took out of existence (was taken out of existence by) | E64 End of Existence | E77 Persistent Item |
| P15 | was influenced by (influenced) | E7 Activity | E1 CRM Entity |
| *P16* | *- used specific object (was used for)* | *E7 Activity* | *E70 Thing* |
| P20 | had specific purpose (was purpose of) | E7 Activity | E5 Event |
| P43 | has dimension (is dimension of) | E70 Thing | E54 Dimension |
| P46 | is composed of (forms part of) | E18 Physical Thing | E18 Physical Thing |
| P59 | has section (is located on or within) | E18 Physical Thing | E53 Place |
| P67 | refers to ( is referred to by) | E89 Propositional Object | E1 CRM Entity |
| P75 | possesses (is possessed by) | E39 Actor | E30 Right |
| P81 | ongoing throughout | E52 Time-Span | E61 Time Primitive |

Figure 20. Some properties of CIDOC-CRM core ontologies.

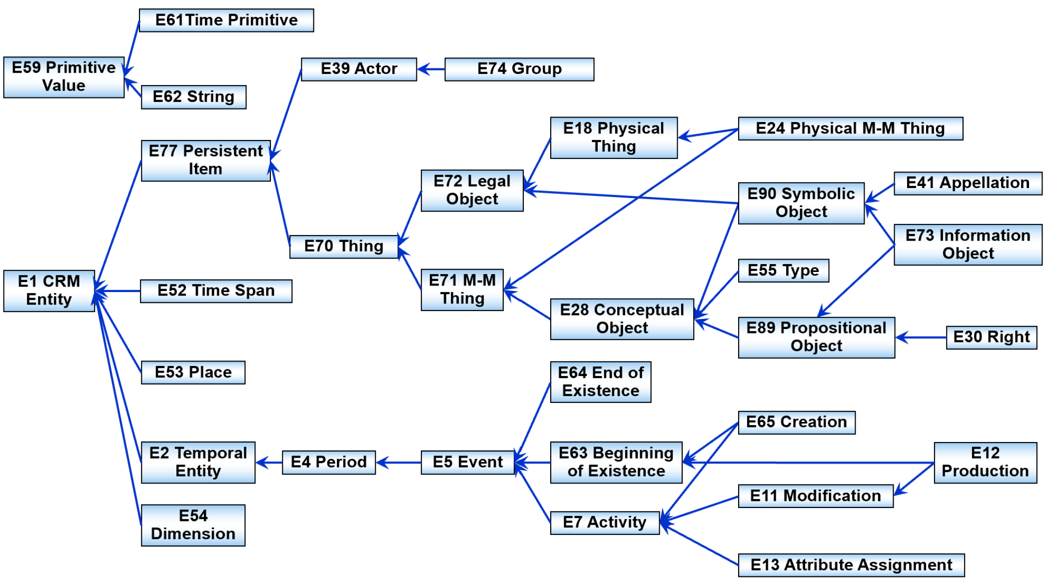
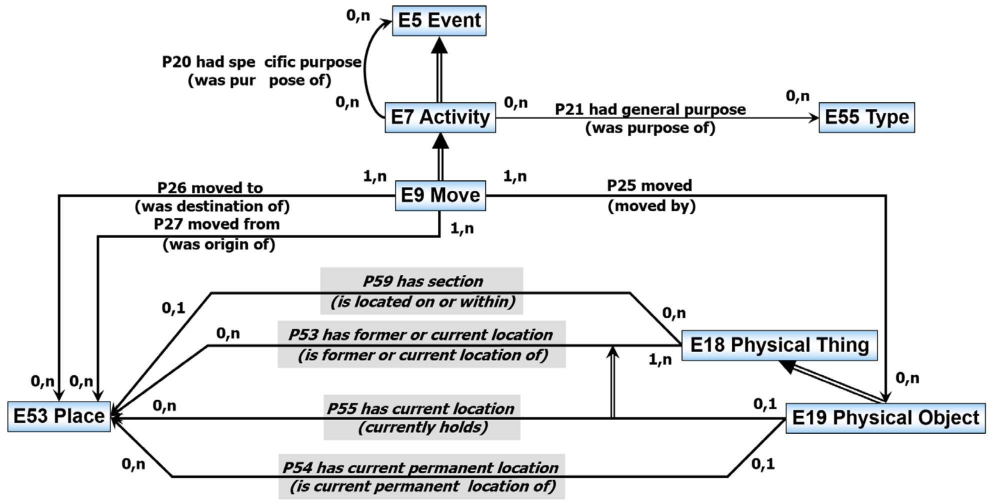



Figure 21. Hierarchy of core classes.

Figure 22 shows an overview of the main concepts considered to model the information about the location of objects. The part-of relations are established in Figure 23 and condition information classes in Figure 24.



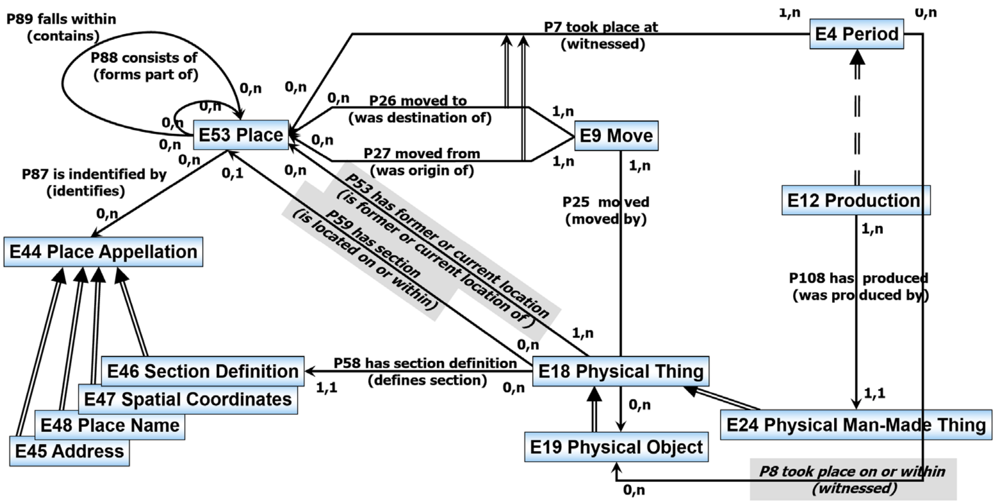




Figure 22. Location information classes, CIDOC-CRM.

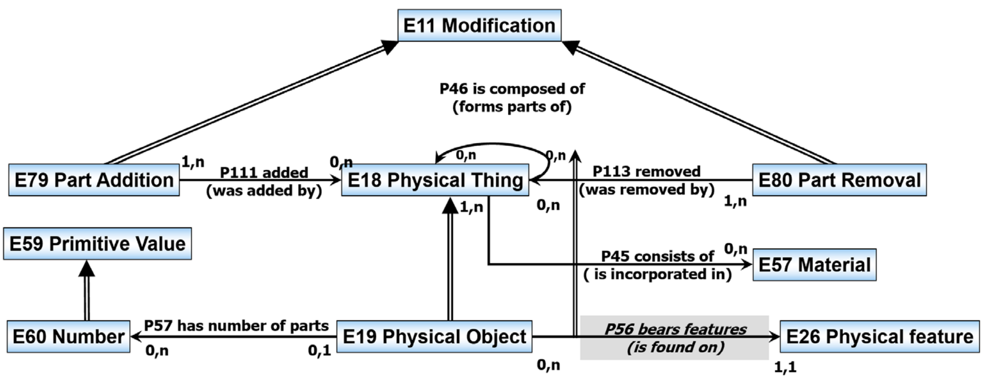



Figure 23. Part and component information, CIDOC-CRM.

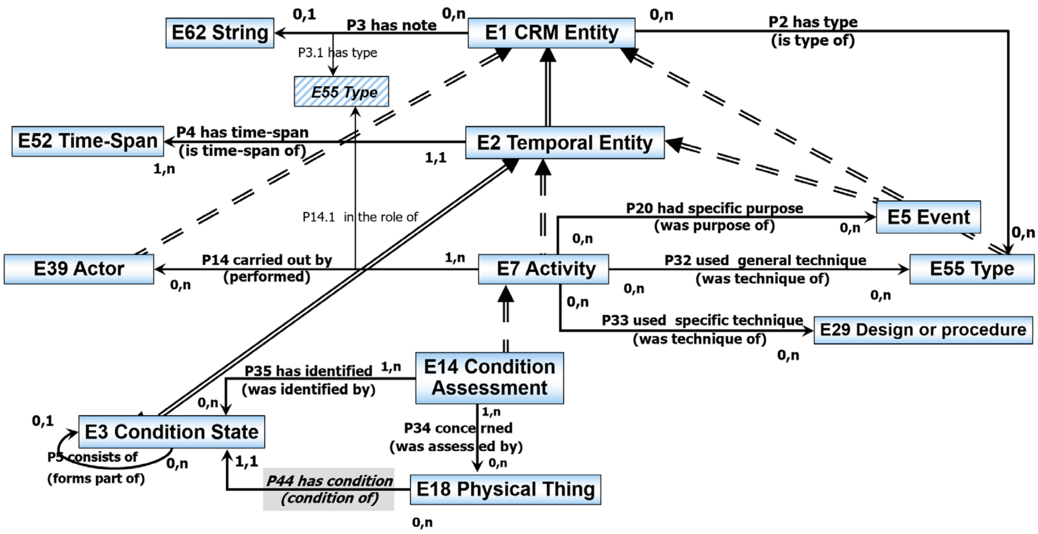



Figure 24. Condition information classes CIDOC-CRM.

In the framework of the CIDOC-CRM ontology some *projects and extensions* have been developed:

- The CRMgeo[41] (Figure 25, Figure 26) "integrates spatiotemporal properties of temporal entities and persistent items. It is a formal ontology which aims to integrate integrating all kinds of geoinformation in GIS formats into CIDOC CRM representations". This aim connects the CIDOC CRM to the OGC standard GeoSPARQL (Doerr et al., 2013).

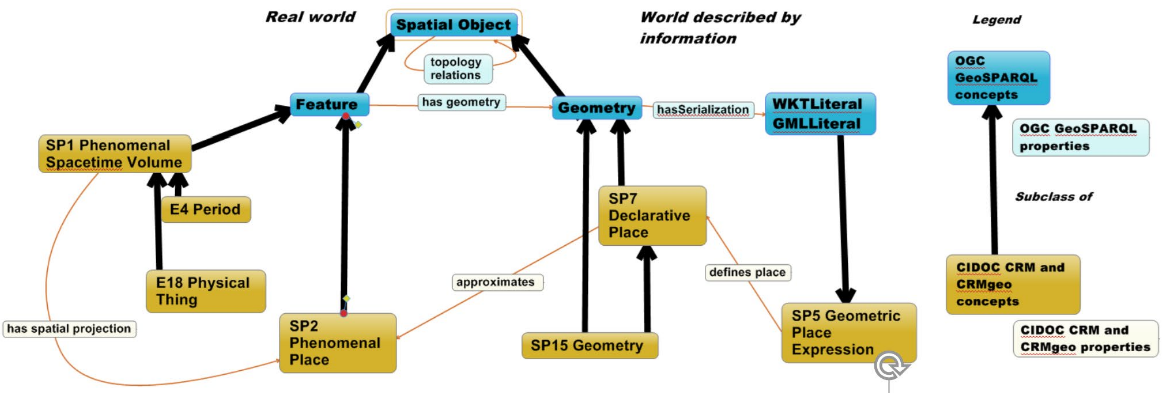



Figure 25. CIDOC CRM and CRMgeo classes and their relation to GeoSPARQL classes.

[41] http://www.cidoc-crm.org/

| P. id | Property Name | Entity – Domain | Entity - Range |
|---|---|---|---|
| Q1 | occupied | E4 Period | SP1 Phenomenal Spacetime Volume |
| Q2 | occupied | E18 Physical Thing | SP1 Phenomenal Spacetime Volume |
| Q3 | has temporal projection | SP1 Phenomenal Spacetime Volume | SP13 Phenomenal Time-Span |
| Q4 | has spatial projection | SP1 Phenomenal Spacetime Volume | SP2 Phenomenal Place |
| Q5 | defined in | E53 Place | SP3 Reference Space |
| Q6 | is at rest in relation to | SP3 Reference Space | E18 Physical Thing |
| Q7 | describes | SP4 Spatial Coordinate Reference System | SP3 Reference Space |
| Q8 | is fixed on | SP4 Spatial Coordinate Reference System | E26 Physical Feature |
| Q9 | is expressed in terms of | E94 Space Primitive | SP4 Spatial Coordinate Reference System |
| Q10 | defines place | E94 Space Primitive | SP6 Declarative Place |
| Q11 | approximates | SP6 Declarative Place | E53 Place |
| Q12 | approximates | SP7 Declarative Spacetime Volume | E92 Spacetime Volume |
| Q13 | approximates | SP10 Declarative Time-Span | E52 Time-Span |
| Q14 | defines time | SP14 Time Expression | SP10 Declarative Time-Span |
| Q15 | is expressed in terms of | SP14 Time Expression | SP11 Temporal Reference System |
| Q16 | defines spacetime volume | SP12 Spacetime Volume Expression | SP7 Declarative Spacetime Volume |
| Q17 | is expressed in terms of | SP12 Spacetime Volume Expression | SP11 Temporal Reference System |
| Q18 | is expressed in terms of | SP12 Spacetime Volume Expression | SP4 Spatial Coordinate Reference System |
| Q19 | has reference event | SP11 Temporal Reference System | E5 Event |

Figure 26. Spatiotemporal model property hierarchy of CRMgeo.

- The CRMba[42] (Figure 27, Figure 28, Ronzino et al., 2016) encodes metadata about the documentation of archaeological buildings. It identifies the evolution of the structure throughout the centuries by supporting the recording of evidence and discontinuities of matter on archaeological buildings.

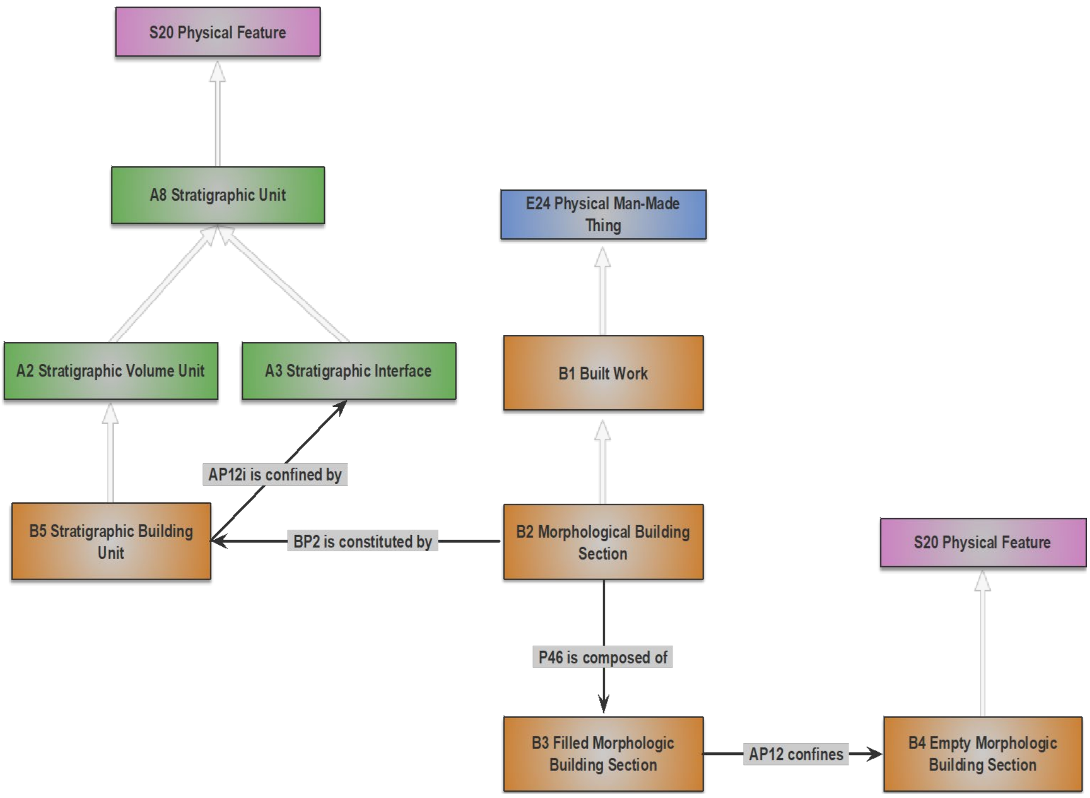



Figure 27. The CRMba conceptual model.

[42] http://www.cidoc-crm.org/crmba/home-7

| Property id | Property Name | Entity – Domain | Entity - Range |
|---|---|---|---|
| BP1 | is section of (has section) | B2 Morphological Building Section | B1 Built Work |
| BP2 | is constituent of (is constituted by) | B5 Stratigraphic Building Unit | B1 Built Work |
| BP3 | is spatial temporary equal to | E92 Spacetime Volume | E92 Spacetime Volume |
| BP4 | terminates the constituency (constituency is terminated by) | E80 Part removal | B2 Morphological Building Section |
| BP5 | initiates the constituency (constituency is initiated by) | E79 Part addition | B2 Morphological Building Section |
| BP8 | is adjacent to | B2 Morphological Building Section | B2 Morphological Building Section |
| BP11 | is connected to | B2 Morphological Building Section | B2 Morphological Building Section |
| BP11.1 | in the mode of | BP11 is connected to | E55 Type |
| BP11.2 | is connected through | BP11 is connected to | E24 Physical Man Made Thing |
| BP13 | used specific object (is specific object used by) | E12 Production | B5 Stratigraphic Building Unit |
| BP14 | re-used specific object (was specific object re-used by) | E12 Production | B5 Stratigraphic Building Unit |

Figure 28. Buildings archaeology model property hierarchy, aligned with portions from the CRMarchaeo, CRMsci, and the CIDOC CRM property hierarchies.

- The CRMsci[43] (Figure 29, Doerr et al., 2018) is a formal ontology intended as a global schema for integrating metadata about scientific observation, measurements and processed data. Besides application-specific extensions, this model is designed to be complemented by CRMgeo.

| Property id | Property Name | Entity – Domain | Entity - Range |
|---|---|---|---|
| O1 | diminished (was diminished by) | S1 Matter Removal | S10 Material Substantial |
| O2 | - removed (was removed by) | S1 Matter Removal | S11 Amount of Matter |
| O5 | - - removed (was removed by) | S2 Sample Taking | S13 Sample |
| O27 | - - - split (was split by) | S2 Sample Taking | S13 Sample |
| O3 | sampled from (was sample by) | S2 Sample Taking | S10 Material Substantial |
| O4 | sampled at (was sampling location of) | S2 Sample Taking | E53 Place |
| O7 | confines (is confined by) | S20 Rigid Physical Feature | S10 Material Substantial |
| O8 | observed (was observed by) | S4 Observation | S15 Observable Entity |
| O24 | - measured (was measured by) | S21 Measurement | S15 Observable Entity |
| O9 | observed property type (property type was observed by) | S4 Observation | S9 Property Type |
| O10 | assigned dimension (dimension was assigned by) | S6 Data Evaluation | E54 Dimension |
| O11 | described (was described by) | S6 Data Evaluation | S15 Observable Entity |
| O12 | has dimension (is dimension of) | S15 Observable Entity | E54 Dimension |
| O13 | triggers (is triggered by) | E5 Event | E5 Event |
| O15 | occupied (was occupied by) | S10 Material Substantial | E53 Place |
| O16 | observed value (value was observed by) | S4 Observation | E1 CRM Entity |
| O17 | generated (was generated by) | S17 Physical Genesis | E18 Physical Thing |
| O18 | altered (was altered by) | S18 Alteration | E18 Physical Thing |
| O19 | has found object (was object found by) | S19 Encounter Event | E18 Physical Thing |
| O20 | sampled from type of part (type of part was sampled by) | S2 Sample Taking | E55 Type |
| O21 | has found at (witnessed) | S19 Encounter Event | E53 Place |
| O23 | is defined by (defines) | S22 Segment of Matter | E92 Spacetime Volume |
| O25 | contains (is contained in) | S10 Material Substantial | S10 Material Substantial |
| O6 | - is former or current part of (has former or current part) | S12 Amount of Fluid | S14 Fluid Body |
| O26 | is conceptually greater than (is conceptually less than) | E55 Type | E55 Type |

Figure 29. Scientific Observation Model Property Hierarchy.

- The CRMarcheo[44] (Figure 30, Doerr, Felicetti, et al., 2020) supports the archaeological excavation process and all the various entities and

[43] http://www.cidoc-crm.org/crmsci/home-1
[44] http://www.cidoc-crm.org/crmarchaeo/home-3

activities. "CRM*archaeo* intends to provide all necessary tools to manage and integrate existing documentation to formalise knowledge extracted from observations made by archaeologists, recorded in various ways and adopting different standards".

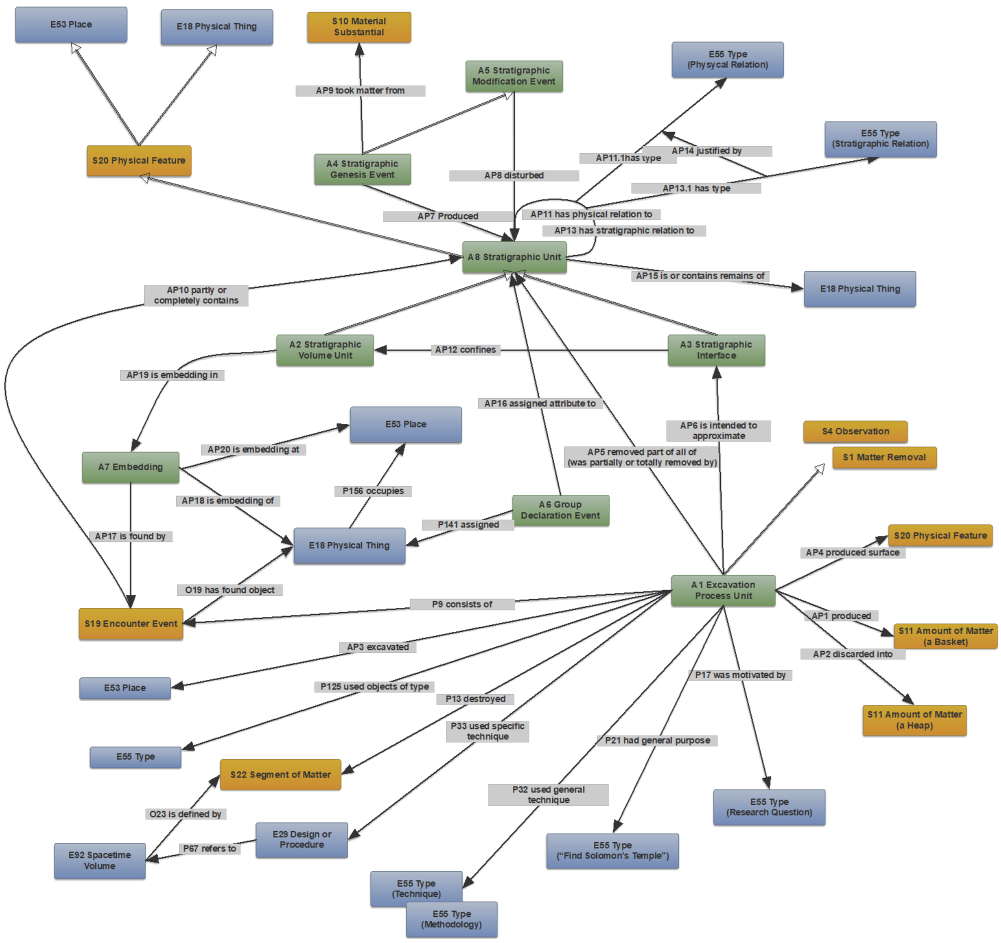



Figure 30. CRMarchaeo classes and properties with relations to CRM and CRMsci classes.

Property hierarchy, in Figure 31, derives from the Excavation Model, the CRM*sci* and CIDOC CRM.

| Property id | Property Name | Entity – Domain | Entity-Range |
|---|---|---|---|
| AP1 | produced (was produced by | A1 Excavation Process Unit | S11 Amount of Matter |
| AP2 | discarded into (was discarded by) | A1 Excavation Process Unit | S11 Amount of Matter |
| AP3 | excavated (was excavated by) | A1 Excavation Process Unit | E53 Place |
| AP4 | produced surface (was surface produced by) | A1 Excavation Process Unit | S20 Physical Feature |
| AP5 | removed part or all of (was partially or totally removed by) | A1 Excavation Process Unit | A8 Stratigraphic Unit |
| AP6 | intended to approximate (was approximate) | A1 Excavation Process Unit | A3 Stratigraphic Interface |
| AP7 | produced (was produced by) | A4 Stratigraphic Genesis | A8 Stratigraphic Unit |
| AP8 | disturbed (was disturbed by) | A5 Stratigraphic Modification | A8 Stratigraphic Unit |
| AP9 | took matter from (provided matter to) | A4 Stratigraphic Genesis | S10 Material Substantial |
| AP10 | destroyed (was destroyed by) | A1 Excavation Process Unit | S22 Segment of Matter |
| AP11 | has physical relation (is physical relation of) | A1 Stratigraphic Unit | A8 Stratigraphic Unit |
| AP12 | confines (is confined by) | A1 Stratigraphic Interface | A2 Stratigraphic Volume Unit |
| AP13 | has stratigraphic relation (is stratigraphic relation of) | A1 Stratigraphic Modification | A5 Stratigraphic Modification |
| AP14 | justified by | AP13 has stratigraphic relation | AP11 has physical relation |
| AP15 | is or contains remains of (is or has remains contained in) | A8 Stratigraphic Unit | E18 Physical Thing |
| AP16 | assigned attribute to (was attributed by) | A6 Group Declaration Event | A8 Stratigraphic Unit |
| AP17 | is found by (found) | E7 Embedding | S19 Encounter Event |
| AP18 | is embedding of (is embedded) | E7 Embedding | E18 Physical Thing |
| AP19 | is embedding in (contains embedding) | E7 Embedding | A2 Stratigraphic Volume Unit |
| AP20 | is embedding at (contains) | E7 Embedding | E53 Place |

Figure 31. Property hierarchy of CRMarcheo.

### 4.1.2 The Getty Vocabularies

The vocabularies[45] of the Getty Research Institute propose terms connected to cultural heritage as premiere references to categorise works of art, architecture, material culture, the names of artists or architects, and the geographic categories. These are:

- the Art and Architecture Thesaurus (AAT), for terms describing works of art and architectures;
- the Thesaurus of Geographic Names (TGN), which includes historical denominations;
- the Union List of Artist Names (ULAN) for authors;
- the Cultural Objects Name Authority (CONA) for the different sects of a cultural item over time.

The Getty vocabularies can be effectively used in cataloguing, retrieval, and linking. Each record has a unique ID; the vocabularies are linked. They share a core data structure. Getty vocabularies are thesauri compliant with national (NISO) and international (ISO) standards for thesaurus construction. They are available also as Liked Open Data[46]. The present thesis considered the AAT vocabulary to define historical centres semantics. The *Art & Architecture Thesaurus*[47] contains terms, concepts and vocabularies related to art, architecture, decorative arts, material culture, and archival materials. It was developed especially for museums, libraries, visual resource collections, archives, conservation projects, cataloguing projects, and bibliographic projects. They are represented following a specific hierarchy and containing a description as a thesaurus. Thus, they are beneficial to be included in the ontology. Figure 32 shows an example of the hierarchy of the AAT thesaurus.


Figure 32. Example of a hierarchy of the AAT thesaurus (Built Environment name).

[45] https://www.getty.edu/research/tools/vocabularies/
[46] https://www.getty.edu/research/tools/vocabularies/lod/index.html
[47] https://www.getty.edu/research/tools/vocabularies/aat/

### 4.1.3 Monument Damage Information System (MONDIS)

Another ontological model developed in OWL and conceived to enhance CIDOC-CRM is MONDIS (Monument Damage Information System). This approach, introduced by Blaško et al. (2012) and Cacciotti et al. (2013), applies an ontological representation to the analysis of cultural heritage decay. The system provides support for damage surveys and diagnosis, as well as for possible conservation action. This project is developed to represent information about monument conservation, monument damages and related interventions. The research has also developed an IT to be used by conservators, monument owners and other stakeholders to share their terminology, contextual knowledge, and experience about existing damages and their interventions (Kremen et al., 2014). Figure 33 shows the ontological model of MONDIS.

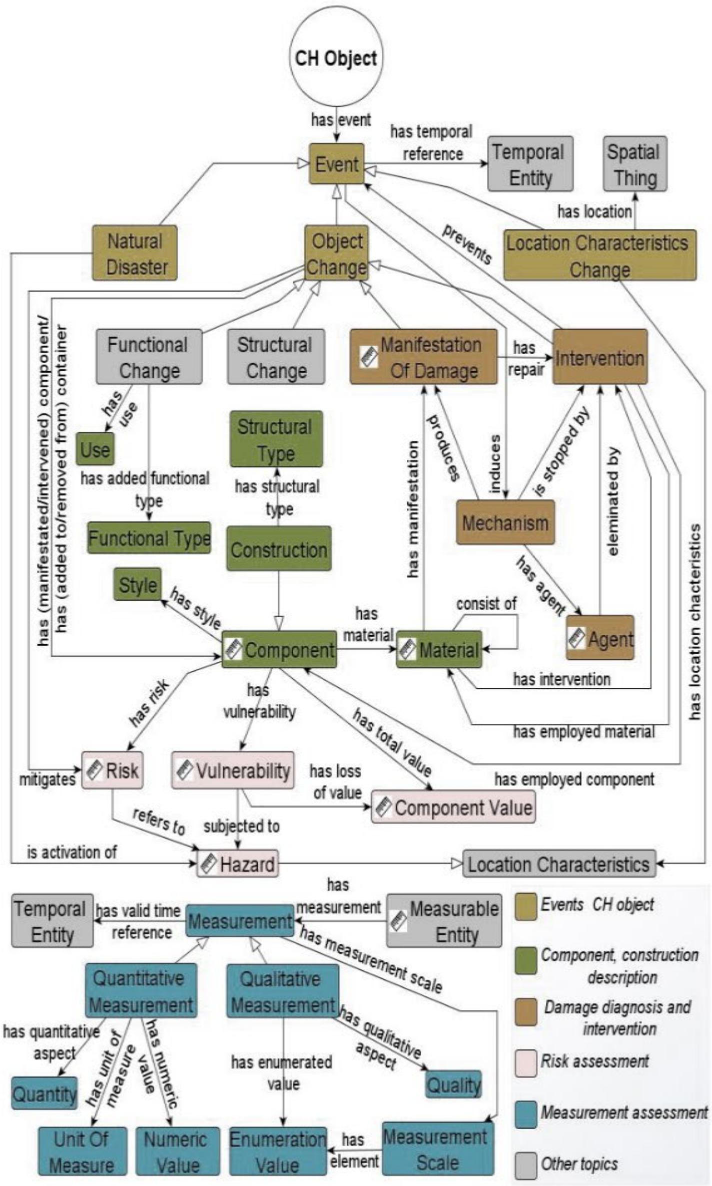



Figure 33. MONDIS ontological model (Cacciotti et al., 2013).

### 4.1.4 European Research Network on Excellence in Processing Open Cultural Heritage (EPOCH)

EPOCH[48] was the EU FP6 Network of Excellence on the Applications of ICT (Information and Communication Technologies) to tangible cultural heritage, realized in cooperation with 95 European partners (active from 2004 to 2008). It combines different expertise in cultural heritage, integrating survey field recording, organisation of data and standards, digital reconstructiona nd visualisation and planning for new sustainable projects. The project promoted activities by using ICT (Information and Communications Technology) in cultural heritage to create an integrated infrastructure[49].

### 4.1.5 GEONAMES

GeoNames is "a geographical database available and accessible through various web services under a Creative Commons Attribution license"[50]. The toponym stored in the DB could also be spatially visualised through a WebGIS application in WGS84 (Word Geodetic System 1984). In the application, they can also be queried, as shown in Figure 34. They are free and open data provided by public sources; moreover, they have a stable Uniform Resource Identifier (URI) linked to the RDF or OWL description of the *GeoNames ontology.* "Through Wikipedia articles Uniform Resource Locator (URL) linked in the RDF descriptions, GeoNames data are linked to DBpedia data and other RDF Linked Data in the Semantic Web"[51].

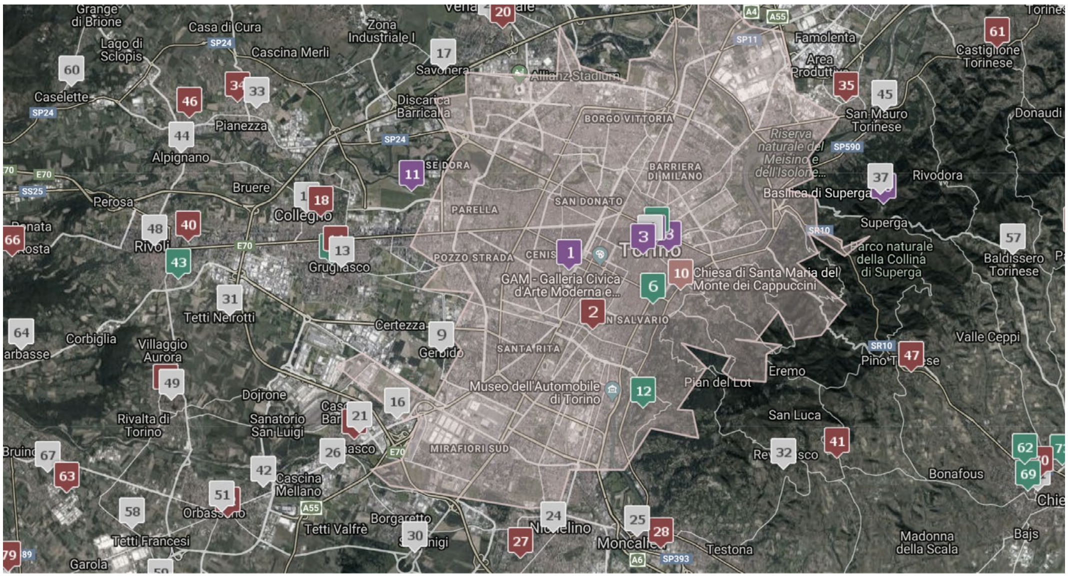



Figure 34. Example of a map in GeoNames querying the database with the toponym "Turin".

[48] http://epoch-net.org/about.html
[49] https://cordis.europa.eu/project/rcn/80601/factsheet/en
[50] http://www.geonames.org/
[51] https://en.wikipedia.org/wiki/GeoNames

### 4.1.6 International Council on Monuments and Sites (ICOMOS) - International Community – 2008

The ICOMOS International Scientific Committee for Stone (ISCS) glossary[52] is an important tool for classifying and terminology for managing stone deterioration by researchers and other operators. It starts from the terms and classification of several further documents to build shared guidelines for intending the same meaning when speaking about stone and its decay (ICOMOS, 2016).

### 4.1.7 Istituto Centrale per il Catalogo e la Documentazione (ICCD) - Central Institute for Catalog and Documentation

The ICCD[53] is an institute of MIBACT. Among its task, there is the cataloguing of CH aim. ICCD catalogue is the most recent in Italy and includes the classes and values defined by the further Italian classifications (Figure 35). It is implemented in the *SIGECweb* platform.[54]


Figure 35. Cataloguing systems of cultural heritage in Italy[55].

In the framework of interoperability data plans actions[56] the MIBACT and the ICCD have been developed different projects and ontologies. The first example is *ArCo*[57], the Knowledge Graph (KG) of the Italian CH and consists of 7 vocabularies describing the CH domain (Figure 36).

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[52] http://iscs.icomos.org/glossary.html
[53] http://www.iccd.beniculturali.it/
[54] http://www.sigecweb.beniculturali.it/it.iccd.sigec.axweb.Main/
[55] www.beniculturali.it, www.cartadelrischio.it, www.benitutelati.it, http://vincoliinrete.beniculturali.it, www.iccd.beniculturali.it, www.culturaitalia.it
[56] http://www.iccd.beniculturali.it/it/per-condividere/interoperabilita
[57] http://wit.istc.cnr.it/arco

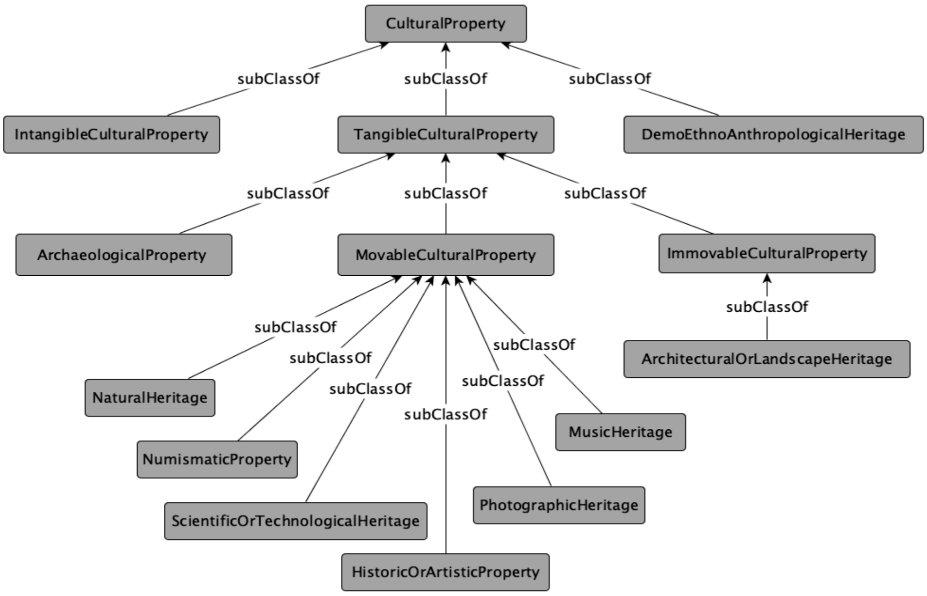


Figure 36. A graphical representation of some classes and relations of the Arco ontology.

Secondly, the *Cultural-ON* ontology[58] aims at modelling the data that characterize cultural places, such as data on entities or people who have a specific role on institutions and cultural areas, the physical locations of the sites, the multimedia that describes an institute and place of culture,

Figure 37.

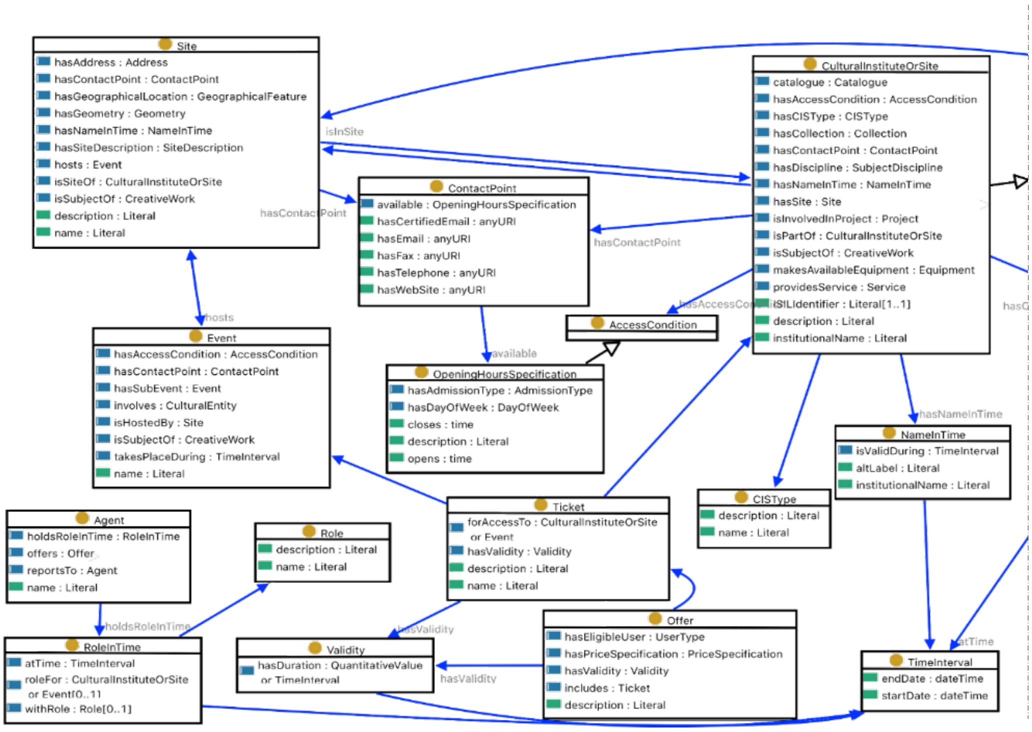


Figure 37. Excerpt of the first version of Cultural-ON (now deprecated).

[58] http://dati.beniculturali.it/cultural_on/

### 4.1.8 EUROPEANA

At the European level, there is *Europeana.eu*, a project funded by the European Commission to build a virtual European library to make Europe’s cultural heritage accessible to all. More than 3,000 institutions across Europe have contributed to Europeana. Their collections let users explore Europe's cultural and scientific heritage from prehistory to the modern-day.[59]

### 4.1.9 Historic Urban Landscape (HUL)

The HUL aims to monitor the landscape heritage considering its environment changes constantly. “It is based on the recognition and identification of a layering and interconnection of natural and cultural, tangible and intangible, international and local values present in any city”[60]. For this dissertation, the definition of HUL by the UNESCO Recommendation (UNESCO, 2011) has been selected. It explains that historic urban landscape is an urban area resulting from “historical layering of cultural and natural values and attributes, extending beyond the notion of historic centre or ensemble to include the broader urban context and geographical setting”. Moreover, it considers “topography, geomorphology and natural features of the sites, the built environment, both historical and contemporary, open spaces, land use patterns and spatial organization, and values, economic processeis and the intangible dimensions of heritage”.

## 4.2 Existing standards of Geographic Information

*Standards for GI*

In the geo-information, there are many spread and used standards. At first, as regards urban content, there is CityGML[61], an international standard data model published by the OGC to represent multiscale 3D information about entities of cities. Secondly, the INSPIRE data model (created in 2007 and compulsory adopted in every County of Europe by 2020)[62]. It is part of the European Directive to reach interoperable cartography in Europe. The INSPIRE standard includes some features linked with the CityGML one in its “buildings” data model part. It is possible to consider the IFC (Industry Foundation Classes) in BIM (Building Information Model) environment for parametric modelling concerning architectural heritage. Unlike the other two above mentioned, this standard considers a higher level of representation, especially concerning interior parts of the building. The main issue with applying this to cultural and built heritage is that it is designed for new buildings; therefore, it is challenging to use it for historical constructions. Some researchers proposed extensions (Costamagna & Spanò, 2012; Fernández Freire et

[59] https://www.europeana.eu/portal/it
[60] http://historicurbanlandscape.com/index.php?classid=5352&id=29&t=show
[61] http://www.opengeospatial.org/standards/citygml
[62] http://inspire.ec.europa.eu/data model/approved/r4618-ir/html/

al., 2013; Noardo, 2016) of the model of these standards to increase the level of detail and to consider heritage.

### 4.2.1. ISO TC211 Geographic information / Geomatics

TC211 is the Technical Committee ISO that, since 1994, deals with standards for digital geographic information and geomatics. These oldest standards describe methods, services and tools in the area of GI. They could be adopted to manage, acquire, process and analyse spatial data. They could be adopted by different stakeholders in various sectors of geomatics[63].

### 4.2.2 Open Geospatial Consortium (OGC) - International Community (1994)

The OGC is "an international not-for-profit organization committed to making quality open standards for the global geospatial community"[64]. The standards developed by OGC are free and open, they could be implemented, and many of its applications are based on the conceptual models defined by ISO or jointly by the OGC and ISO. Among these standards, we could find the Geography Markup Language Encoding Standard (GML) and CityGML. They are below reported.

#### 4.2.2.1 OpenGIS® Geography Markup Language Encoding Standard (GML) - International Community (2007) ISO: 19136

GML is an XML (Extensible Markup Language) grammar to express geographical objects and features. "It is the modelling language for geographic systems on the web. GML is also an ISO standard (ISO 19136:2007)"[65].

#### 4.2.2.2 GeoSPARQL (Geographic Query Language for RDF Data)

GeoSPARQL[66] is an OGC standard. It intends to represent and query geospatial data on the Semantic Web; its core structure defines the geo-classes *Spatial Object, Feature and Geometry*. It is composed by different components: a core component for top-level RDFS/OWL classes for spatial objects, a topology vocabulary with RDF properties, a geometry component for RDFS data types, a geometry topology component, and an RDFS entailment component (Perry & Herring, 2012).

[63] https://www.iso.org/committee/54904.html, https://committee.iso.org/home/tc211
[64] http://www.opengeospatial.org/
[65] http://www.opengeospatial.org/standards/gml
[66] A Geographic Query Language for RDF Data

#### 4.2.2.3 OGC CityGML

CityGML[67] was developed in 2002, and it became ISO standard in 2008. It is the core standards in GIS. It is an open data model to store and exchange information of 3D city models. It extends the GML, by adding the semantic values for the 3D representation of city objects (OGC, 2012). The development of the standard wants to get a common definition of the entities, attributes, and relations for 3D cities. The design of this model could help the reuse of knowledge by adopting the same data in different application fields. Several geometries can be associated with the same entity to get a multi-level representation based on varying levels of detail. The standard implements 5 *Levels Of Detail* (LoD) for a multi-scale model of spatial entities. The LoDs reflect the detail of the selected features in different scales of representation.

- The first level of detail, LoD 0, deals with the representation of 2D or 2.5D (Digital Terrain or Surface Model information – DTM, DSM) objects. This is generally adopted for territorial maps of land (scale about 1:50000 – 1:10000).
- LoD 1 represent buildings in 2,5D or 3D, considering their height but without roofs and openings (scale about 1:25000 – 1:10000).
- LoD2 and LoD3 represent city district or architectural models (outside), including roofs and surfaces detail (scale about 1:10000 – 1:5000 for LoD 2 and 1:2500, 1:2000 in Italy – 1:1000 for LoD3).
- Finally, LoD 4 is dedicated to the interior building, including furniture. A CityGML model in LoD 4 could carry more information than a traditional 1:1000 or 1:500 cartographic representation.

The following LoDs characteristics of buildings are summarized in Table 4.

Table 4. Characteristics of LoDs 1-4 representations in CityGML – Buildings (Fan et al., 2009).

| | **LoD 1** | **LoD 2** | **LoD 3** | **LoD 4** |
|---|---|---|---|---|
| Model scale description | City, region | City district | Architectural models (outside), landmark | Architectural model (interior) |
| Class of accuracy | Low | Middle | High | Very high |
| Accuracy of position and height | 5 m | 2 m | 0.5 m | 0.2 m |
| Approximate representation scale | 1:25000 – 1:10000 | 1:5000 | 1:2500 (1:2000 in Italy) – 1:1000 | 1:1000 – 1:500 |
| Generalization | Object blocks as generalized features >6x6 m | Objects as generalized features >4x4 m | Object as real features >2x2 m | Constructive elements and openings are represented |

[67] https://www.ogc.org/standards/citygml

| | LoD 1 | LoD 2 | LoD 3 | LoD 4 |
|---|---|---|---|---|
| Building installation | | | Representative exterior effects | Real object form |
| Roof form / structure | flat | Roof type and orientation | Real object form | Real object form |

The concept of LoDs, as implemented in CityGML, is an essential issue to structure 3D city-data. Hence, different levels of detail in the representation of the city and the landscape enable different scale levels in analysing the data. The standard provides data models of city objects (structured as shown by the UML model in Figure 39). One of the model's advantages is that the modules can be extended or added to adapt to the different fields of application needs.

Due to inadequacy of the model level, research (Biljecki et al., 2016) carried out a new methodology of CityGML representation. The new LoDs align with the LoDs of CityGML 2.0 and are intended to supplement rather than replace the geometric part of the current specification (Figure 38).

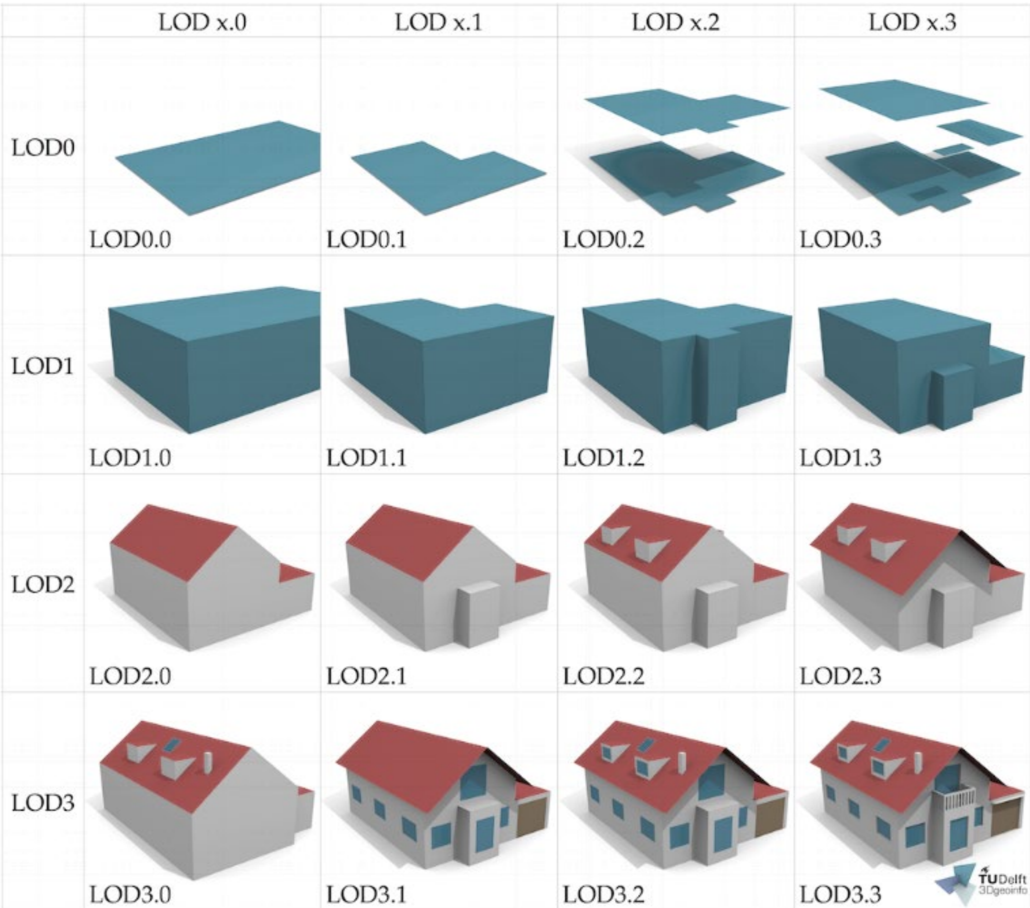


Figure 38. Refined series of 16 LoDs by (Biljecki et al., 2016).

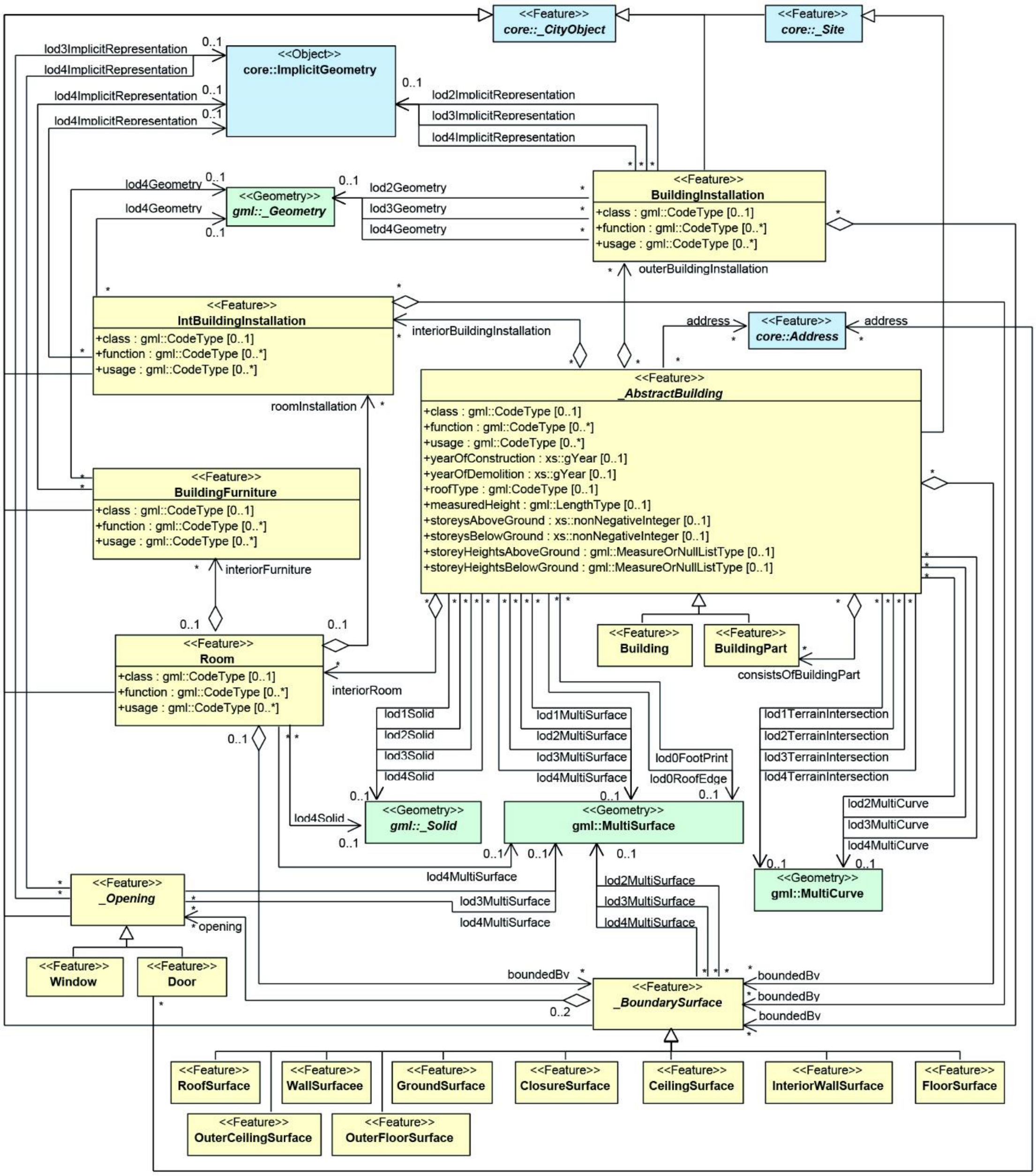


Figure 39. UML schema of the CityGML Building module - OGC, 2012.

### 4.2.3 Infrastructure for Spatial Information in the European Community (INSPIRE), European Directive

INSPIRE[68] is a Directive of the European Parliament (Directive 2007/2/EC) and of the Council (14 March 2007) establishing an infrastructure for spatial information to support a unique Community underground to share environmental spatial information among the European States. It aimed to harmonise spatial information as a reference for the Community environmental policies and activities that may impact the environment. For this reason, several entities related to the risk,

[68] https://inspire.ec.europa.eu/

the hazard and the necessity to protect some specific areas are included in the INSPIRE data model, besides the usual cartographic entities for mapping the land. The INSPIRE themes are grouped into three annexes, summarized in Table 5.

Table 5. INSPIRE data themes divided in the three annexes.

| **Annex I (essential core of the database)** | **Annex II (describing the land morphology)** | **Annex III (natural or artificial elements connected to the land)** |
|---|---|---|
| • Addresses<br>• Administrative Units<br>• Cadastral Parcels<br>• Coordinate Reference Systems<br>• Geographical Grid Systems<br>• Geographical Names<br>• Hydrography<br>• Protected Sites<br>• Transport Networks | • EL (elevation)<br>• GE (geology)<br>• LC (land cover)<br>• OI (orthoimagery) | • AC-MF (atmospheric conditions - meteorological geo.features)<br>• BU (Buildings)<br>• AF (Agricultural, Aquaculture Facilities)<br>• AM (Area Management Restriction and Regulation<br>• BR (Bio-geographical Regions)<br>• EF (Environmental Monitoring Facilities)<br>• ER (Energy Resources)<br>• HB (Habitats and Biotopes)<br>• HH (Human Health – Safety)<br>• LU (land use)<br>• MR (Mineral Resources)<br>• NZ (Natural Risk Zone)<br>• OF (Oceanographic Geographical Feature)<br>• PD (Population Distributon - demography)<br>• PF (Production and Industrial Facilities)<br>• SD (Species Distribution)<br>• SO (Soil)<br>• SR (Sea Regions)<br>• SU (Statistical Units)<br>• US (Administrative - social governmental services, environmental management facilities, utility network profile) |

The level of detail in INSPIRE is lower than in CityGML, since the object of interest of INSPIRE are broad areas with transboundary dimension and, consequently, being that the objects of interest differ, the represented entities differ. The Buildings Data Theme (Annex III) and the Protected sites data theme (Annex I) have been analysed for the present research. The data theme *Protected site*[69] (INSPIRE, 2014) is more intended to represent sites having a specific vulnerability. Being the INSPIRE Directive aimed at supporting the development of environmental policies, the theme is more suitable for representing natural sites. The cultural value is, however foreseen as a reason for considering an area a protected site. Nevertheless, it must be extended with further details. As it is possible to read in the INSPIRE data Specification, the theme *Building*[70] (INSPIRE, 2013) is modelled on the data specification for "Building" in CityGML (Figure 40), so that a harmonization between the two specification is easy, being one the base for the other. Some differences between the two data specification exist (for example, in some cases the CityGML Building specification was simplified, and in

[69] https://inspire.ec.europa.eu/Themes/117/2892
[70] https://inspire.ec.europa.eu/Themes/126/2892

other cases it was enriched; or some common attributes to all the INSPIRE data themes were substituted to the CityGML ones). However, the mapping between CityGML and INSPIRE Building model is foreseen. Even if both the standards consider a multi-scale representation with many levels of detail, the management of geometry is different in the CityGML and INSPIRE since they employ other models for representing geometry. The INSPIRE data model uses the specification of ISO 19107:2003 Spatial Schema of ISO TC211. In contrast, CityGML refers to the geometry packages included in the OGC GML standard, which is also ISO TC211 – ISO 19136 GML.

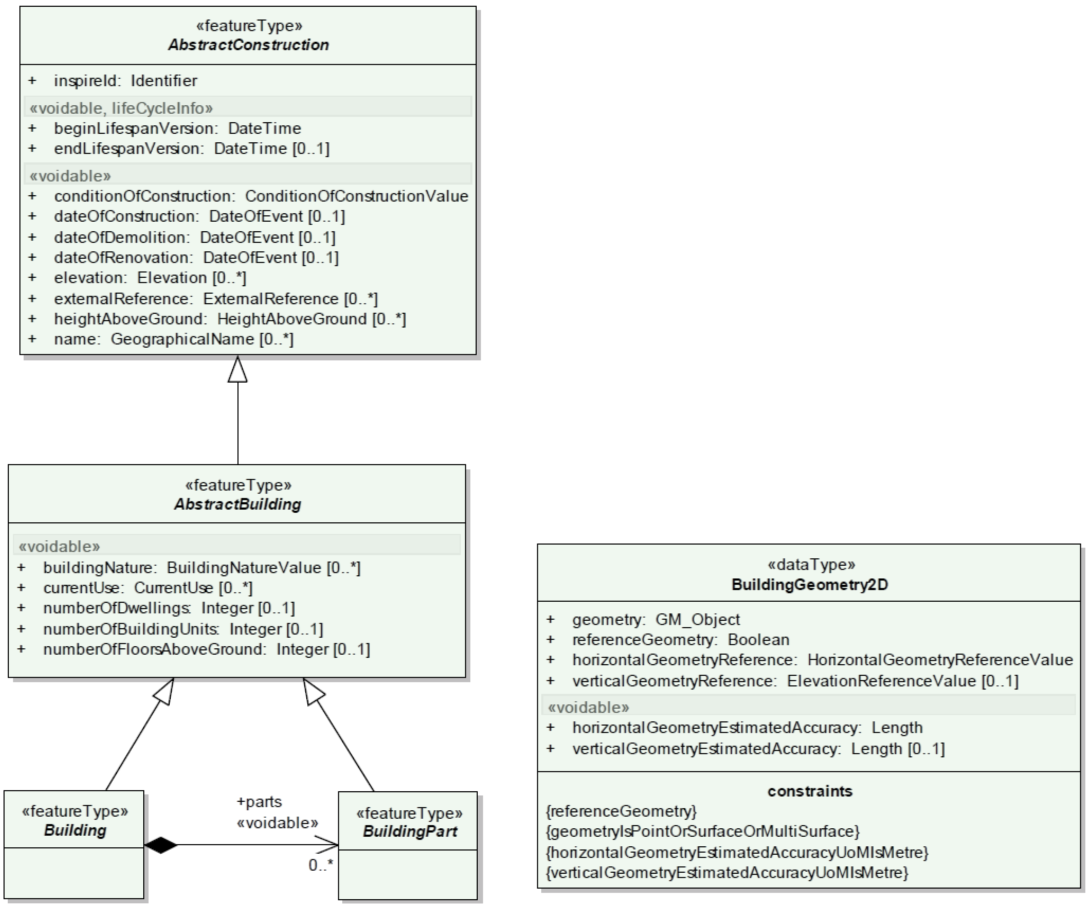


Figure 40. UML class diagram: Overview of the Building Base - Main types (INSPIRE, 2013).

### 4.2.4 Industry Foundation Classes (IFC)

Regarding architectural heritage, it is possible to consider also the IFC[71] (Industry Foundation Classes) in BIM environment for parametric modelling. The specification of this standard consists of the data schema represented as an *express* schema specification and alternatively as an XML Schema specification, and reference data, defined as XML definitions of property and quantity definitions. The data schema architecture of IFC defines four conceptual layers. Each schema is assigned to precisely one abstract layer (Figure 41). The main issue with applying

[71] https://www.buildingsmart.org/standards/bsi-standards/industry-foundation-classes/

this to cultural and built heritage is since it is designed for new buildings. It is therefore challenging to use it for historical constructions. Built and urban heritage could be represented through the adoption of BIM with the recent definition of the HBIM models (Historical BIM) (Adami et al., 2019; Adami & Fregonese, 2020; Banfi, 2020; Barazzetti et al., 2015; Brumana et al., 2019; Colucci, De Ruvo, et al., 2020; Inzerillo et al., 2016; Matrone et al., 2019; Oreni et al., 2013).

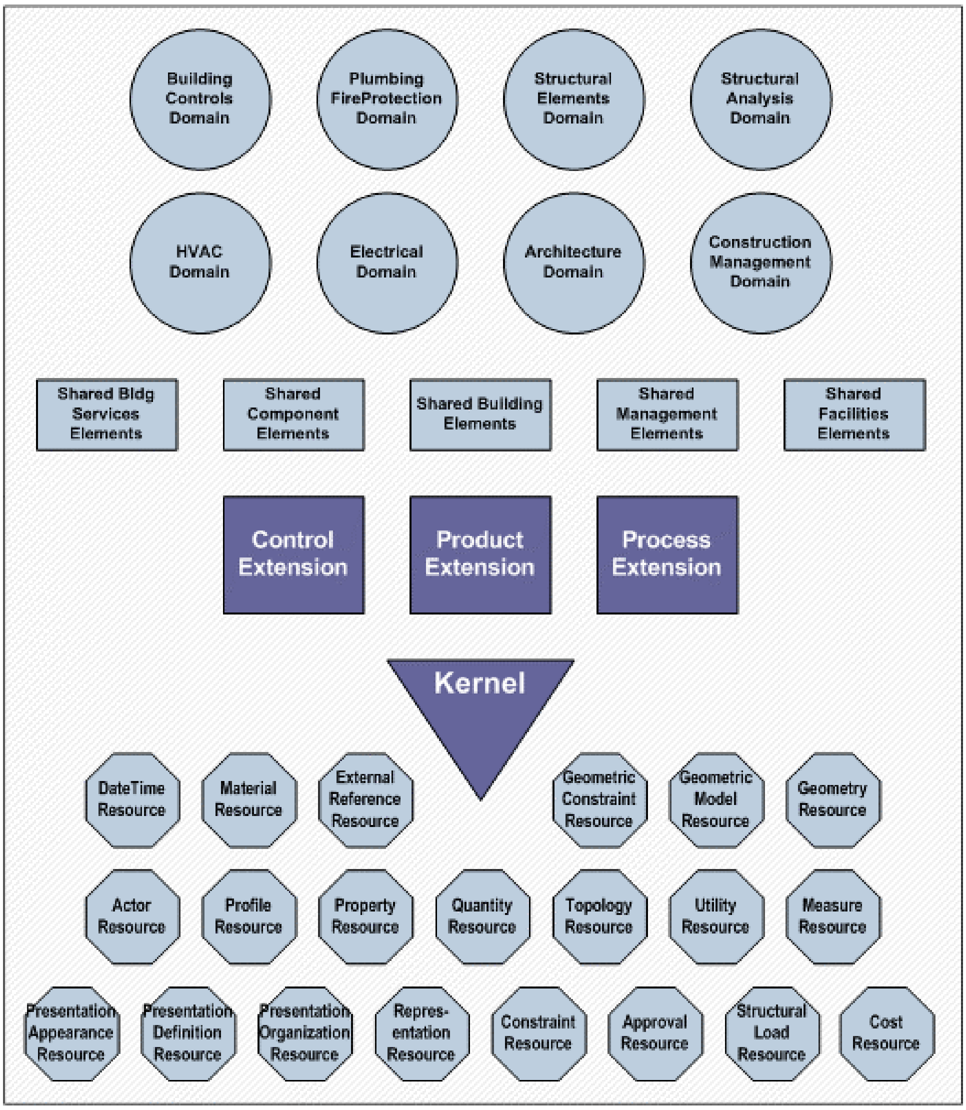

Figure 41. IFC data schema architecture.

## 4.3 Ontologies to solve interoperability problems

As it is possible to notice in the above paragraphs, there are many standards and related software and data formats in the built heritage and GI domains. This multitude of sources implies some interoperability issues. Ontologies could be adopted to solve this problem, as explained below.

It is possible to classify different kinds of interoperability before explaining why and what ontologies should improve interoperability between heterogeneous

*interoperability*

information systems. In Falquet et al. (2011), interoperability is presented as the ability of an information system or its components to share information and applications. In this regard, it is possible to consider four kinds of interoperability: *lexical, data, knowledge model and object* (Figure 42).

For the first one, it is possible to say that one of the goals of linguistic ontologies is to normalize the vocabulary used in the document to avoid lexical ambiguity. In this sense, *lexical* interoperability is fundamental for evading incongruences or duplications in the ontology structure.

For the second type of interoperability, software ontologies are used as a *data* exchange format between different systems. The data exchange format derives from agreements among software companies on vocabulary and structure to be adopted (considering the lexical interoperability). At the same time, the internal model of each system does not depend on the data exchange format. Assuming that the "data exchange format" is an ontology, it must be a core ontology adopted by different systems.

A study (Fonseca et al., 2000) reports a methodology to generate software components using an urban ontology concerning the *knowledge model* interoperability. These components make it possible to share data at different levels and reuse knowledge. The use of existing knowledge from already structured GIS is fundamental since many aspects characterize the exchange of data and knowledge among GIS users in the domain of urban heritage. At the same time, data reuse is horizontal. The reuse of knowledge must be done horizontally and vertically. The goal is not to directly exchange data or query a heterogeneous data source but to efficiently design, implement, or update an information system using a series of ontologies.

Although ontologies have begun with AI, ongoing research on ontology can be found throughout the computing community in computational linguistics and database theory. Knowledge engineering, information integration and object-oriented analysis (GIS) are all fields of it. Using ontologies to create GIS applications can help data integration and avoid problems, such as the inconsistency between the *ad-hoc* ontologies integrated into the system. However, there is a gap between ontologies and software components. To transfer knowledge from ontologists to software engineers, it is necessary to focus on the coherent part of an ontology instead of highlighting the differences between ontologies. Ontologies are crucial for the GIS since they establish correspondences and interrelations between the different domains of entities and spatial relations (Smith & Mark, 1998).

Finally, through the adoption of core ontology, object interoperability could allow different interface systems sharing common information and the possibility to query entities.

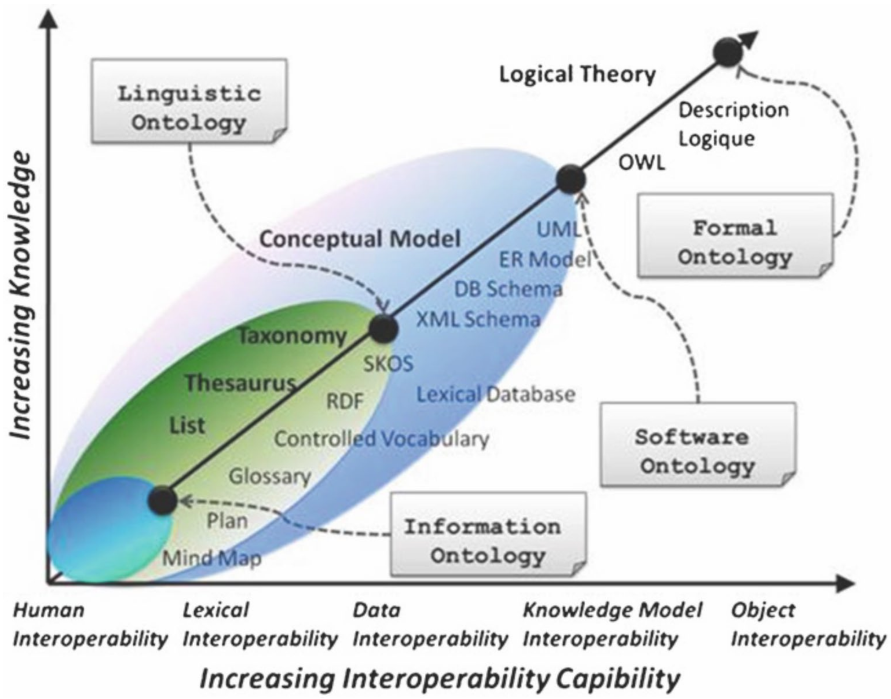

Figure 42. A schematic representation of a different kind of interoperability based on the Falquet et al., (2011) ontology.

It is possible to investigate the motivations for which ontologies could be very useful to fulfil interoperability issues. In this paragraph, the review presented in Falquet et al. (2011) about the state of the art of ontologies in geographic information interoperability scenarios is reported. Firstly, the use of ontologies to help discover and retrieve geographic and spatial resources is described in the following list (1). It explained how ontologies could solve interoperability issues of data integration (2). Finally, the role of the conceptual model of ontologies for the design and development of information systems is investigated (3).

1. *Discover and download geographic information.*

In many cases, the keyword researches in SDI is not always efficient as there can be problems with semantics, ambiguity and heterogeneity. Generally, SDIs provide catalogues services to discover data and services for specific activities. The explorations in these catalogues are currently mainly based on keywords corresponding to strings with metadata entries. The creation and use of ontologies could overcome semantic interoperability problems between the user and the description of the GIS, improving the matching process. In the recent literature, there are many examples of ontologies aimed at enhancing the querying of data infrastructures based on WFS services (Web Feature Service) (Bernard et al., 2004; Lutz & Klien, 2006) or structured according to the GML language. Finally, the use of ontologies to enrich the description of metadata and services within SDI, allows the automatic interpretation of semantics and permits users to have the possibility to ask defined questions. Moreover, logical reasoning can discover implicit relationships between terms and descriptions.

2. O*ntologies could solve data integration issues from different sources.*

Ontologies define semantics independently of data representation and reflect the relevance of data without opening or accessing it. This high-level description of semantics in GI provides new tools to compare and integrate spatial data. Furthermore, ontologies allow the reuse of knowledge by semantically describing data from the different GIS communities. In the context of SDI, various ontologies have been created in recent years to facilitate data integration. An example is an ontology for GML (Ontology for Geography Markup Language, Drexel University, 2004)[72] which provides a representation based on ontology using the OWL language. Moreover, the Geospatial Resource Description Framework (GRDF) (Alam et al., 2011), another OWL ontology whose concepts and properties, extends the definitions of GML ontology. This ontology aims to define an expressive language in the geospatial domain by exploiting the advantages offered by the semantic languages of the Web.

*3. Ontologies play an important role as a conceptual model for creating GIS.*

Ontologies are proposed in (Guarino, 1998) with a central role in the information system life cycle, leading to information systems based on ontology (ODIS - Ontology-Driven Information System). In ODIS, ontology is called "application ontology", and it is a specialisation of a domain ontology and a task ontology. A shared vocabulary among heterogeneous platforms guarantees the reuse and sharing of knowledge within the application domain. Therefore, designers can focus on the structure of the domain instead of being overly concerned with implementation details. The development and use of ontologies should be a prerequisite for conceptual modelling, as the ontologies are broader by definition of conceptual schemes (Fonseca & Martin, 2007).

## 4.4 Ontologies in the urban and built heritage domain

In urban and built heritage, many applications and communities are involved in the processes and activities for the management, development, and enhancement of cultural heritage, buildings, and cities. In this scenario, it is possible to mention restoration, conservation, documentation, risk management activities and energy disciplines. In this regard, some research on ontologies for representing built heritage at different scales and varying granularity levels has been carried out. Focusing attention on the urban and built heritage domain makes it possible to identify some cases developed for the semantic formalization of cities, cultural heritage, historical centres, and buildings. These ontologies examples analysed are the background to lay the basis for developing the new ontology on MHC. This investigation helped to individuate the lacks of existing methodologies.

*Ontologies in Urban domain*

The book of Teller et al. (2007), *Ontologies for urban development* and the study of Berdier & Roussey (2007) and *Urban ontologies: The towntology prototype towards case studies. Ontologies for Urban Development* are selected to describe ontologies in urban domain areas. Both worked in the framework of the

[72] http://efe.ege.edu.tr/~unalir/MK/gml30.owl

towntology project in the COST Action C21[73] (Towntology – Urban Ontologies for an Improved Communication in Urban Civil Engineering Projects - UCE) started in 2008 and ended in 2012. The main objective was to increase the knowledge in the domain of urban civil engineering using ontologies. It aimed to facilitate communications among information systems, stakeholders and specialists at a European level. Other purposes were finalised to create a taxonomy of ontologies in the UCE field by reusing existing glossaries and standards. The aim was to develop an urban civil engineering ontology both in textual and visual representation.

Over the years, many studies have been tried to achieve the purposes of the action tasks. Many researchers have tested the ontology applying it in real UCE projects to validate the taxonomy and the general ontological structure. In this regard, the study of Teller et al. (2007) summarised the Action C21 after the Workshop of November 2006 organized to address emerging issues in the field. The volume presented some contributions from the workshop, revised after the outcomes of the discussion. Berdier & Roussey (2007) research described the work performed in the framework of the towntology project investigating meanings and classifications of ontologies for urban studies and their applications. The authors developed three ontologies (road system, urban mobility and urban renewal). In Figure 43, an example of Road System Ontology is represented. For the taxonomy creation, 1000 terms in the domain have been selected from several dictionaries and standards, and 21 relationships have been defined to link entities and concepts. The work demonstrated as ontologies aim to produce an accurate representation of realty.

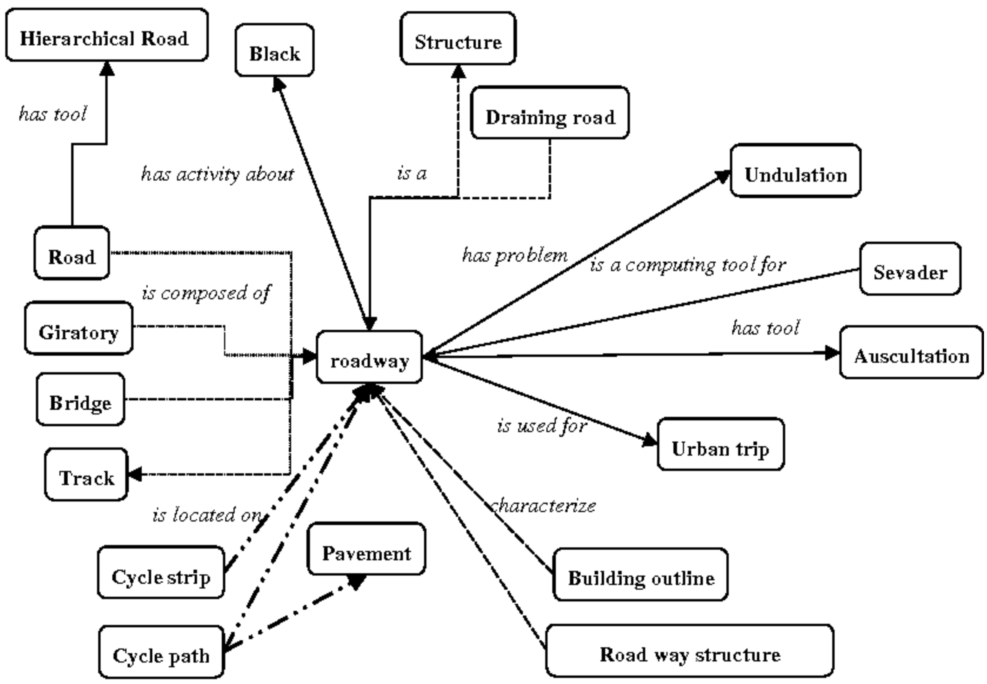

Figure 43. Part of the road system ontology (Berdier & Roussey, 2007).

73 https://www.cost.eu/actions/C21/#tabs|Name:overview

Another example in the urban domain is represented by the book of Falquet et al. (2011). It embodies the first attempts to create an ontology in the urban environment. Researchers of various fields (computer science, information systems, ontology engineering, urban planning and design, civil and building engineering and architecture) present an interdisciplinary study of ontology engineering and its application in urban development projects.

In the framework of architectural built heritage, few attempts have been made to design an ontology. Examples are the works of Messaoudi et al., (2015) "*Towards an Ontology for Annotating Degradation Phenomena",* in the archaeological area, and the one of Kokla et al., "2019) "*Towards Building a Semantic Formalization of (Small) Historical Centres",* to represent historical small urban centres. In the context of this thesis, the most recent and significant works on ontologies in the architectural and cultural domain are: "*An ontology-based framework for conservation process" (*Acierno et al., 2017), and "*Ontologie per i Centri Storici*" (Acierno, 2019) in "*Il futuro dei centri storici. Digitalizzazione e strategia conservative"* (Fiorani, 2019). The first research designed the architectural heritage knowledge in an ontology-based framework for conservation actions considering modelling the building in a BIM environment. They started from existing standards and the CIDOC- CRM and MONDIS for designing the modelling framework for representing architectural heritage (Figure 44). They selected four domains (Figure 45): artefact, architectural investigation process, artefact lifecycle and actors. After the formalisation phase, an application case study of a BIM of architectural, historical-cultural heritage was selected to validate the ontology. The work could be configured to support knowledge management in conservation phases, allowing public institutions to share information.

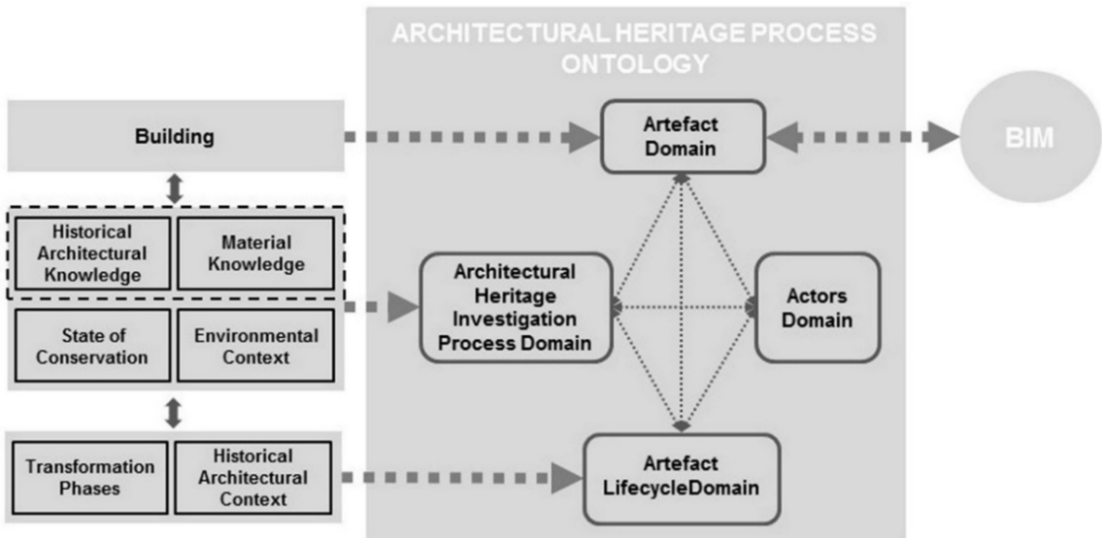


Figure 44. The modelling framework for representing architectural heritage. The figure shows the association between the subjects traditionally addressed within architectural heritage studies and the ontology domains. The dashed frames bound the topics so far modelled (Acierno et al., 2017).

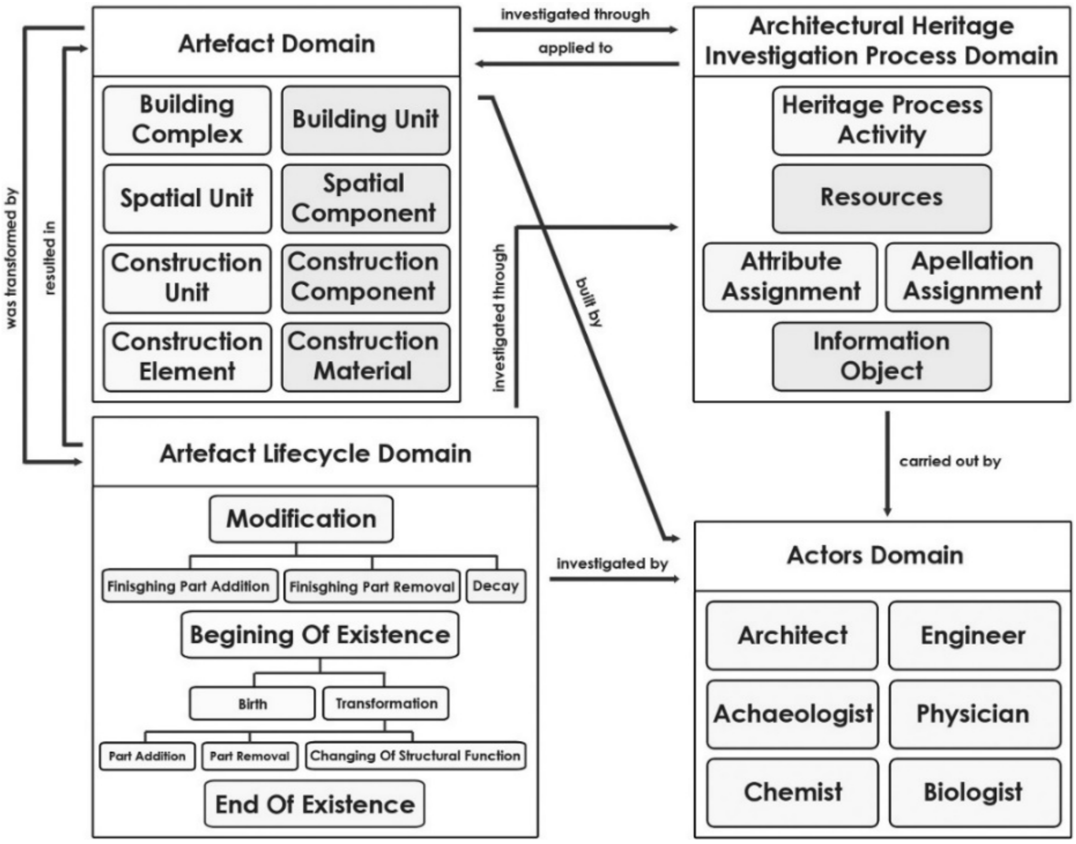


Figure 45. Ontology structure. Schematic representation of the four formalized domains. The sketch shows the main classes and subclasses (grey background) and the relations occurring between them (dashed arrows) (Acierno et al., 2017).

In Acierno (2019), a methodology for structuring ontology for evaluating the vulnerability of historical centres was proposed. In this case, for the formalisation, the Italian Risk Map[74] and the GeoSPARQL[75] ontology of OGC has been considered as standard data models.

The integration (Figure 46) of these models has made it possible to create schemas of the road, localisation, environmental aspects, historical documentation and demographic characteristics. This work could be a starting point for implementing the ontologies in an open-source ontology editor and framework for building intelligent systems, such as Protégé[76], aimed at conservation evaluation processes of historical centres. Moreover, the study could be implemented for urban planning and architectural design projects using the Risk Map to find the necessary information.

[74] http://www.cartadelrischio.it/
[75] http://www.geosparql.org/
[76] https://protege.stanford.edu/

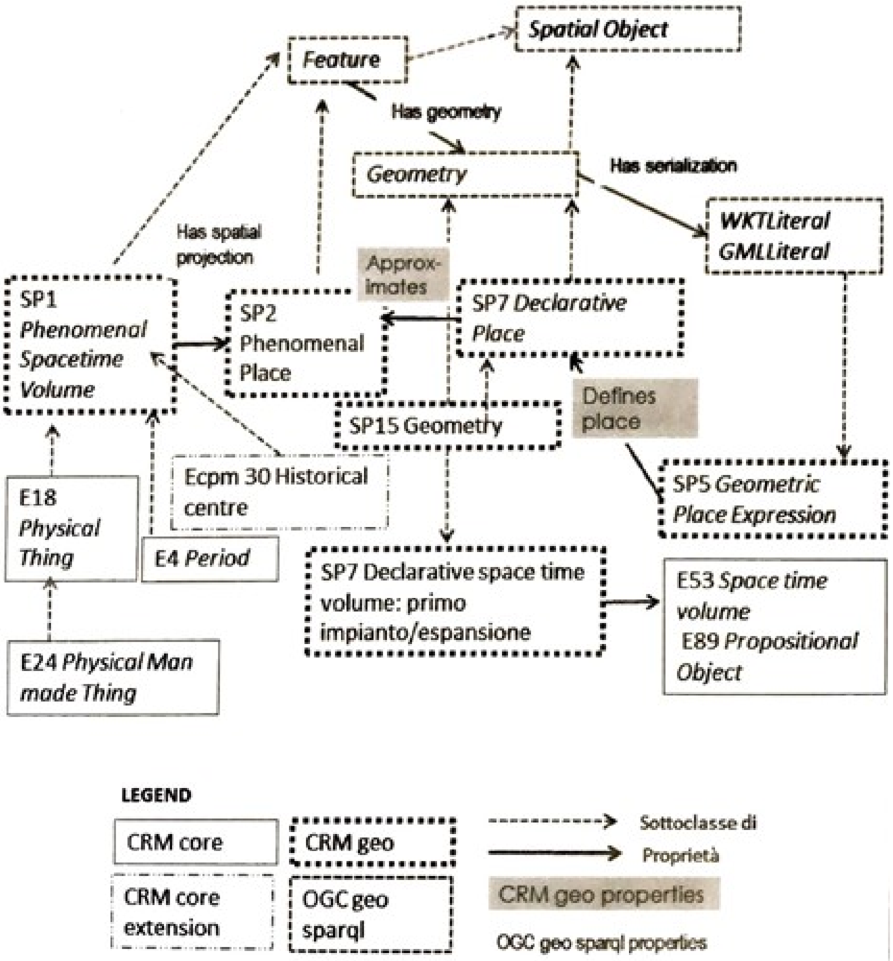


Figure 46. Graphic schema of relations and classes of Cidoc-CRM model, CRMgeo and GeoSPARQL model (Acierno, 2019).

Finally, Quattrini et al. (2017) developed an ontology to solve interoperability problems for integrating CityGML and IFC standards (Figure 47).

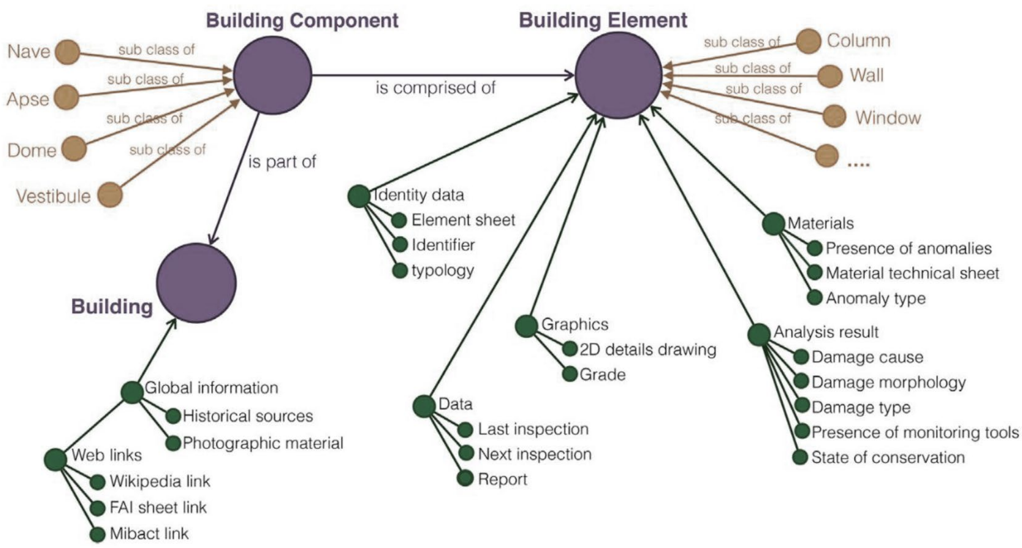


Figure 47. OWL ontology was developed for the semantic data representation of historical architecture. Classes (purple), sub-classes (orange) and metadata (green) are identified (Quattrini et al., 2017).

***Part of the work described in the next chapters has been previously published in Colucci et al., (2020, 2021).***

→ Colucci, E., Kokla, M., Mostafavi, M. A., Noardo, F., & Spanò, A. (2020). Semantically describing urban historical buildings across different levels of granularity. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *43*.

→ Colucci, E., Kokla, M., Noardo, F. (2021). Ontology-based data mapping to support planning in Historical urban centres. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XLIII-B4-2021, 39–45, https://doi.org/10.5194/isprs-archives-XLIII-B4-2021-39-2021, 2021.

# Methodology, results, and validation

Part II presents the methodological framework and the outcomes of the ontology development. Semantic definitions of MHC concepts, classifications and standards conceptualisations and data models are considered existing knowledge to reuse and integrate. This central part of the thesis starts describing ***ontology design* or *engineering*** (described in § 3.3), the process of creation of the new ontology for MHC. It could be summarised in the following different steps:

- Determine the scope and the domain of the ontology, clarifying the application use cases and the competency questions (§ 5.1);
- Consider the reuse of existing conceptualisations and ontologies from previous knowledge. Define concepts and relations with the Top-Down approach (§ 5.2);
- Ontology enrichment and mapping adding instances and relations from structured and unstructured knowledge to formalise the information through the Bottom-up Approach (§ 6.3 and 6.5);
- Ontology population with information from real case studies (§ 6.3 and 6.5);
- Data analysis, harmonisation and mapping of spatial datasets and data models of case studies (§ 7.1);
- Methodology validation and connection of spatial data with their semantics (§ 7.2 and 7.3).

# PART II

5

Chapter 5

# Geospatial Ontology design

The primary part of the methodology was developed during the first PhD visiting research period thanks to the collaboration with the National Technical University of Athens (NTUA), School of Rural and Surveying Engineering and the Laboratory of Cartography (Academic tutor and Co-supervisor: Dr Margarita Kokla), from February to June 2020 (with a telematic period due to COVID-19 emergency).

National Technical University of Athens

The ontology design follows an iterative process considering the Ontology Development Guide (Noy & McGuinness, 2001, Figure 48). Firstly, the methodology of this thesis clarifies and defines the *domain* and the *scope* of the ontology.

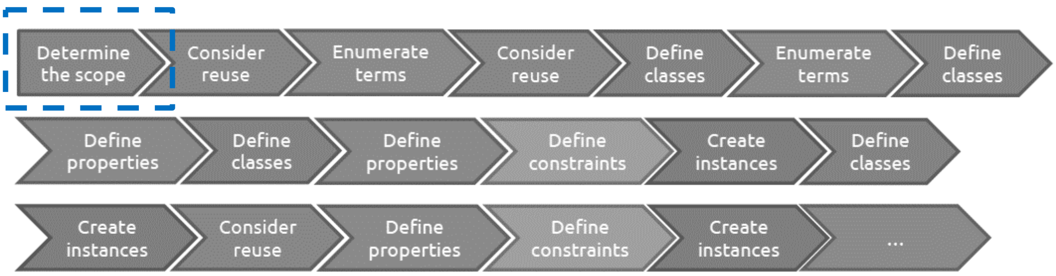


Figure 48. ONTOLOGY101 GUIDE (Standford University, Noy and McGuinness, 2001).

After listing the many reasons for building an ontology for historical centres, this part of the dissertation outlines the main aim of the ontology:

- the *spatial documentation* for urban and rural historical centres.

*Domain & Scope*

This choice derives from a long workflow and a careful investigation of the needs of many use cases and communities involved in the cultural urban and built heritage domain. Different levels of details (national, regional, and local, with varying scales of representation, from territory to buildings) and levels of granularity (both geometric and semantic) have been considered to study existing conceptualisation for cultural, historical and built heritage. Therefore, concepts representing MHC and their context have been selected from standards, vocabularies, and ontologies. Extraction of semantic images from knowledge, formalisation of natural language text, and sub-ontology extraction have been applied to enumerate practical terms for the design of spatial ontology. Moreover, ontology matching and alignment methods were used to integrate and merge existing ontologies.

## 5.1 Definition of scope and domain

A proper and well-defined ontology is essential to reuse domain knowledge, make the domain assumptions explicit, separate domain knowledge from operational knowledge, and analyse the domain knowledge (Noy & McGuinness, 2001). To share a common understanding among different users, scientists, researchers, policymakers and other stakeholders is a fundamental goal in developing ontologies (Gruber, 1993; Musen, 1992). The domain that has been selected is ***historical centres, villages*****, and** ***minor and abandoned HC*** for many reasons. Firstly - as mentioned in Chapter 1 Introduction, and as pointed out in the literature review - a specific ontology to support different stakeholders involved in various tasks and fields working on urban and rural management, urban development, restoration projects, structural analysis, policy process does not exist. Moreover, since historical centres have cultural values, they need to be protected and documented. Although many fields and communities are involved in activities and tasks concerning HC, none of these considered individually can fully represent the heritage with a whole level of detail and information (Colucci et al., 2020). Hence, before enumerating concepts and connecting them through relationships, it is necessary to clarify the scope of the ontology, answering several fundamental questions:

- What is the domain the ontology will cover?
- Who will use and maintain the ontology?
- For what types of questions the ontology should provide answers?
- For what, we are going to use this ontology?

The following sections try to answer these different questions, defining the scope, the domain and the users, listing the competency questions the ontology must answer and delineating the general and specific scope.

### 5.1.1 Domain, users and questions

*1. Domain:* historical centres

As underlined in the theoretical background (Part I), different levels of meanings, definitions and domains of HC have been delineated following a multi-scale approach. These domains are helpful to define different levels (super-class, sub-class, equivalence among terms) of conceptualisations of classes designed in the ontology. Firstly, the proposed ontology considers HC as *core urban centres* *and historical parts of cities* at the general level. This sub-domain starts from the general conceptualisation of cultural built heritage with cultural, social and historical value and architectural metropolitan areas. Then, the specific level includes *minor and abandoned historical centres* in rural areas, villages, hamlets and small built centres. In this case, the ontology classes are defined as sub-concepts of general entities (cultural heritage, landscape, cities, etc.).

2. Users & stakeholders

The systematic use of ontologies supports the representation of the exact information needed in operational use cases. Therefore, it is essential to define the different application and user areas starting from the general concept of CH value. Official documents (such as UNESCO conventions[77] and CH European documents[78]) assert cultural and architectural heritage values and needs. Besides, use cases and different communities involved in CH assets present different needs according to their various roles and the granularity levels (territorial/landscape, urban, architectural). Figure 49 highlights the complexity of the schemes and relationships that need to be considered. Colucci et al. (2020) reviewed some efforts to provide ontological structures, conceptualisations, and vocabularies. This work helped to assess their state of implementation and to underline the need for further development. After a literature investigation, it can be acknowledged to define at least these prominent use cases:

- Restoration;
- Documentation and Heritage Study;
- Risk Prevention;
- Heritage Asset and Facilities Management, Fruition (Education and Tourism);
- Urban Planning;
- Energy Refurbishment and Performance.

For the Conservation case, several studies proposed solutions and implementation of official ontologies such as the CIDOC-CRM (Acierno, 2019; Acierno et al., 2017; Blaško et al., 2012; Cacciotti et al., 2013; Tait & While, 2009). In Restoration, Acierno (2019) proposes an ontology for the historical centre conservation and management (described in the previous section). In the Documentation and heritage studies domain, some conceptualisations about the architectural and built heritage have been developed (Hois et al., 2009). A specific data model was proposed regarding heritage risk prevention starting from standardised structures and vocabularies within the ResCult project (Chiabrando et al., 2018). For energy refurbishment of historical centres and buildings, an extension of CityGML was proposed (Egusquiza et al., 2018). For urban planning, some examples exist, mainly related to the representation of the city without a specific focus on historical aspects (Berdier & Roussey, 2007; Teller et al., 2007).

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[77]http://portal.unesco.org/en/ev.php-URL_ID=12025&URL_DO=DO_TOPIC&URL_SECTION=-471.html
[78] https://whc.unesco.org/en/documents/

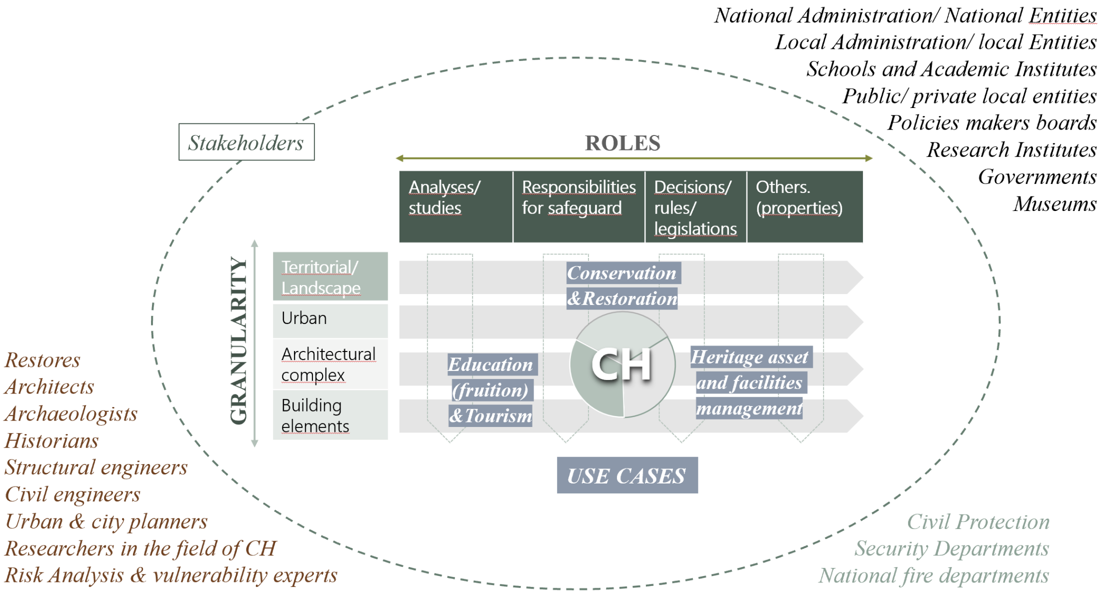



Figure 49. A possible graphical view of communities involved in specific use cases and the grid of parameters concerning roles and granularity considered in the complex action undertaken in the CH domain (Colucci et al., 2020).

Based on the definition of the different use cases, it was possible to identify three groups of stakeholders involved in historical centres analysis, valorisation, documentation, safeguard, etc. The first group includes restorers, architects, archaeologists, historians, structural engineers, civil engineers, urban & city planners, researchers in CH, risk analysis & vulnerability experts. The second one considers all the public and private administrations (national administration, local entities, schools and universities, public and private entities, policymakers' boards, research institutes, governments and museums). The civil protection, security department and national firefight bodies must also be considered (Figure 49).

*3. Competency questions*

Some questions that a knowledge base based on ontology should answer are listed. These are named *competency questions* (Grüninger & Fox, 1995) and are based on the various needs of different communities. According to the Ontology Guide by (Noy and & McGuinness, 2001), some examples of questions may include the followings:

- What type of historical centre is it (urban core, hamlet, village)?
- Where is it located (geographically and orographically)?
- What is the territory morphology?
- What was/is its function?
- What are the (physical/health) conditions of the considered HC?
- Does it need any planning or restoration actions?
- What are the relations with the context?
- Are there transports/connections with urban areas?
- In which period was it built?
- How many buildings are there in this historical centre?
- How many people live in this historical centre?

### 5.1.2 General aims of the ontology

General reasons

It is commonly recognized that ontologies are very useful to create a common language to ensure semantic interoperability, building a unique and standard thesaurus that will let different disciplines and stakeholders talk together. This paragraph reports general reasons motivating the use of spatial ontologies to represent historical centres' elements and concepts. Noy & McGuinness (2001) states that the main reason to design ontologies is to share a common understanding of information structure among people and software artefacts. They are accommodating to enable the reuse of domain knowledge to avoid *"re-inventing the wheel"* and introduce standards to allow interoperability. Among various and general aims and scopes, for the ontology of this thesis, it is possible to identify the following two main reasons (Figure 50). The first one regards the necessity to exchange knowledge on historical centres among different stakeholders (1). The second one is related to the possibility of developing a semantic formalisation to support further analysis in AI and GI fields to manage the multitude of heterogeneous data nowadays scenario (2).

(1) To share a common understanding, studying and integrating the existing knowledge is fundamental. Noy and & McGuinness (2001) mentioned that the reuse of existing knowledge is crucial in the ontology creation approach. It allows the exchange of information among stakeholders involved in different tasks of an application. The first reason to design this ontology arises because existing ontologies in CH domain don't answer to the temporal and spatial documentation needs of HC. As explained before, the current documents and standards do not cover their conceptualisations and definitions. For example, some of them are too general to specify entities of urban and rural centres (as well as the CIDOC-CRM core ontology) and others with a too high level of detail (CityGML or IFC models). In this regard, this dissertation compasses the study of the existing domain (cultural heritage, architecture, history, geography) and task ontologies (restoration, conservation, risk prevention, urban design and planning) and their different conceptualisations to develop a new structure. Therefore, after analysing possible inconsistencies, the thesis tries to merge different conceptualisations. Integrating other ontological systems is crucial for the reuse and exchange of knowledge among different domains (as already underlined in Kavouras & Kokla (2007)).

(2) The second reason is connected to the current scenario of the massive amount of data availability and technology innovation. In particular, we refer to spatial information and computer science engineering (in the AI) fields. Developing a spatial ontology could help the interactions and integrations among different kinds of data. In the current scenario, with the extensive availability of spatial 2D and 3D data, heterogenety among data could be helpful for various tasks (data representation, data formats, conceptual model, logical models.). In this framework, semantic formalisation and organization of spatial knowledge could be helpful to support many methods and processes (e.g., information extraction, automatic recognition of geometries and entities, automatic segmentation of geometries and elements such as historical centres, building parts, roads and so on).

The following paragraph (5.1.3) clarifies the specific scope of this ontology development based on:

- the literature review on existing standards, vocabularies and ontologies for CH and spatial knowledge;
- the investigation of needs and competency questions of the various use cases and communities involved in historical centres' activities with different levels of granularity and details and, finally;
- the need for a practical instrument to connect multiscale data and semantically query these data.

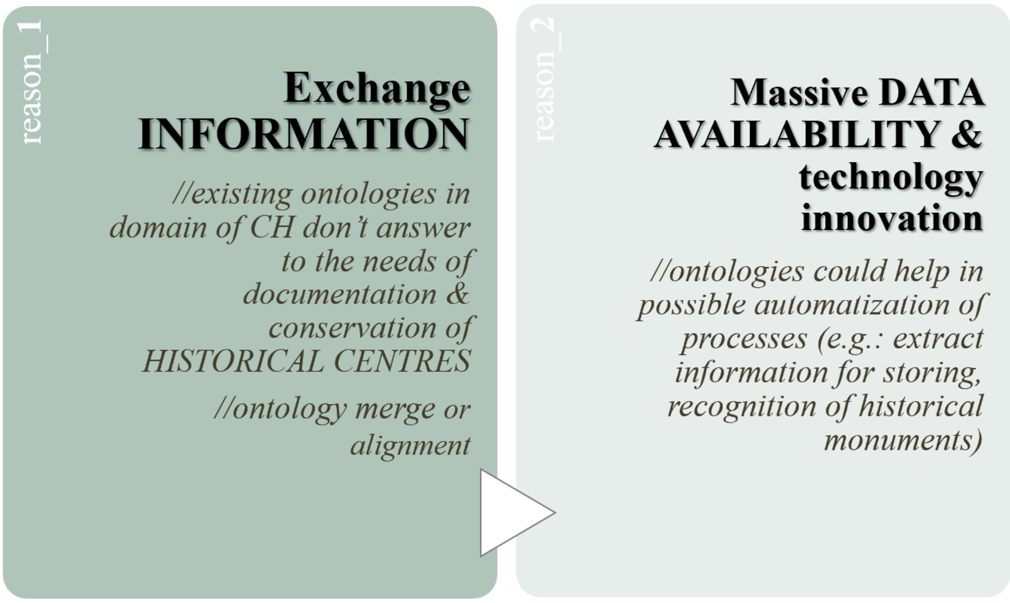



Figure 50. General reasons and scopes for ontology creation (Colucci et al., 2020).

### 5.1.3 The main scope of the ontology

*4. Scope:* spatial and temporal documentation of minor historical centres

One of the characteristics of a well-designed ontology is the "limitation of the scope". The ontology should not contain all the possible information about the domain, but it must fulfil a specific aim. It is unnecessary to specialize (or generalize) more than the concepts desired for an application. The scope of the ontology for the present thesis has been narrowed to the *documentation* purpose. Since it represents a considerable domain, the aim has been focused on the spatial documentation of historical centres to query multiscale spatial data and gather semantic information. Since documentation involves many experts and disciplines (as well as historians of architecture, cataloguing entities, heritage management), a more specific use case of ***urban HC and minor and abandoned HC temporal and spatial documentation*** has been identified. The task of temporal documentation is related to the "historical" intrinsic characteristic of the HC domain. The thesis focuses on concepts and features suitable to geometrically document and digitally represent the built heritage with different methods, applications and techniques (GIS, WebGIS, 2D/3D city models, and BIM). As mentioned before, built, historical and cultural heritage documentation is included in the multidisciplinary activity of conservation and valorisation. This domain is evolving and constantly growing due to the many factors affecting CH, cities and buildings (such as deterioration in time, natural and man-made hazards, climate change effects, evolving city planning dynamics, etc.). Generally, it is possible to assert that "documentation consists of the records procedures made by the experts of different areas" (ICOMOS & ISPRS, 2007; Letellier et al., 2007). For this purpose, the ontology will be the structure in which it will be possible to store knowledge to represent MHC.

This complex domain is also characterised by multi and interdisciplinarity tasks, various levels of detail, granularity and scale, and multiple information and multi-temporal factors. Thus, the research could evolve in future work of *3D spatial documentation* of HC (through 3D metric survey, digital twins, 3D city models representation). The 3D representation is considered a fundamental step in the workflow of spatial documentation (GCI, 2017; Letellier et al., 2007; Patias, 2006; Sammartano & Spanò, 2018).

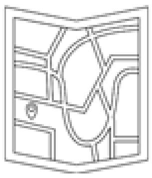
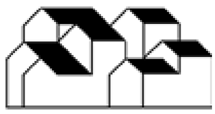
In many literature examples (Arp et al., 2015[79]; Grenon & Smith, 2004; Guarino, 1998), formal and geographic ontologies are usually developed independently from spatial data. They designed semantic geographic concepts without connecting them to spatial datasets. This thesis aims to go one step further in this vast and consolidated research scenario, linking the ontology structure to 2D, structured and unstructured data. This method allows the possibility to identify the spatial and geographical position of entities of HC. It aims to enable the opportunity to identify and detect, for example, the location of buildings in urban and rural centres and their spatial relation with the context. Moreover, the methodology aims to recognise information and properties related to entities using and applying semantic rules and queries. These rules allow inferencing data based on spatial relations or classification. In this way, this ontology could benefit the broadest community of web users and be valuable not only for geospatial data experts and scientists.

*Application ontology*

To achieve the scope of "HC spatial and temporal documentation", it is essential to identify the different levels of representation we intend to consider. The present thesis aims to design an ***application ontology*** because it integrated data from real case studies. Semantic rules and queries are applied to spatial data. To define the limits of an application ontology in the vast domain of CH, it is significant to clarify the different levels of detail and granularity. Furthermore, to consider all the possible use cases, it is essential to adopt a holistic view of the domain, including different levels of representation describing many aspects such as regional features, city elements, buildings, buildings features (Table 6).

[79] Basic Formal Ontology. https://mitpress.mit.edu/books/building-ontologies-basic-formal-ontology

Table 6. Levels of detail and granularity for existing knowledge in the domain of built heritage (Colucci et al., 2020).

| **Levels of representation** | **Relevant aspects** | **Existing ontologies/models** | **Level of granularity** |
|---|---|---|---|
|  | Territory<br>Landscape<br>Regional features | Spatial ontologies *(e.g., GEOSPARQL, INSPIRE)* | *Geometric:*<br>National area, regional area<br><br>*Semantic:*<br>Territory, landscape heritage |
|  | City and city parts<br>**Historical centres**, urban core, historical part of cities | Cultural Heritage ontology (CIDOC CRM)<br>Urban planning ontologies<br>City ontologies *(Towntolg* - Teller et al., 2007-, *CityGML)* | *Geometric:*<br>Cities, parts of city, city centres, buildings, roads, vegetations<br><br>*Semantic:*<br>architectural heritage, historical centres |
|  | Building and building parts | CH (CRMba) & Architecture ontologies (CityGML, IFC)<br>Archaeological ontologies (CRMarcheo) | *Geometric:*<br>Buildings and building parts, architectural elements<br><br>*Semantic:*<br>Built heritage, historical buildings, fortified structures, archaeological sites/heritage |

The semantic formalization of HC requires various semantic categories and rules describing specific components and related aspects, the particular shape and features of their parts and their mutual relationships. Different conceptualisations have to be analysed (see following paragraphs 5.2) to investigate the already defined classes with their definitions (Kokla et al., 2018). This analysis could be made starting from the available ontologies, standard data models, and vocabularies to illustrate the concepts, properties, relations, and rules related to this existing knowledge. It will be necessary to assess which of the available schemas will be the most suitable ones, or possibly use several of them connected, analysing them and possible individuating heterogeneities (Colucci et al., 2020). Due to the multiscale nature of the domain, before specifying concepts, properties and definitions, the different main entities and their connections are outlined in Figure 51.

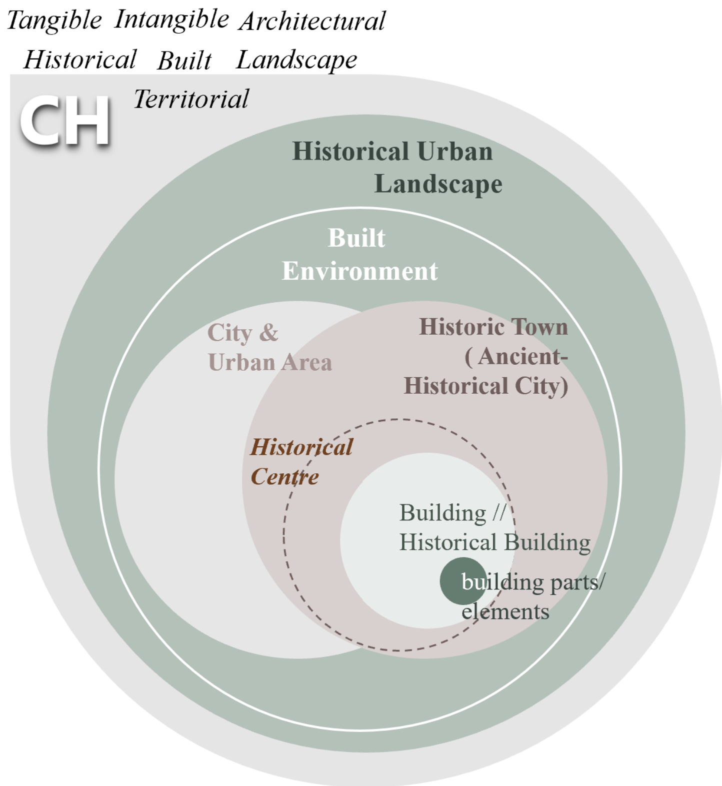



Figure 51. Connections between CH main classes, objects and concepts (Colucci et al., 2020).

## 5.2 Considering the reuse and defining classes

*The reuse*

The study and the analysis of Geospatial Semantics (Hu, 2017) reported ontology creation as one of its major research areas. During ontology engineering, one task aims to define the semantics of the "primitive terms, the atomic concepts that cannot be further divided" in different manners. Before defining these geographic semantic concepts, the thesis briefly lists the components of the geographic context. Kokla & Kavouras (2001) explained that these components are concepts types, relations, characteristics and properties. Concepts are existing or not-existing entities of a specific domain; they have properties or features, elements, attributes. These properties are essential to define unique semantic definitions of geographic terms in the spatial context. Semantic relationships, defined in Miller et al. (1990), can be classified into three main categories:

- *Synonymy,* for similar meanings of terms;
- *Hyponymy*, *subtype/supertype*. They inherit the properties of their super/generic concept;
- *Meronymy* expresses part-whole relation.

### 5.2.1 Semantic analysis from existing knowledge

By taking into account these premises, one of the first steps of ontological development regards the specification of concepts and their relations. This paragraph aims to reuse existing knowledge and interact with other ontologies to define entities, classes and relations for the present ontology of MHC. Following the guide of Noy and McGuinness (2001), this approach consists of different steps (Figure 52):

- consider existing conceptualisations;
- compare concepts and definitions among standards and enumerate the first important terms on historical centres;
- define classes and properties and evaluate inconsistencies.

However, there is no correct way to model a domain, so many alternatives result from an iterative process.


Figure 52. ONTOLOGY101 GUIDE (Standford University, Noy and McGuinness, 2001).

*Top-down approach*

As mentioned in Part I, there are different approaches aimed at ontology development. This dissertation starts with the top-down approach, defining the general concepts and specialising them. Following the different levels of the ontology (5.1.1), the methodology begins representing entities from general concepts of CH, landscape and cities, adding successively ontologies, data models, and vocabularies that specify concepts and characteristics of buildings (Figure 53).

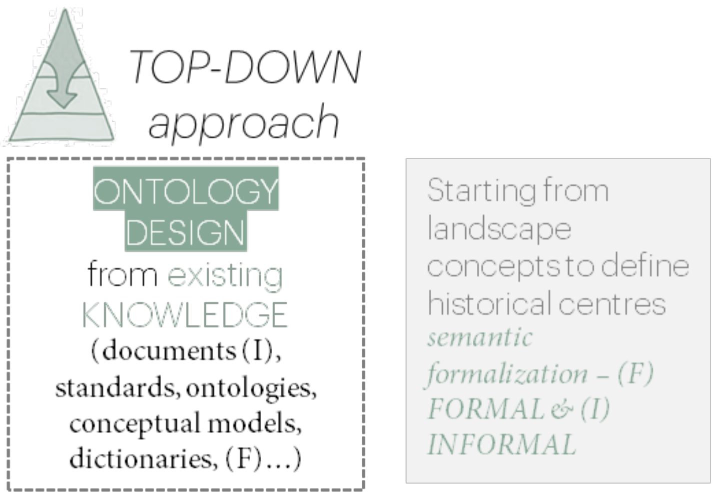



Figure 53. The top-down approach of ontology creation.

After the in-depth investigation of standards presented in Chapter 4, many concepts and classes have been extracted from already published information, thesaurus and documents. That analysis answer the scope of reusing existing knowledge. *Appendix A*, *Classes from standards, conceptualisations and books,* reports a list of all the classes selected from the diverse built heritage or geographic information standards. In particular, the concepts from standards for built heritage knowledge have been analysed and selected from UNESCO thesaurus (as classes), UNESCO Heritage Urban Landscape definition (2009), ICOMOS description of historic towns and urban areas (2011), NLUD (The National Land Use Database) meanings of buildings, the CIDOC-CRM core ontology on cultural heritage and its extensions on archaeological site, buildings and geographic objects, and the Getty Vocabulary of AAT (Art and Architecture). Concepts from Standards of Geographic Information derive from the GEOSPARQL ontology, CITYGML standard, conceptual model and ontology in RDF and the IFC standard described in OWL. Finally, after the literature investigation and the study of books related to historical centres meaning and evolution, many concepts have been selected with their definitions and semantics.

### 5.2.2 Comparing concepts and definitions among standards

*Comparing concepts*

Investigating the different *standards, literature and conceptualisations*, it is possible to notice that the same semantic terms have different definitions and similar terms have common descriptions. The following Table 7 reports an excerpt of a comprehensive list of terms in the multi-level domain of HC to evaluate the possible overlap between concepts. Definitions derive both form *standards and books* above analysed and *encyclopedias or articles* that better specify such terms. This comparison is significant to underline possible semantics similitude among terms. In this way, it is possible to select classes and add them to the ontology with their semantic descriptions and source. Moreover, this approach helps also in defining meronymy ("part-of") and "is-a" relations among classes (e.g., historical centres is a superclass of historical urban centres because it is a specification of the concepts with a different connotation).

Table 7. Excerpt of comparison of similar concepts (grouped with matching colours) from different definitions and standards.

| CONCEPTS | DEFINITIONS (if available) or group | SOURCES |
|---|---|---|
| CITY | *Distinctions among **villages, towns, and cities** are relative and vary according to their regional contexts. Generally, cities designate large or important communities with population, status, and internal complexity greater than most towns in the region* | *GETTY AAT*[80] |
| URBAN AREA | *Areas within city limits or closely linked to them by common use of public utilities or services* | *GETTY AAT* |
| | *spatial structures that express the evolution of a **society and of its cultural identity*** | *ICOMOS, 2011* |
| BUILT ENVIRONMENT | *It refers to the aggregates of human-made structures, infrastructural elements, and associated spaces and features*<br>*The Built Environment hierarchy includes terms for the built and natural environment, covering constructed works and natural landscapes, forming a continuum from the most significant natural landscapes and settled areas to the smallest of individual built works* | *GETTY AAT* |

[80] https://www.getty.edu/research/tools/vocabularies/aat/

| CONCEPTS | DEFINITIONS (if available) or group | SOURCES |
|---|---|---|
| BUILDING | *A substantial and permanent construction with a* ***roof and walls for giving shelter, e.g. house, office, shop, warehouse, factory, church, barn*** | *NLUD*[81] |
| | *Concept: Architecture - Group: Culture > Visual arts* | *UNESCO THESAURUS*[82] |
| ARCHITECTURAL HERITAGE | ***Built works*** *transmitted inter-generationally within a society and that are invested with significance in that society.* | *GETTY AAT* |
| | *An architectural heritage can be interpreted as an "artefact", where its elements are witnesses of the cultures, actors, and of events occurred during the life of the building* | *Brusaporci, 2020* |
| BUILT WORK | *This class comprises instances of man-made things such as freestanding buildings, components of buildings, and complexes of buildings. It refers to man-made environments, typically large enough for humans to enter, serving a practical purpose, being relatively permanent and stable (AAT). Instances of built works are composed of parts that share an aspect of role, which often perform a distinct function.* | *CIDOC-CRM BA*[83] |
| | *A general term used to refer to freestanding* ***buildings, components of buildings, complexes of buildings, other structures****, or a man-made environment, typically large enough for humans to enter, serving a practical purpose, being relatively permanent and stable, and usually considered to have aesthetic value* | *GETTY AAT* |
| MONUMENT | *concept: Architecture - Group: Culture > Visual arts* | *UNESCO THESAURUS* |
| HISTORIC TOWN | *Evolution of a society and of its cultural identity Historic sites are an integral part of a broader natural or man-made context and the two must be considered inseparable* | *ICOMOS 2011* |
| HISTORICAL URBAN LANDSCAPE | *The urban area understood as the result of a historical layering of cultural and natural values and attributes, extending beyond the notion of historical centre or ensemble* | *UNESCO 2011* |
| HISTORICAL LANDSCAPE | *Cultural landscapes that are significant in the history of landscape architecture or gardening or that were developed as a result of historic use of natural features; includes shaped areas of land and sometimes structures* | *GETTY AAT* |
| HISTORIC CITY | *historic city is the one that, with the stratification of its monuments and the entire urban fabric, exemplary reflects the historical, anthropological, cultural and artistic evolutionary process of which it was the protagonist* | *Dezzi Bardeschi, 1998* |
| | *Concept: Ancient cities - Group: Social and human sciences > Human settlements and land use* | *UNESCO THESAURUS* |

[81] https://discovery.nationalarchives.gov.uk/details/r/C16828
[82] http://vocabularies.unesco.org/browser/thesaurus/en/
[83] http://www.cidoc-crm.org/crmba/home-7

| CONCEPTS | DEFINITIONS (if available) or group | SOURCES |
|---|---|---|
| HISTORIC BUILDING | *Buildings that are significant in the history of architecture, incorporate significant architectural features, or played significant historic roles in local cultural or social development; may or may not be officially designated For buildings that are abandoned but not considered necessarily historical, use "abandoned buildings* | *GETTY AAT* |
| | *A historical building is a complex system of spaces, volumes, materials, surfaces, constructive aspects, actual and past functions and configurations, degradation, etc. The whole is the result of a continuous historical process of modification and transformation* | *Brusaporci, 2020* |
| HISTORIC MONUMENT | *Refers to monuments with local, regional, or international political, cultural, or artistic significance.* | *GETTY AAT* |
| | *Concept: Monument - Group: Culture > Visual arts* | *UNESCO THESAURUS* |
| CULTURAL CENTRE | *Public buildings, sites, or complexes set aside for activities related to the culture of an area, such as music, dance, drama, or fine arts.* | *GETTY AAT* |
| HISTORICAL CITY CORE | *Core of a city that constitutes a complex linked to particular historical moments due to formal, typological and urban characteristics. Sometimes the concept of the historic centre is extended to the whole city, when it represents a living testimony of other eras* | *Dizionario Enciclopedico di Architettura e urbanistica, 1969* |
| HISTORICAL CENTRE | *The oldest part of an urban settlement, generally the richest in historical evidence; in urban planning* | *Dizionario Treccani XXI century, 2021* |
| | *historical centers" the "complexes of properties that form a characteristic appearance having aesthetic and traditional value* | *Bottai Laws* |
| | *A historical centre, however, as well as the neighborhoods of the new city connected to it, continues to live; it has its own population which often carries out its work activities within the center itself, maintains social and political relationships and cultural exchanges; has its own face validly expressed through the architectures and the environment formed by them.* | *Fano, 1974* |
| | *centres comprising a considerable number of cultural heritages called "monumental centres"* | *Unesco, 1954* |
| | *A historical centre is the place of people traditions and culture* | *GETTY AAT* |
| HISTORICAL QUARTER | *Urban areas that are historically significant and retain characteristics and buildings from an historical period or periods* | *GETTY AAT* |
| URBAN CENTRE | *An urban center, both old and new, in fact represents an entity with life (in the broadest sense that can be attributed to this expression* | *Fano, 1974* |
| URBAN CORE | *Urban core is a large urban area The urban core must have a population (based on the previous census) of at least 100,000 persons* | *Geographic Definition, 1996* |
| URBAN HISTORICAL CENTRE | *They are urban settlement structures that constitute a cultural unit or the original and authentic part of settlements and testify to the characteristics of a lively urban culture For them, the law must provide adequate instruments, both financial and operational* | *Astengo, 1967* |

| CONCEPTS | DEFINITIONS (if available) or group | SOURCES |
|---|---|---|
| SUBURB | *Compactly developed or developing, usually residential, areas on the outskirts of a central city; distinguished from central cities by their more homogeneous socio-economic and physical character, although rarely is there an identifiable boundary between suburbs and central cities* | *GETTY AAT* |
| | *Concept: Social and human sciences > Human settlements and land use - Urban areas* | *UNESCO THESAURUS* |
| NEIGHBORHOOD | *Residential areas within a larger town or city, more or less cohered into integral communities having their own shops and other facilities, and other distinguishing characteristics* | *GETTY AAT* |
| CENTRAL CITY | *Largest core areas within the incorporated limits of metropolitan areas; often used to distinguish the center from the suburban or newer outlying sections of metropolitan areas; generally excludes the central business district and inner city sections* | *GETTY AAT* |
| SMALL TOWN | *Social and human sciences > Human settlements and land use – Urban Area* | *UNESCO THESAURUS* |
| | *Used to refer to small social groups where ordinary people live* | *Cambridge Dictionary* |
| HAMLET | *Small rural centers that contain basic community, education, and religious facilities generally do not exceed 250 residents; may also refer to the smallest incorporated units of a municipal government* | *GETTY AAT* |
| VILLAGE | *Distinctions among villages, towns, and cities are relative and vary according to their individual regional contexts Villages generally designate units of compact settlement, varying in size but usually larger than hamlets and smaller than towns and distinguished from the surrounding rural territory* | *GETTY AAT* |
| OLD CITY | *Old City often refers to an old town, the historic or original core of a city or town The oldest part or historic centre of a city, usually contained within its modern limits* | *Oxford Dictionary*[84] |
| ANCIENT CITY | *Ancient cities were in origin clubs of warrior-farmers, whose membership (citizenship) and political participation were predicated on their ownership of land in the community's territory and who supplied their own armoury* | *Zuiderhoek, 2016* |

In addition, to underline how the investigated existing standard and literature in the domain in CH, cities and HC should be integrated into the MHC ontology, a schematic view (Table 8) from Colucci et al. (2020) has been reported. The schema also demonstrates as international standards are based on the existing literature. The table lists general terms and shows different application areas (such as CH, GI,

[84] https://www.lexico.com/definition/old_city

archaeology, restoration, scientific area, …), related concepts (super class or sub class), and comments and remarks highlighting inconsistencies and problems. The main issues are reported in column *Comments,* and the following points are listed (in the bulleted list):

- Concepts related to HC;
- Level of representation (related to Table 6: (A) territory, landscape; (B) Cities and parts of cities; (C) buildings and parts of buildings);
- Formal/non-formal representation;
- Granularity;
- Explicit spatial concepts.

Table 8. Investigating issues and inconsistencies in existing conceptualisations

<table>
<tr><th>Existing knowledge</th><th>Application area</th><th>Concepts Related to Historical Centres (HC)</th><th>Definitions (with different levels of detail)</th><th>Comments</th></tr>
<tr><td>ICOMOS</td><td>CH</td><td>Historic Town and Urban Area</td><td>evolution of society and its cultural identity</td><td>- no concepts that directly express HC<br>- level of representation A/B<br>- no formal representation/only natural text language<br>- no enough granularity<br>- no spatial information</td></tr>
<tr><td rowspan="3">UNESCO</td><td rowspan="3">CH</td><td>Ancient city → Historic city</td><td>-</td><td rowspan="3">- historical centres are considered<br>- level of representation A/B<br>- no formal representation/only natural text language<br>- no enough granularity<br>- no spatial information</td></tr>
<tr><td>Historic Urban Landscape</td><td>result of historical layering of cultural and natural values and attributes</td></tr>
<tr><td>Historical Centres</td><td>centres comprising a considerable number of cultural heritages called "monumental centres"</td></tr>
<tr><td rowspan="4">CIDOC-CRM core</td><td rowspan="4">CH</td><td>Man-Made Thing → Physical Man-Made Thing → Man-Made Object</td><td>physical objects purposely created by human activity</td><td rowspan="4">- no concepts that directly express HC<br>- level of representation A<br>- ontology and related formal representation<br>- some levels of granularity are represented<br>- location information is included</td></tr>
<tr><td>CRM Entity → Observable entity → temporal entity → State → Condition State</td><td>states of objects characterised by a specific condition over a timespan</td></tr>
<tr><td>Physical Feature → Site</td><td>pieces of land or seafloor</td></tr>
<tr><td>CRM Entity → Place</td><td>extents in space</td></tr>
</table>

| Existing knowledge | Application area | Concepts Related to Historical Centres (HC) | Definitions (with different levels of detail) | Comments |
|---|---|---|---|---|
| CRM archeo | archaeological excavations | Matter Removal → Observations → Archaeological Excavations | *general concept of archaeological escalation intended as a coordinated set of excavation process units* | - no concepts that directly express HC<br>- formal representation<br>- detailed level of concept and relations (A/B)<br>- some levels of granularity are considered/possibility for ontology extension with other CIDOC-CRM ontologies<br>- geographic query language |
| GEOSPARQL | GI | Spatial Object | *it represents everything that can have a spatial representation. It is a superclass of feature and geometry"* | - no concepts that directly express HC<br>- already integrated into the CIDOC-CRM geo<br>- many levels of detail are considered (A/B)<br>- no levels of granularity are represented<br>- valid for spatial documentation and geographic query language |
| | | Geometry | *it defines a vocabulary for asserting and querying information about geometry data, and it defines query functions for operating on geometry data* | |
| | | Feature | *it represents everything that can have a spatial representation. It is superclass of feature and geometry* | |
| CRM geo | GI | Information Object → Geometric Place Expression | *definitions of places by quantitative expressions* | - concepts of HC don't exist explicitly<br>- formal representation<br>- some level of granularity<br>- detailed level of concept and relation<br>- useful for a spatial documentation |
| | | Place → Declarative Place | *instances of places* | |
| | | Spatial Coordinates Reference System | - | |
| | | Phenomenal Place | - | |
| CRM sci | scientific knowledge | Observation → Measurement | *actions measuring instances* | - concepts of HC don't exist explicitly<br>- formal representation<br>- not enough granularity<br>- formal representation<br>- specific for documentation |
| | | Observations | *activity of gaining scientific knowledge about particular states of physical reality through empirical evidence, experiments and measurements* | |

| **Existing knowledge** | **Application area** | **Concepts Related to Historical Centres (HC)** | **Definitions (with different levels of detail)** | **Comments** |
|---|---|---|---|---|
| CRM ba | archaeological buildings | built work → single built work | *buildings, components of buildings, and complexes of buildings. It refers to man-made environments* | - concepts of HC don't exist explicitly<br>- formal representation/detailed level of concept and relation<br>- level of representation B/C<br>- some level of granularity<br>- useful for documentation |
| (Acierno et al., 2017, 2019) | conservation & restoration | **Historical centre** → Historical Buildings | - | - HC concept<br>- formally expressed<br>- restoration purposes<br>- no high level of granularity<br>- spatial component is not present |
| | | Artefact_Entity | - | |
| GETTY AAT Vocabulary | art and architecture | built environment | *constructed works and natural landscapes* | - HC are expressed<br>- level of representation A/B/C<br>- high level of granularity<br>- very detailed definitions of concepts<br>- formally represented<br>- no spatial concepts |
| | | built environment → settlements and landscapes → cities | *Distinctions among villages, towns, and cities are relative and vary according to their regional contexts* | |
| | | Tangible cultural heritage → architectural heritage | *Built works transmitted intergenerationally within a society, and that are invested with significance in that society.* | |
| | | single built work (built environment) → historic building | *buildings that are significant in the history of architecture* | |
| | | single built work (built environment) → monuments → historical monuments | *monuments with local, regional, or international political, cultural, or artistic significance* | |
| | | single built work (built environment) → fortifications | *General term for any works made to oppose a small number of troops against a greater* | |
| | | fortified settlements | *Settlements of any kind with defensive structures such as moats, enclosures, or ramparts* | |

| Existing knowledge | Application area | Concepts Related to Historical Centres (HC) | Definitions (with different levels of detail) | Comments |
|---|---|---|---|---|
| CityGML | cities and buildings (GIS) | CityObject → Site → AbstractBuilding → Building | *It allows the representation of thematic and spatial aspects of buildings, building parts and installations in four levels of detail, LoD1 to LoD4* | - concept of buildings and cities are defined<br>- formal representation<br>- level of representation B/C<br>- different levels of detail for buildings representation<br>- not intended for heritage<br>- spatial knowledge is included |
| | | Building → Building parts | | |
| IFC | buildings and buildings part (BIM) | IfcSite → IfcBuilding | *A building represents a structure that provides shelter for its occupants or contents and stands in one place* | - concept of buildings are defined<br>- level of representation C<br>- formal representation<br>- not intended for heritage<br>- high level of granularity/detail<br>- spatial knowledge is included |
| | | IfcSite → IfcBuilding → IfcBuildingElements | *The building element comprises all elements that are primarily part of the construction of a building* | |

## 5.2.3 Definition of ontological rules

These paragraphs describe the process of ontologies merging and the creation of classes, properties and constraints. For this purpose, the Protégé software[85] (version 5.5.0) has been selected. It is a "free, open-source ontology editor and framework for building intelligent systems". It supports the OWL 2 Web Ontology Language and "direct in-memory connections to description logic reasoners like HermiT and Pellet" useful to validate the correctness of the ontology. Protégé is available also online as WebProtégé[86].

The first version of "geographical ontology for the spatial documentation of minor and abandoned historical centres" had the IRI (Internationalized Resource identifier):

- *http://www.semanticweb.org/betti/ontologies/2020/5/minor_historical_centres_v1*

[85] https://protege.stanford.edu/
[86] https://webprotege.stanford.edu/

It has been changed in the following phases to store the ontology online using a stable URI. The ontology file has been saved in .owl format (OWL2). For graphically visualising the Web Visual OWL's ontology structure[87] (version 1.1.7) has been selected (Lohmann et al., 2016).

#### 5.2.3.1 MHC ontology rules

Before starting adding concepts and relations in Protégé, some rules have been set for MHC ontology, taking into account the scope of my ontology:

- classes are expressed with “singular” terms;
- IS-A relations are hierarchies (inheritance concept super-classes/sub-classes);
- new meronymy, “part-of” relations are codified adding one number and the letters (the initials of the two tables related) before the world “has-part” or “is-part-of” (e.g., 01_CH_has-part);
- words, properties and definitions are expressed in Great Britain English (e.g., historical centres – not historical centers);
- classes can have more than one superclass because Protégé (and OWL) supports multiple-inheritance;
- entities have different “roles”. They could be ABSTRACT (without instances) or CONCRETE (with data/instances);
- semantic descriptions of concepts have been added as “rdfs:comment” with their source (e.g., Getty ATT, HC books, CIDOC-CRM and so on);
- the concepts historic and historical are intended as the same adjective “historical”, with the meaning “concerning history or belonging to the past”.

In OWL 2, there are axioms (basic statements), entities (real-word objects) and expressions (combinations of entities). In Protégé, it is possible to define:

- classes as entities;
- instances or individuals as data (rows);
- properties divided in object properties (relations among classes), data properties (attributes, characteristics of classes) and datatypes (typology of data, e.g. character varying, integer);
- annotations (to define and describe entities);
- restrictions or constraints (defined in owl as “all Value from”, “some Value from” and “has Value”).

Figure 54 shows some information of MHC ontology in Protégé.

[87] http://vowl.visualdataweb.org/webvowl.html, https://github.com/VisualDataWeb/WebVOWL

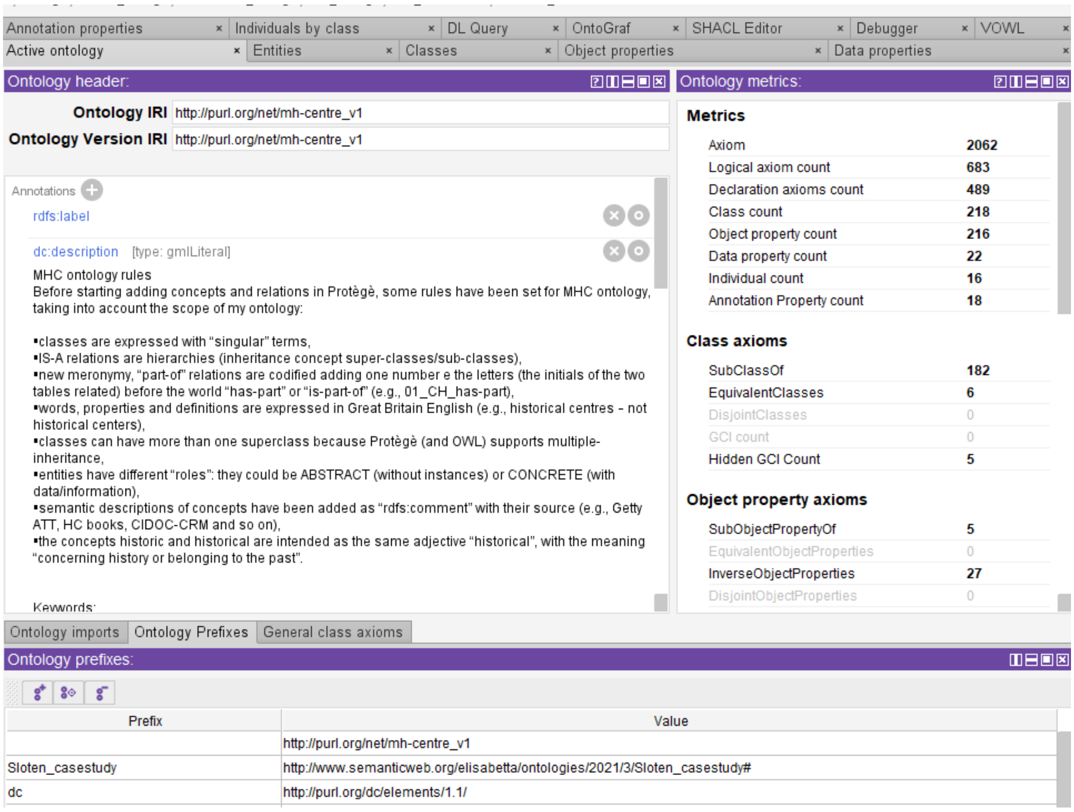



Figure 54. Protégé information (ontology version, IRI, metrics, prefixes, …) of MHC ontology.

Moreover, from the CIDOC-CRM Documentation (Doerr, Bekiari, et al., 2020) concepts of "endurant, perdurant" and "disjointness" have been selected. They are:

- Endurant, perdurant:

"The difference between enduring and perduring entities is related to their behaviour in time. Endurants are wholly present at any time they are present. Perdurants are entities that happen in time and can have temporal parts (all their parts are fixed in time)" (Gangemi et al., 2002).

- Disjointness:

"Classes are disjoint if they share no common instances in any possible world. That implies that it is not possible to instantiate an item using a combination of classes that are mutually disjoint or with subclasses of them" (Doerr, Bekiari, et al., 2020).

### 5.2.3.2 General steps of the ontology engineering

*Steps of the ontology engineering*

In addition to the Ontology Guide (Noy and McGuinness, 2001), the present methodology follows a specific workflow. The main steps of this procedure to develop the spatial ontology are reported:

- Individuate different areas of the domain ontology (below explained);
- Merge of the concepts, with Protégé tools, related to Cultural and Historical Heritage from UNESCO, ICOMOS and NLUD definitions;

- Compare other existing ontologies in Protégé (such as CIDOC-CRM and its extensions, GEOSPARQL, …);
- Add to the ontology new concepts and definitions from books and literature of MHC;
- Merge of other conceptualisations, new terms, ontologies and standards (such as CityGML and IFC) in Protégé using different tools and methods;
- Add classes, data properties, object properties from other standards and ontologies and start to create documentation;
- Add instances and new classes from structured and unstructured sources with ontology enrichment, mapping and population methods (Chapter 6).

#### 5.2.3.3 Different areas of MHC ontology

*Areas of the application domain ontology of MHC*

It has been crucial to define different *areas* in the domain of minor historical buildings to design the ontology structure. Identifying such groups, the entire process of selecting and creating terms for the domain ontology has been straightforward and linear without repetitions of concepts and incongruences. In addition, this approach allows the ontology implementation and reuse for other future purposes and specific domains about CH and HC activities. These areas are the following:

- ***History and Time***. It expresses the historical point of view of concepts and their evolution in time. It includes temporal entities, actors of the past periods and the definition of classes related to the past. This topic considers the conceptualisations of existing concepts from the Getty Art and Architecture vocabulary, books on concepts and evolution of HC and cities, UNESCO definitions and thesaurus, CIDOC-CRM ontology, ICOMOS documentation, NLUD database.
- ***Spatial Documentation***. It regards the definition of geometries and geographical concepts to the ontology. The topics of geographical and territorial context, geometry types definition and elements of buildings and cities have been selected. Different standards help to represent spatial concepts, such as GEOSPARQL, CIDOC-CRMsci, CIDOC-CRMgeo, CityGML ontologies, IFC standards, Getty Thesaurus of Geographic Names [88] and GeoNames[89]. Some of these conceptualisations have been included in the MHC ontology. This area also includes sub-areas of ***2D and 3D data*** and ***Transport and Networks*** connecting cities to rural, marginal and inner areas. This task is related to the historical one since many concepts express both spatial and temporal value.

[88] https://www.getty.edu/research/tools/vocabularies/tgn/
[89] http://www.geonames.org/

- ***Demographic Aspects.*** Definition of aspects related to populations. It is strictly linked with the Historical and Administrative tasks. Some data sources derive from national and local bodies, administrations and entities (CIDOC-CRM core, ISTAT, Getty, …).
- ***Environmental and Risk data.*** They have not been considered for the present ontology but, as part of HC context and scenario (especially in risk areas), some concepts from INSPIRE data model, CRED[90] classification and UNDRR[91] documentations could be further included.
- ***Administrative Entities.*** The concepts of this area derive from national and local organisations and associations, public bodies and local administration. These classes, not included for the moment in MHC ontology, would be implemented in future for possible planning activities, building permits and restoration actions.

These areas are not considered a distinct group, but they are all connected and related (Figure 55). Many classes and entities express more than one topic.

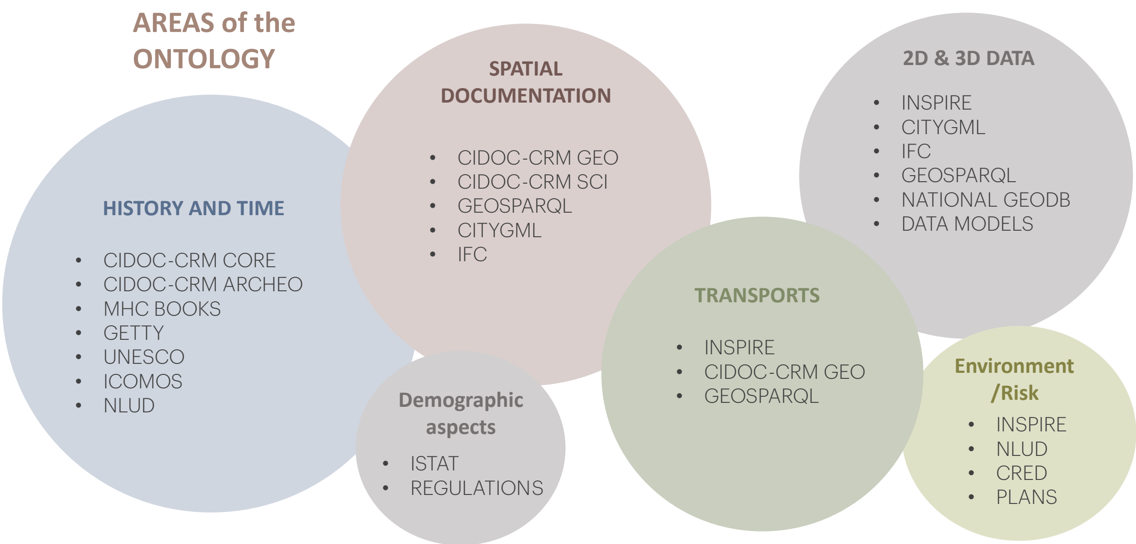



Figure 55. Ontology of HC areas connections and different conceptualisations.

#### 5.2.3.4 Ontology merge and alignment of MHC ontology

Since this ontology results from different existing conceptualisations, different ontology merges and alignment strategies have been considered to enhance the reuse of existing knowledge. To achieve the *ontology mapping and integration*, as reported in (Ehrig & Staab, 2004; Ekaputra et al., 2017), Protégé offers different tools and plug-in. The first algorithm considered is the *merge-ontology* one. It has been used to merge one ontology into another one. It has been helpful, especially

[90] https://www.cred.be/
[91] https://www.undrr.org/

for CIDOC-CRM ontologies conceptualisations. Then, the *ontology difference* or *compare ontology* tool has been selected to verify new concepts compatibility comparing different ontology versions. For example, the first version of MHC ontology has been merged with historical centres concepts from books definitions and GEOSPARQL and CIDCOC core ontologies. Hiebel et al. (2013) presented an example of the integration of standards as well. Finally, the most helpful Protégé tool used is *"copy/move/delete axioms"*, choosing axioms by definitions. It has been adopted to import the singular entity, the property and relations into the thesis ontology. In this way, it was possible to deeply study the existing models and consider only entities or values that adequately express the selected domain.

## 5.3 First result: the ontology structure

As explained before, the ontology process considered in defining semantic classes, selecting by other ontologies or creating them, defining relations among them and their semantic properties. Relations are integrated and imported from existing ontologies or standards or *ad-hoc* created to connect classes of the MHC ontology. In this way, the first draft of the ontology has been completed. Terminology used into this methodology and adopted by Protégé are: classes, subclasses, superclasses, properties and subproperties, "is equal to", annotation (such as scope note, source, description), "inverse of", domain and range. The following paragraphs explain all the steps made in Protégé to design the MHC ontology.

*Ontology design steps in Protégé*

The first step consists of the definition of classes. They have been defined as "entities" under the identifier owl:Thing. Classes were designed following a hierarchy (with superclasses and subclasses). Every class defined is a subclass of owl:Thing[92]. Each class, imported or created as new, has its proper IRI or URI, providing a simple and extensible way to identify a resource. For example, concepts imported from the CIDOC-CRM ontologies have the IRI *http://www.cidoc-crm.org/cidoc-crm*, concepts from CRM-geo ontology *http://www.ics.forth.gr/isl/CRMgeo, IFC classes http://www.buildingsmart-tech.org/ifcOWL/IFC4_ADD,* and CityGML classes the *IRI http://www.opengis.net/citygml/2.0.* New classes have as provisional IRI http://www.semanticweb.org/betti/ontologies/2020/5/minor_historical_centres_v1 (see 5.2.3). Each class also has a semantic description specifying the source of the entity and its definition (Figure 56).

After defining classes, properties have been added as "object properties" with a *Range* and a *Domain*. An example is: "hamlet" "has value" "cultural and natural values and attributes", where "has_value" is the object property, "hamlet" is the Domain and "cultural and natural values and attributes" is the Range (Figure 57 and Figure 58). Moreover, properties can be defined as a specialization (sub-property) of an existing property. After that, "object properties" and "data types" have been

[92] https://www.w3.org/TR/owl-guide/

determined to specify characteristics of objects (such as dimension, duration, historical, ancient, …) or types of data (such as literal, boolean, …).

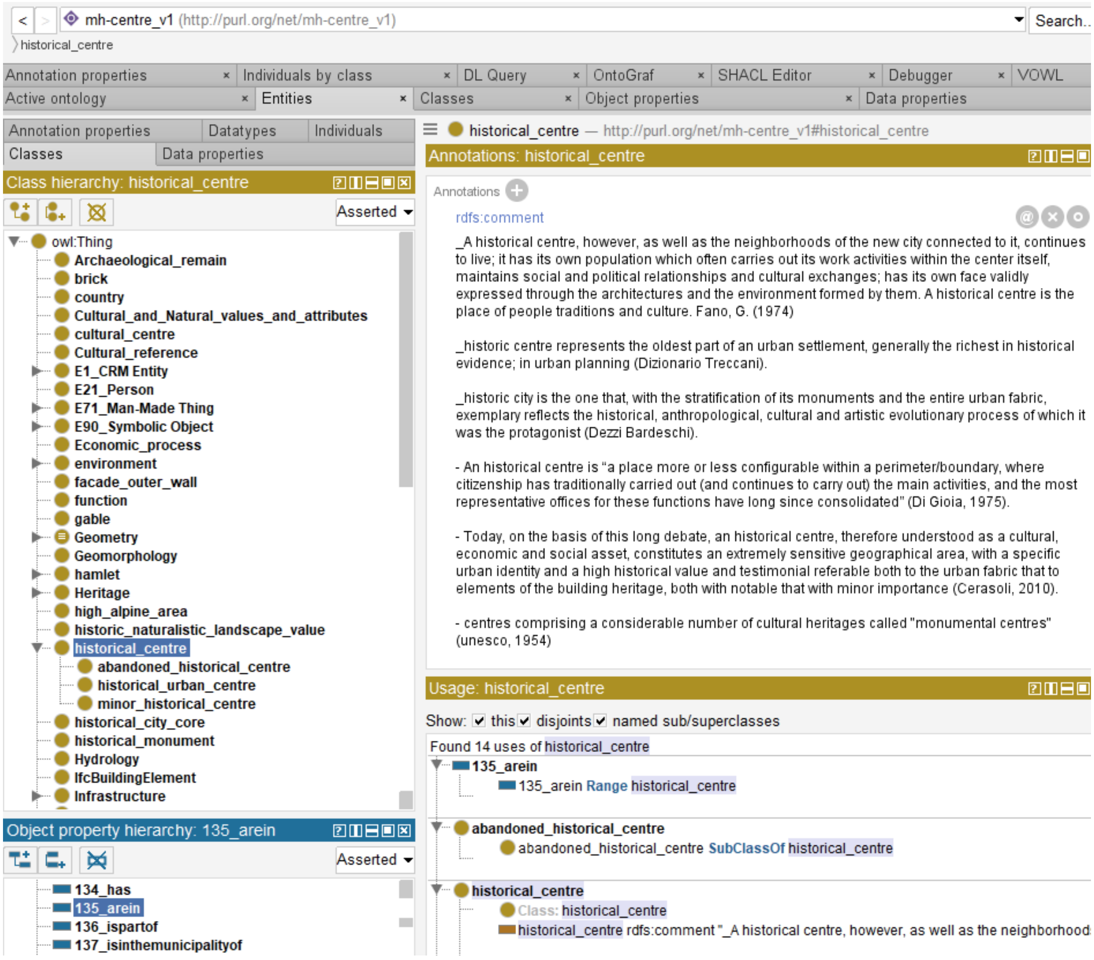



Figure 56. "Historical centre" class in Protégé, with its semantics definitions and usage.

To check ontology inconsistencies (such as entities with no subclasses or properties), it is possible to use some ontology viewer. They allow visualising the ontology as a graph, in which entities are expressed as circles or rectangles and connected to the other classes with different arrows (relations). One of these tools is already implemented into Protégé, and it is OntoGraf. By selecting entities, it is possible to visualize them in a graph interface directly. Another tool is WebVOWL[93], now available in GitHub[94]. Figure 59 and Figure 62 show examples of these graphs.

Finally, a documentation with all the classes, properties, relations and instances of the ontology can be exported with the tool "exportOWLdoc" of Protégé. The ontology documentation (Figure 60) reports all the classes and properties implemented. This ontology documentation exported from the software will be published online to make the ontology open and available (see Chapter 7).

[93] http://vowl.visualdataweb.org/webvowl.html
[94] https://github.com/VisualDataWeb/WebVOWL


Figure 57. Example of object properties in OntoGraf, Protégé.

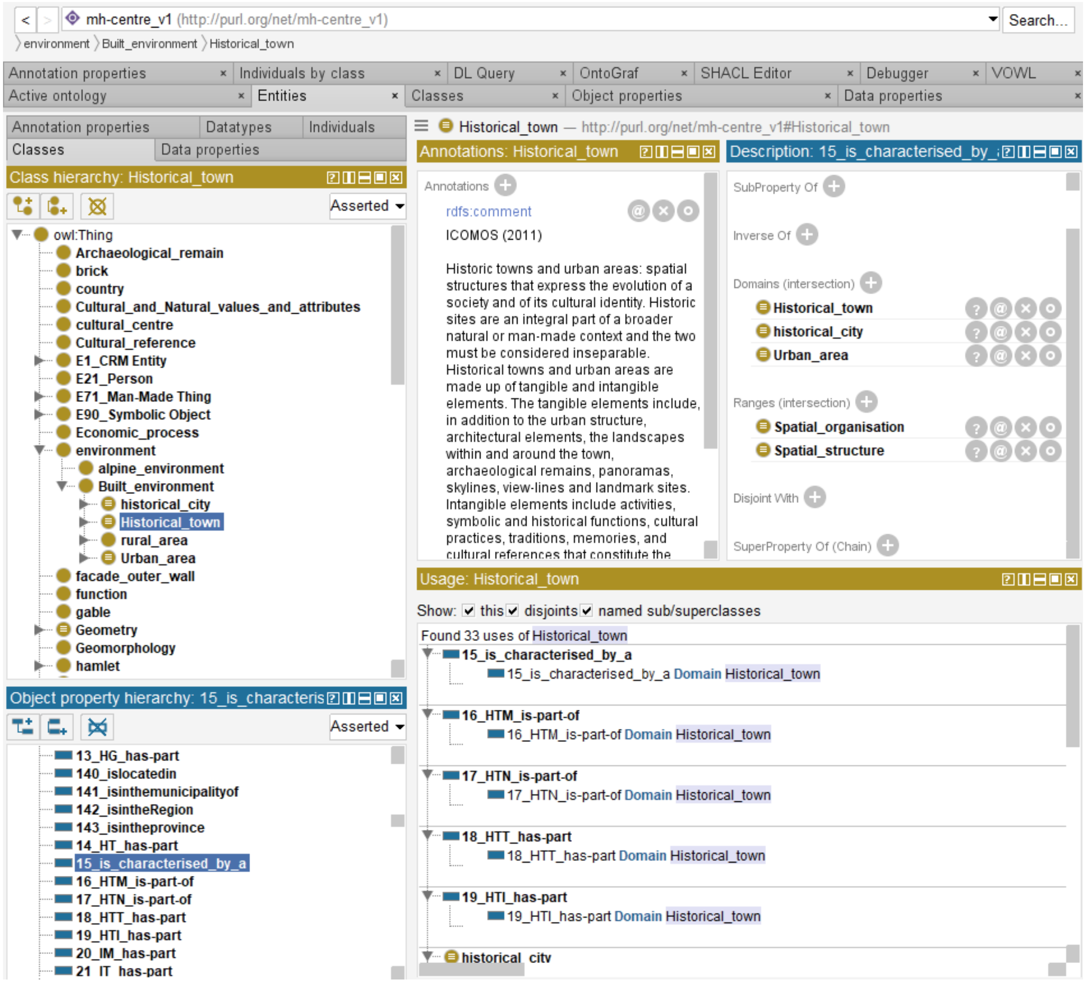



Figure 58. Example of property: "historic town" class and its relation with "spatial structure", "is characterised by".

Another important step of the ontology design process regards the ontology validation by applying some reasoners and tools. The first one here adopted is the HermiT-OWL reasoner (1.4.3.456)[95], available in Protégé 5. It generates a log file in which it is possible to visualize all the information of the ontology. Furthermore, it directly highlights classes or properties showing inconsistencies or incongruencies. All the issues for the MHC ontology (version 1) have been solved. The second validator was used to check if the ontology is correctly generated according to the OWL 2 standard. It is the OWL 2 Validator[96]. Figure 61 shows the correctness of the OWL file of the MHC ontology.

[95] http://www.hermit-reasoner.com/
[96] http://visualdataweb.de/validator/

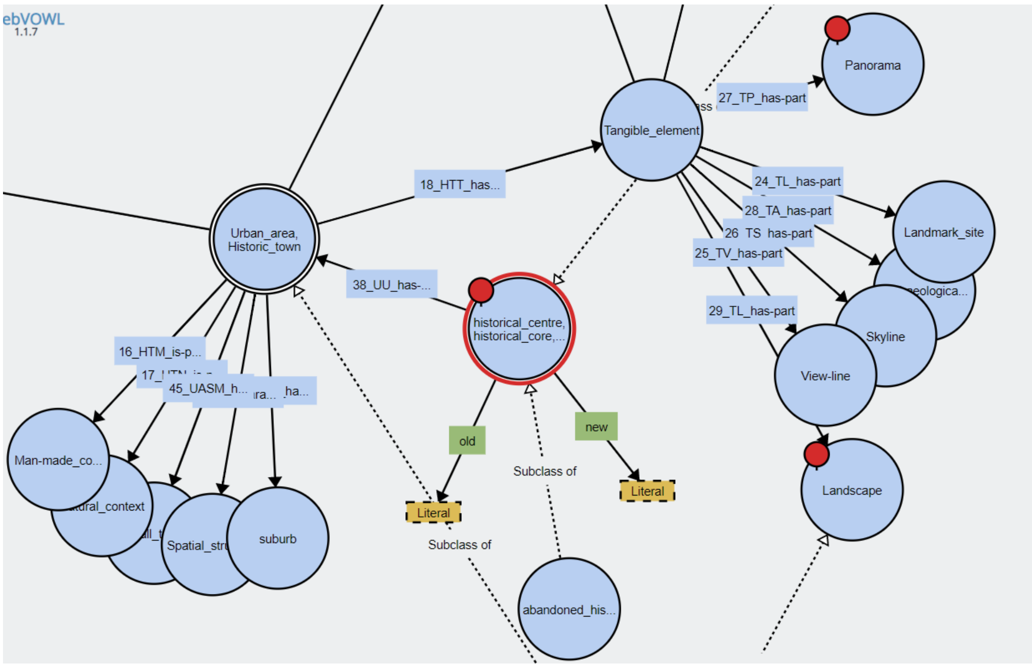



Figure 59. Excerpt of the ontology graph in the WebVowl viewer (old online version, now deprecated).

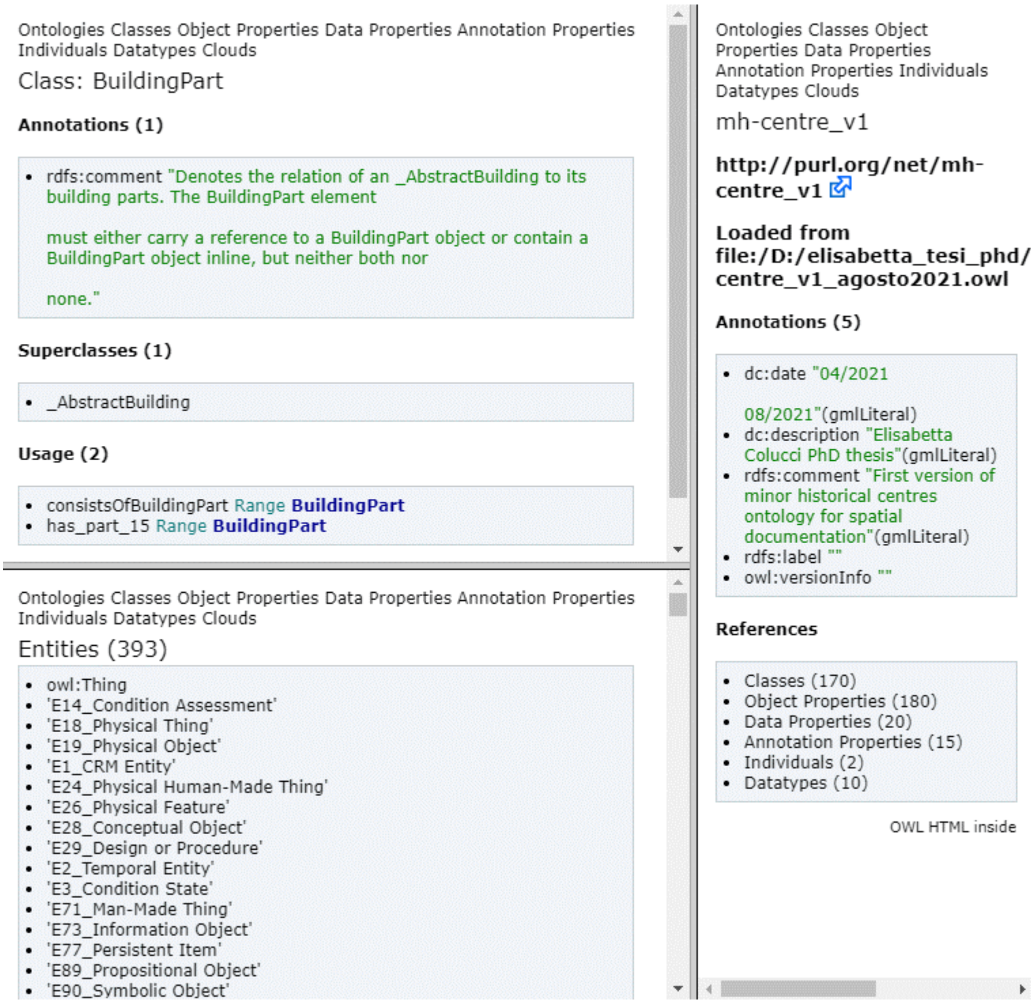



Figure 60. Ontology documentation online.

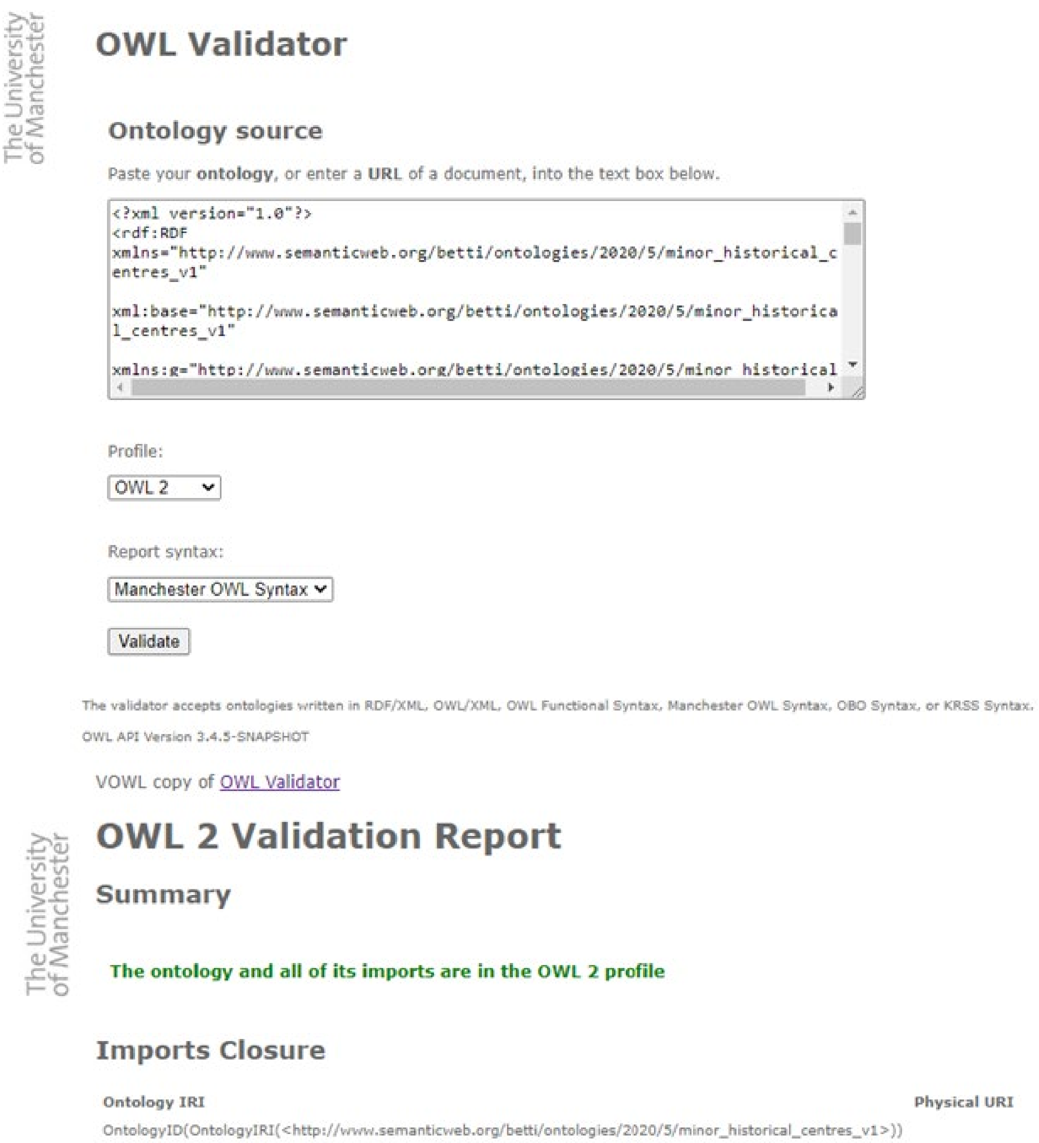



Figure 61. OWL 2 validator developed by the University of Manchester.

Figure 62, a screenshot of the WebVowl viewer (now deactivated[97]), shows the complexity of the graph and the relations (meronymic or “is-a”) which characterised the MHC ontology (version 1). Different colors express entities belonging to many standards and ontologies, here integrated and merged. On the right it is possible to visualize information details and descriptions of the Minor Historical centres ontology. The image is reported just to see the complexity of the structure.

[97] http://vowl.visualdataweb.org/webvowl.html

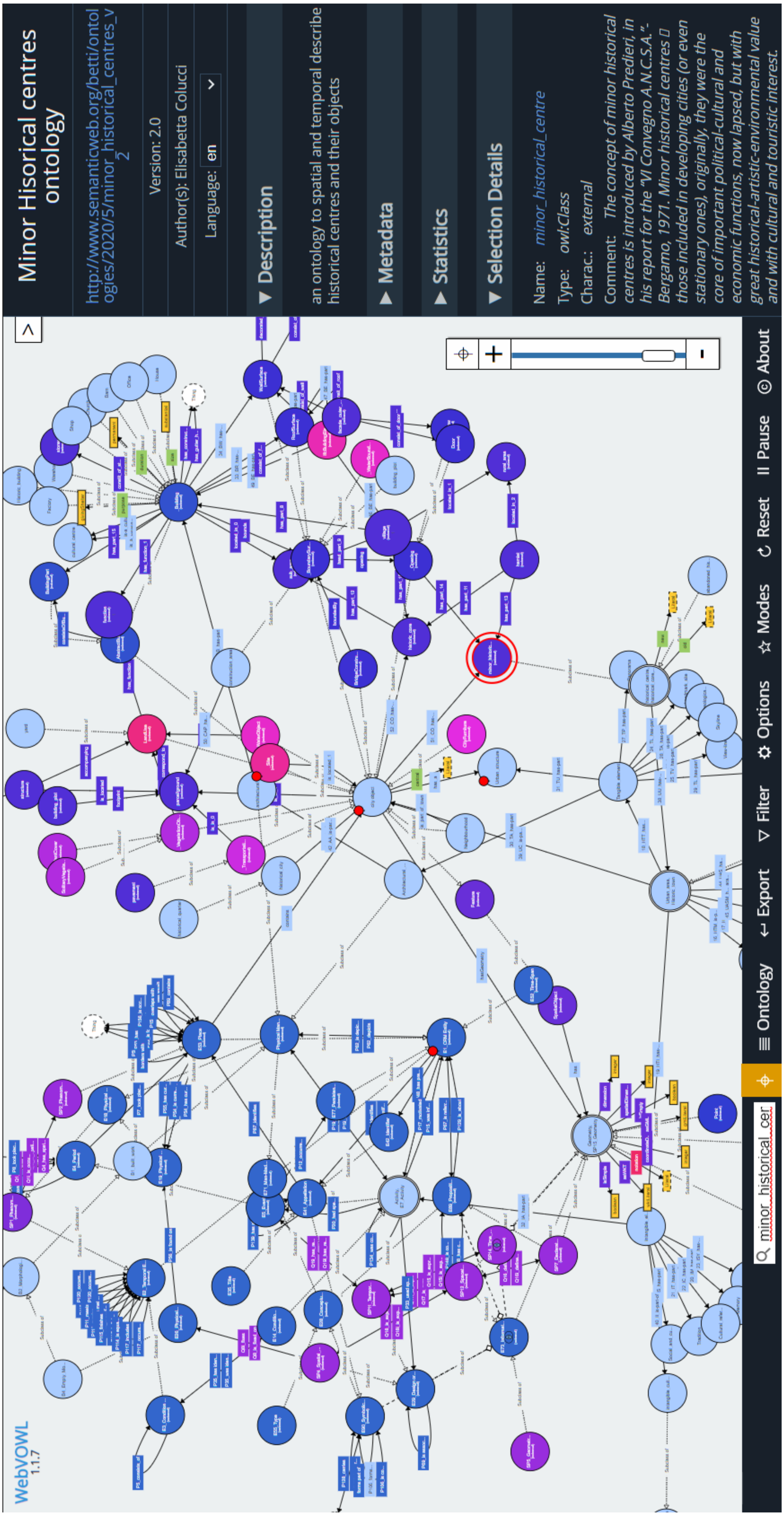



Figure 62. Minor historical centres ontology graph of concepts and relations.

### 5.3.1 Publishing the OWL file of the MHC ontology on the web

The ontology has been published and stored on the web to reuse open knowledge. The document of Garijo (2013) describes the first steps to publish an ontology on the web correctly. The first one is the 5-star Linked Data scale[98] by Vatant (2012)[99]. The main steps are:

a. Publish your vocabulary on the Web at a stable URI;
b. Provide human-readable documentation and basic metadata such as creator, publisher, date of creation, last modification, version number;
c. Provide labels and descriptions, if possible in several languages, to make your vocabulary usable in multiple linguistic scopes;
d. Make your vocabulary available via its namespace URI, both as a formal file and human-readable documentation, using content negotiation;
e. Link to other vocabularies by re-using elements rather than re-inventing.

Other principles for ontology publication are reported in "The AMOR Manifesto" (2013). It lists the following principles based on the 5-star scheme defined for Linked Open Data[100]:

A. The ontology is available on the web with an open licence;
B. Available as machine-readable structured data;
C. Non-proprietary format;
D. Use open standards from the W3C (RDF Schema and OWL);
E. Reuse ontologies in your ontology.

*MHC ontology publication*

In addition, some steps are required to publish the ontology vocabulary at a stable URI using RDFS/OWL. The first aim of the MHC ontology publication focused on addressing the requirements A, B, C, D and *a*. After selecting the name of the ontology, ***"mh-centres"***, it is essential to define a proper and permanent URI to allow the reuse of the developed knowledge. By taking into account this premise, this research selected PURL[101], Persistent Uniform Resource Locator, to create a new domain. In this case, the URI has been defined: *http://purl.org/net/mh-centre_v1* (Figure 63). Then, after designing the ontology in RDF/OWL in Protégé, it is required to change the *ontology IRI* with the one registered in PURL. In this way, all the domain entities will have a standard URI followed by the signs # or /, and the name of the class (e.g. city: http://purl.org/net/mh-centre_v1#city). Classes from existing ontologies maintain their IRI (CityGML, GeoSPARQL or CIDOC ontologies). Finally, the last step redirects the permanent URI to the ontology file. To achieve this, the .owl file of the ontology has been hosted in a GitHub[102] repository. Hence, version 1 of the ontology has been published on GitHub at the

[98] https://www.w3.org/DesignIssues/LinkedData.html
[99] https://bvatant.blogspot.com/2012/02/is-your-Linked Data-vocabulary-5-star_9588.html
[100] http://knowledgecraver.blogspot.com/2013/04/the-amor-manifesto.html
[101] https://archive.org/services/purl/
[102] https://github.com/

link *https://github.com/elicolu/mh-centre_v1* (Figure 64), using the Ontoology system "to automate part of the collaborative ontology development process. Given a repository." Ontoology can handle OWL and RDFS vocabularies in RDF+XML and Turtle serialization[103]. Following some stages (enter the personal GitHub repository as user/repo; authorize OnToology to access the repository, update the ontology and push; merge the pull request created by OnToology), it is possible to store the ontology file in GitHub (Figure 65). After that, the basic redirection to the target URL set up has been replaced with the new link *https://raw.githubusercontent.com/elicolu/mh-centre_v1/gh-pages-branch/mh-centre_v1.owl* in the proper PURL page. Doing this, whenever the user enters the URI of the ontology, it will be redirected to the OWL file.

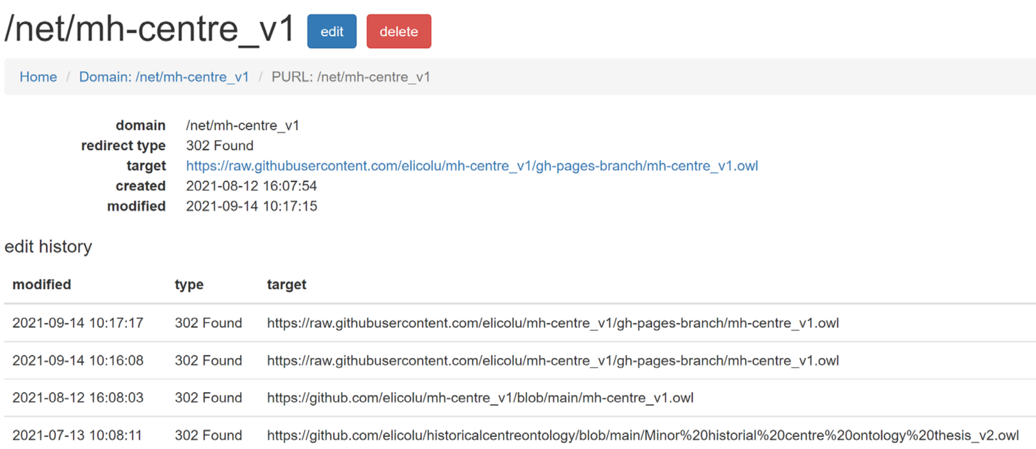



Figure 63. PURL page of "mh-centre ontology" to define a stable URI.

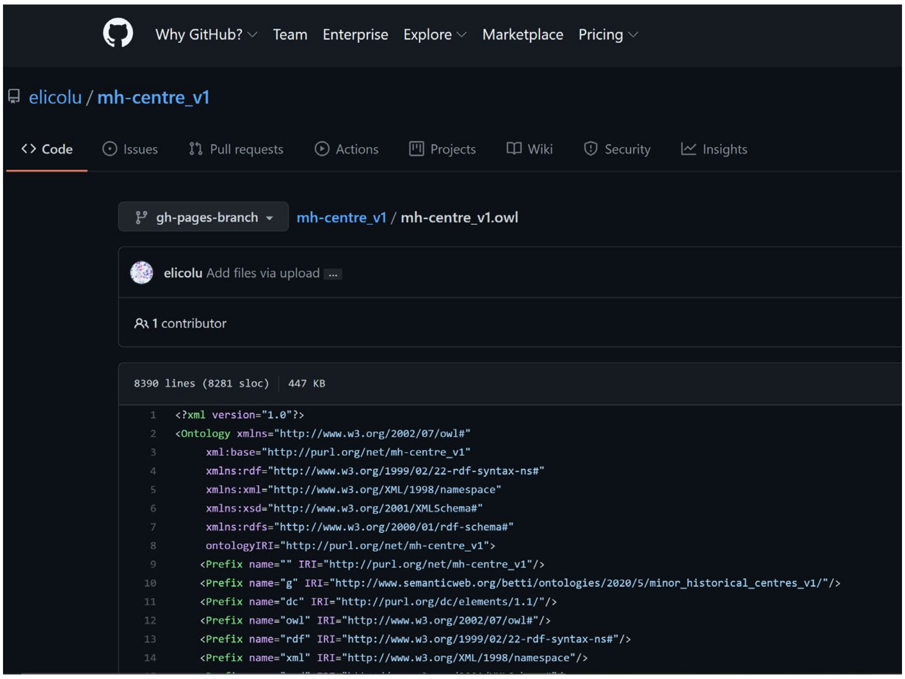



Figure 64. GitHub pages of MHC ontology.

[103] http://ontoology.linkeddata.es/

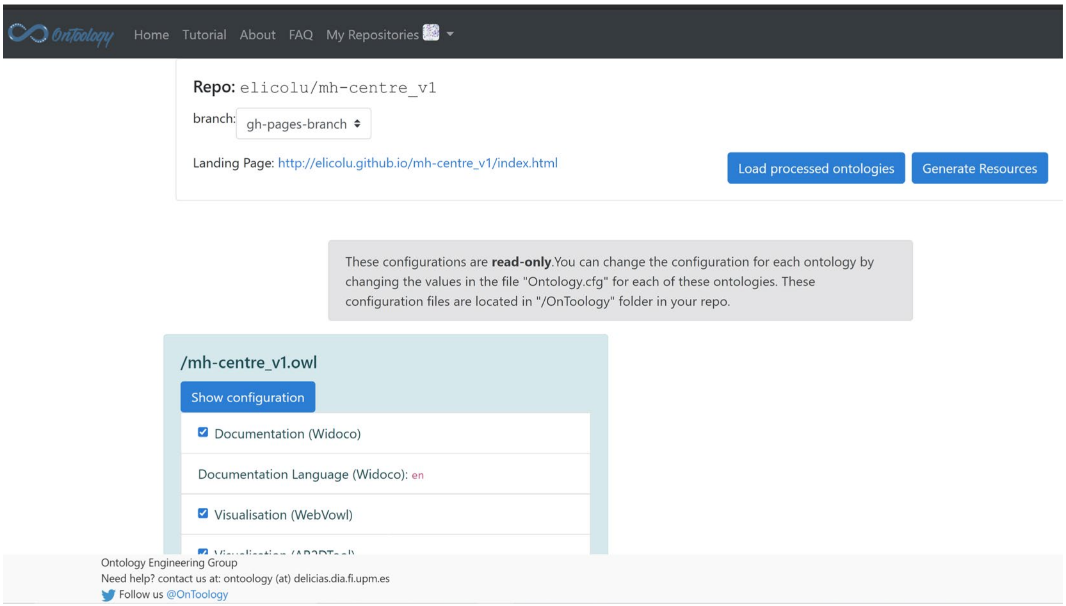



Figure 65. Ontoology page of "mh-centre repository".

To conclude this section, before explaining the different inconsistencies noticed during the ontology construction, we have to recap and mention that, since ontology engineering is an iterative process, new classes and properties have been added in the subsequent phases of ontology creation. Chapter 6 focuses on ontology enrichment, mapping and population (later explained) with further information from structured and unstructured knowledge (such as data models, standards, regulation for historical centres and spatial data).

#### 5.3.1.1 Summary of some ontology inconsistencies noticed during the first steps of the ontology design

There are some issues and inconsistencies encountered during the iterative ontology engineering process.

*first inconsistencies*

- Protégé is not created for *spatial* ontologies purposes, then spatial object and relation are expressed only with their semantics without considering location and boundaries (in RDF or XML formats).
- It was possible to notice some incongruences among standards' documentation during the ontology design. For example, in GEOSPARQL ontology, "GML literal" is a datatype, while in CIDOC-CRMgeo is a class.
- Using Protégé and WebVOLW, it is not possible to create meronymic properties with the same names/IRI (e.g. "has part of"). It was chosen to enumerate and codify each property.

> "Representing part-whole relations is a widespread issue for developing ontologies. OWL does not provide any built-in primitives for part-whole relations. The study of part-whole relations is an entire field in itself - "mereology" - this note is intended only to deal with

> straightforward cases for defining classes involving part-whole relations. Still, it supports good machinery to express most of what one may want to represent about part-whole relations. Where it does not, there are several "workarounds" that suffice in most situations”[104].

- Geometry classes are expressed differently in various ontologies. For example, in CIDOC-CRMgeo and GEOSPARQL, they have different semantics: *SP15_Geometry* and *Geometry*. Moreover, they do not specify if the Geometry of GEOSPARQL expresses both 2 and 3 dimensions.
- The class *E47_Spatial_Coordinates* of the CIDOC-CRM ontology has been deprecated. It comprised “the textual or numeric information required to locate specific instances of E53 Place within schemes of spatial identification”. It has been replaced by E41_Appellation instead. For the present ontology, it has been decided to not include coordinates as classes but to link them to spatial objects in GIS directly.
- *Old city* and *ancient city* concepts have been considered as data properties.
- No Range and Domain are reported for CityGML properties in the OWL ontology.

These issues have been investigated during the subsequent phases of the ontology creation (enrichment, mapping and population), solving some of them through the definition of new classes, properties and instances from data of real case studies.

[104] https://www.w3.org/2001/sw/BestPractices/OEP/SimplePartWhole/

# 6

Chapter 6

# Ontology enrichment, mapping and population

*collaborations*

This second part of the methodology was developed during the second PhD visiting research period. This work was carried out with the collaboration of the "*3D geoinformation research group of the Delft University of Technology, Department of Urbanism, Faculty of the Built Environment*". The academic tutor was *Francesca Noardo*, and it took place from January to March 2021. This methodological part and its results are also derived from the work performed in the *Geomatics Lab* (Department of Environment, Land and Infrastructure Engineering, DIATI, Politecnico di Torino) and the *Geomatics for Cultural Heritage Lab (*Department of Architecture and design, DAD, Politecnico di Torino). Moreover, ontology *enrichment and population* have been carried out thanks to the supervisor Margarita Kokla (NTUA).

This chapter focuses on applying the spatial ontology for minor historical centres in real situations with case studies. As explained in Chapter 1 Introduction, historical centres are interested in sustainability and environment-friendly choices and need to safeguard their cultural values. They are also involved in urban planning and transformation (regulated by building permit processes), restoration actions, and territorial and landscape plans. These processes and planning activities require diverse information and knowledge. Moreover, they could be effectively supported by digitalisation and efficient information representation, including semantic, spatial and temporal aspects.

For these reasons, starting with the ontology structure developed (see § 5.3), some other object classes and instances from real case studies involved in the processes above have been added. This information derives from structured datasets

*Bottom-up approach*

(e.g., maps, national and regional geoportals, Spatial Data Infrastructures, data models) and unstructured data (such as documentation, regulations and rules). Hence, the bottom-up approach has been adopted, selecting data from case studies to enrich and populate the application domain ontology (Figure 67, Figure 68). ***Ontology enrichment*** is used to extend the MHC ontology with new concepts and relations, whereas ***ontology population*** is used to add new instances. These ontology integration steps are fundamental for creating an integrated system (Buccella et al., 2010; Sotnykova et al., 2005). This task has also been made considering real case studies and information to better answer the ontology application domain and MHC temporal and spatial documentation. Figure 66 shows the whole methodology application workflow.

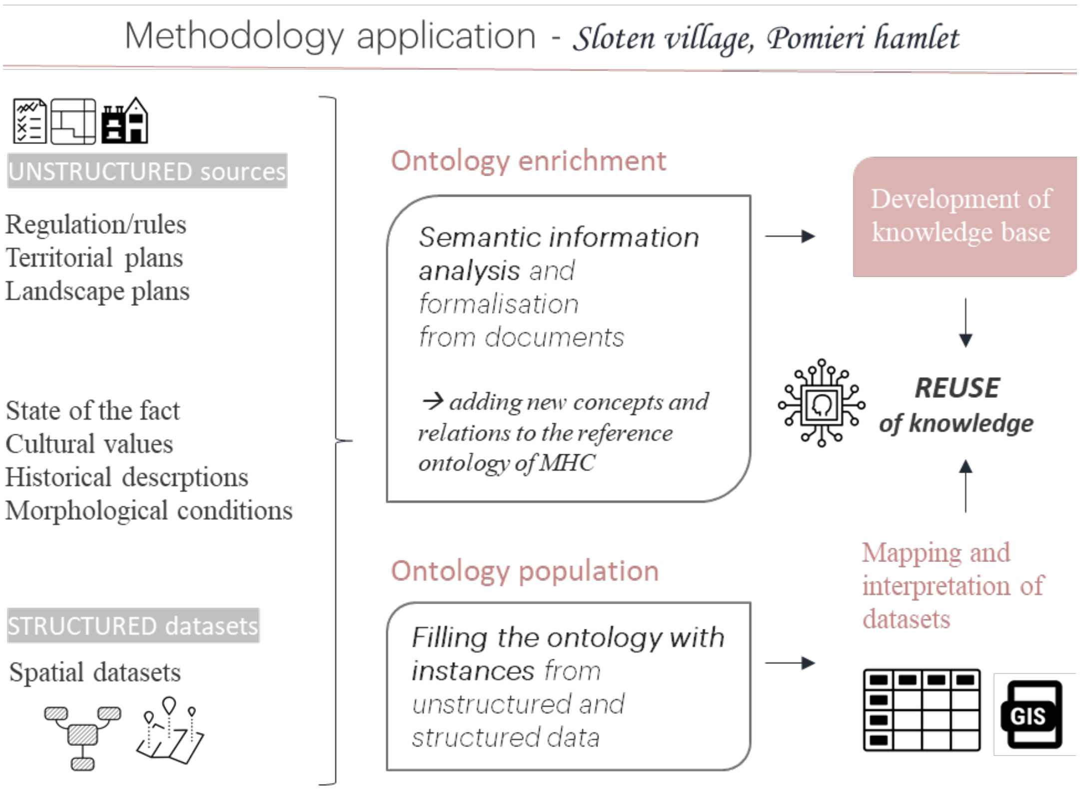



Figure 66. Methodology application workflow - case studies I and II.

The ontology-based enrichment and population approaches consider data models of national and regional maps and geoportals plus semantic information derived from official documents (such as urban regulation plans, landscape plans, building permits, …). These data describe additional aspects of historical value. The zoning and regional landscape plans, policy framework and regulations for HC protection are mapped to the MHC ontology. For this purpose, two proper case studies of a village and a hamlet have been selected. Structured data stored in CityGML and ESRI shapefile[105] formats and standards have been mapped and harmonised with non-structured data, such as concepts derived from documents and

[105] https://support.esri.com/en/white-paper/279

regulations, to create a new knowledge base following semantic and ontological rules (Colucci et al., 2021).


Figure 67. ONTOLOGY101 GUIDE (Standford University, Noy and McGuinness, 2001).

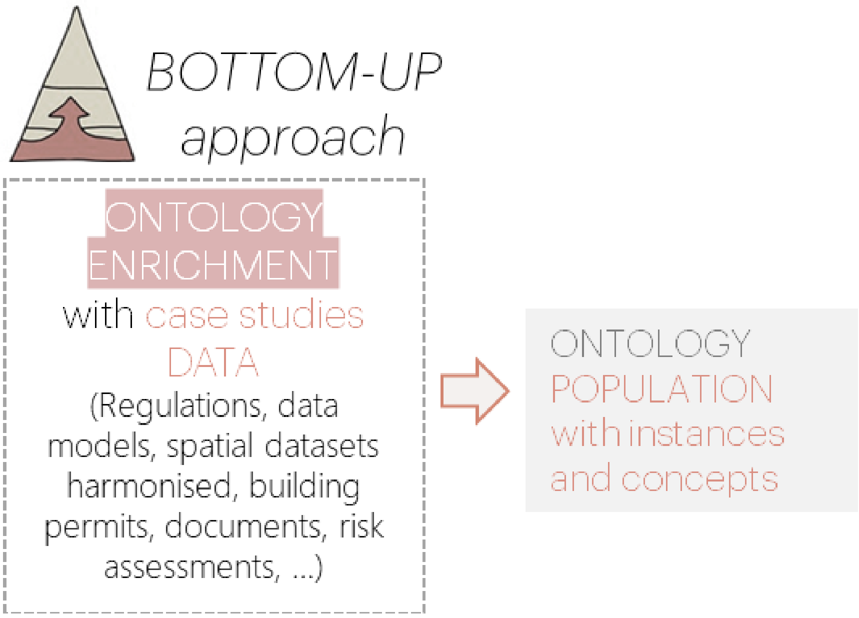



Figure 68. The bottom-up approach of the methodology.

## 6.1 Criteria for the selection of case studies

Different case studies have been chosen for the present thesis to validate the methodology. As announced before, the ontology structure could be populated with instances from actual minor historical centres. Moreover, selecting some case studies also helped in the ontology engineering process. The analysis of an existing situation helped the ontology enrichment with classes and relations not considered before (Chapter 5). These *two* minor historical centres selected for this dissertation have been chosen following some criteria. They were selected considering some measures such as *dimension, extension, data availability, existing spatial data, presence of regulations* (zoning plan, landscape plans, building permits), *geographical condition, historical period, the need of management, valorisation and restoration plans, morphology, climatic conditions, location* (rural, urban, hilly, mountainous areas) and so on.

The two case studies (I and II) are:

- The ***village of Sloten*** (Gaasterlân-Sleat, Friesland, The Netherlands), Figure 69.

It has a historic core with cultural values. This first case study has been selected due to its morphology; it represented an ancient fortified structure with city walls. Moreover, this could be very helpful in the ontology enrichment step due to its regulations (such as the zoning plan). This case study helped the ontology mapping (finding correspondences among different ontologies), enrichment, and population (as presented in the following paragraphs). Because of the availability of many structured spatial datasets (in CityGML compliant formats), it was possible to perform a spatial data mapping (comparison and harmonisation of different datasets) and interpretation and design a unique dataset presented as a GIS project and a geodatabase (GDB) (Chapter 7).

Figure 69. View of the water channel of Sloten[106].

- The ***hamlet of Pomieri*** (Prali, Turin, Piedmont, Italy), Figure 70.

A second case study has been selected to validate the methodological approach by checking if the necessary information to describe and document minor historical centres have been considered. This step also represents the possible replicability of the innovative methodology. It represents semi-abandoned mountain hamlets in Piedmont Alps, damaged by natural phenomena requiring spatial documentation for restoration, valorisation, and sustainable urban resilient planning. This approach also shows the potential reuse of this knowledge, as underlined in one of the ontology tasks of the Ontology Guide of Noy & McGuinness (2001). Moreover, this ontological structure could be applied in a whole or part to other case studies becoming an application ontology.

[106] https://www.flickr.com/photos/155686653@N02/35362629565

Figure 70. Aerial view of the Pomieri hamlet. Image acquired during the 3D integrated metric survey performed by the Geomatics group and the Team Direct[107] of Politecnico of Turin in 2019.

### 6.1.1 Comparison of case studies characteristics

The present research has been decided to choose two different minor built areas to validate the methodology. The two small historical centres have been compared to underline their similarity and differences to completely fulfil other areas and characteristics of the selected domain of the ontology. For this purpose, a synoptic table has been carried out listing some observations and parameters reported for both the case studies.

Table 9. Synoptic table of case studies.

| Characteristics & observations | Case Study I – Sloten village | Case study II – Pomieri hamlet | Comments & Notes |
|---|---|---|---|
| ***Country, Region, Municipality*** | The Netherlands - Gaasterlân - Sleat, Friesland | Italy - Piedmont - Turin - Valle Germanasca - Prali, Vallone di Prali | *Different Countries have been considered* |
| ***Geographical Location*** | Plain, near the Slotermeer lake, close to the IJesselmer inland bay – 0 (m a.s.l.) | Mountains Alps – 1511 (m a.s.l.) | *Different altitude and morphology* |
| ***Area of domain (related to the ontology)*** | Minor historical centre: village | Minor historical centre: hamlet | *Two typologies of minor historical centres have been selected* |
| ***Level of details and granularity considered*** | Territory, municipality, historical centre, buildings | Landscape, valley, municipality, hamlet, buildings | *Many levels of granularity have been considered* |

[107] https://www.g4ch.polito.it/wordpress/team-direct/

| Characteristics & observations | Case Study I – Sloten village | Case study II – Pomieri hamlet | Comments & Notes |
|---|---|---|---|
| ***Spatial data availability (structured data)*** | National and regional geoportal and Open Street Map datasets | Regional Geoportal and 3D metric survey data | *Standardised structured data and acquired data are used to enrich the ontology and for the GIS project* |
| ***Data harmonisation with GIS standards*** | Yes, the data are provided in CityGML, GML or CityJSON | Datasets are compliant only with INSPIRE (from BDTRE of Piedmont Region) | *The datasets of Sloten are already harmonised with GML standards. Different typologies of data format have been considered. One integrated and harmonised with GIS standards and the other one not standardised.* |
| ***Related risk*** | Flooding by sea and rivers | Landslides and avalanches | *Different natural hazards correspond to the case studies* |
| ***Historical period*** | Sloten originated in the thirteenth century as a settlement at a *stins*[108] of the Van Harinxma the Slooten family. Sloten is first mentioned having city rights in a charter dated to 30 August 1426. | Pomieri is a hamlet of Prali. The history of Prali is ancient. Some testimonies revealed the existence of Prali even in the 11th century, but the most reliable start from the 15th century. In Prali, there are many Waldensians, illegal immigrants from France since the Middle Ages. | *Due to the different locations and morphologies, the evolution of the two villages is further, as the construction techniques of architecture* |
| ***Geomorphology*** | Mostly flat | Mountains | *Contrasting morphology of the small centres selected* |
| ***Presence of Regulation (unstructured data)*** | Umbrella zoning plan parking standards - Municipality of De Fryske Marren Historic core of Sloten– Zoning and destination plan | PPR – Piano Paesistico Regionale (Landscape plan) Building Permits Prali Piano Regolatore Generale Intercomunale (Regulator Plan), Val Germanasca | *The village in The Netherlands is reacher in terms of available city plans* |
| ***Climate conditions*** | Temperate, marine | Temperate-cold, cold, rainy | *Temperature and climate condition depends on their location* |
| ***Historical centres built elements*** | City walls, rivers, small roads | Located at the mountain feet, minor roads and narrow valleys | *Both the case studies have cultural and historical values. The village of Sloten answers to the definition of a minor historical centre because it is an ancient fortified city. The hamlet of Pomieri is an ancient core in the Alps in which buildings are made with traditional materials and techniques* |
| ***Dimensions around the small cities*** | $\simeq$ 650.000 sqm | $\simeq$ 22.500 sqm, 17 building only | *The village is huge compared to the hamlet* |
| ***Inhabitants*** | 628 | 11 | *Nowadays in the mountain live only few permanent residents* |

[108] https://en.wikipedia.org/wiki/Stins

| Characteristics & observations | Case Study I – Sloten village | Case study II – Pomieri hamlet | Comments & Notes |
|---|---|---|---|
| ***Buildings/ built heritage conditions*** | Good, existing plan of restoration | Some ruins of mountain buildings (‘baite’= mountain cabin, hat, chalet), buildings needing restoration | *The hamlet of Pomieri needs restoration actions and plans to valorise the area and its old buildings* |
| ***Transport - accesibility*** | Close to the town of Lemmer and Balk, city roads | Access from mountain roads, 1,30 hours from the city of Turin by car, mountain paths | *The hamlet of Pomieri is not well connected with public transport due to the morphology of the area. The village of Sloten is close to some major roads and cities* |
| ***Tourism*** | Yes, all year; cultural events | In the summer for hiking and in the winter for the Ski area in Prali. It is also possible to visit the Waldensian museum in Prali | *Both the historical centres could be valorised, and the tourism could be enhanced* |

After this comparison, it is possible to notice that due to the selection of one village and one hamlet, it is possible to cover a vast area for the historical centre ontology domain. Moreover, thanks to this selection two different notions of MHC have been considered: village and hamlet. The following paragraphs focus on extracting useful information from the case studies documentation and datasets to enrich and populate the developed knowledge. In this dissertation, the case studies analysis follow the methodology workflow.

## 6.2 Case study I - The historical core of Sloten village

*Case study I: Sloten village*

The first case study is the village of Sloten (or Slooten) in the Netherlands (Figure 71). Sloten was a fortified city, located in the municipality of Gaasterlân-Sleat, in the Dutch province of Fryslân (Friesland). Sloten belonged to the Frisian eleven cities and was an independent municipality until 1984[109].

Figure 71. Aerial view of the village of Sloten, 1920-1940 (left)[110] and now (2022, right).

[109] https://www.friesland.nl/en/discover/eleven-cities-and-villages/sloten

[110] https://commons.wikimedia.org/wiki/File:NIMH_-_2011_-_0468_-_Aerial_photograph_of_Sloten,_Friesland,_The_Netherlands_-_1920_-_1940.jpg

The city of Sloten provides one of the most beautiful and most astonishing cityscapes found in the country. This city canal is closed on both sides by a waterport, the Sneekerpoort and the Lemsterpoort. The city map within the ramparts dating from 1581 is divided into four parts. The intersection of the canal and the street also forms the origin of the settlement. The city was of enormous strategic importance in earlier times due to its location on a significant waterway from Sneek to the Zuiderzee. Although being a populated centre, quite distant from other examples of abandoned villages or mountain hamlets, it allows testing the methodology with a data structured case with compliant features regarding dimensions, history, cultural relevance, the morphology of elements, and available data to represent and describe it. As regards its spatial structure, the city plan has not changed since the construction of the 16th-century ramparts, except for the eastern and western entrances (Figure 72). The entrance of the west was modified in the middle of the last century. The essential part of Sloten from the point of view of urban beauty is undoubted "Het Diep", the old waterway within the fortress. The most important buildings, such as the Ned, can be found along the Herenwal on the east side. Unlike most other towns, Sloten has virtually no buildings on the north and south sides. It gives you a unique view of the broad Frisian landscape from the fortress (Pouderoyen Compagnons, 2012). Due to such historical value and the consequent characteristics of the village, reflected in the city regulations, Sloten is selected as an exemplary case study. We can take advantage of the several structured geodatasets available (provided by Kadaster, the Dutch National Mapping and Cadastral Agency, and other organisations) plus the information available as descriptions in natural language in the documents aimed at its preservation  (definitions and rules), which are stored as part of planning regulations.


Figure 72. Historical image of the village of Sloten, 1664 (Pouderoyen Compagnons, 2012).

### 6.2.1 The Zoning Plan for the historical core of Sloten

*Sloten regulations*

The thesis analysed the *Destination Zoning Plan* of the historical core of Sloten, shown in Figure 73, (Pouderoyen Compagnons, 2012). Preserving the mix of functions is one of the most critical principles of the plan. So the quality of the living environment is at least maintained. The current blend of functions gives Sloten a tourist attraction compatible with the residential part.


Figure 73. Historical Core Sloten, Destination Plan, available at the national portal viewer for spatial plans *Ruimtelijkeplannen.nl*.

The plan contains three sections: *explanations, rules and maps*. The first part describes the different destinations: company, retail, mixed, green, industry, social, garden, traffic, water, living and archaeological value. For the methodological part of the thesis, *Rules* have been considered. In particular, Article 5 from mixed destination and Article 20 from Value - Cultural history. So, to test this thesis methodology, *Article 5*, '*Zoning rules to be applied'* and *Article 20, 'Current State',*[111] have been selected. The destination plans (Article 5) refer to city zones represented as geometric objects in the zoning map. They can be downloaded in GML format and visualised and queried within GIS tools. Other regulations refer to different zoning areas, which are often not represented within the same WebGIS (*Ruimtelikeplannen.nl*) but are reported in further documents. An example related is illustrated by the sub-areas referred to *Article 20*. Three sub-areas are distinguished within the urban area (Figure 74). The subareas have been chosen to

[111]https://www.ruimtelijkeplannen.nl/documents/NL.IMRO.0653.BPL2010220001-VG01/r_NL.IMRO.0653.BPL2010220001-VG01.html

be regarded individually as spatial units within the historical core. One sub-area differs from the other by several specific urban design elements:

− Sub-area A: the precious closed facade walls on the deep,

− Sub-area B: the more small-scale facade walls on *Dubbelstraat* street with the adjacent parts,

− Sub-area C: the residual area on the east side around the factory.

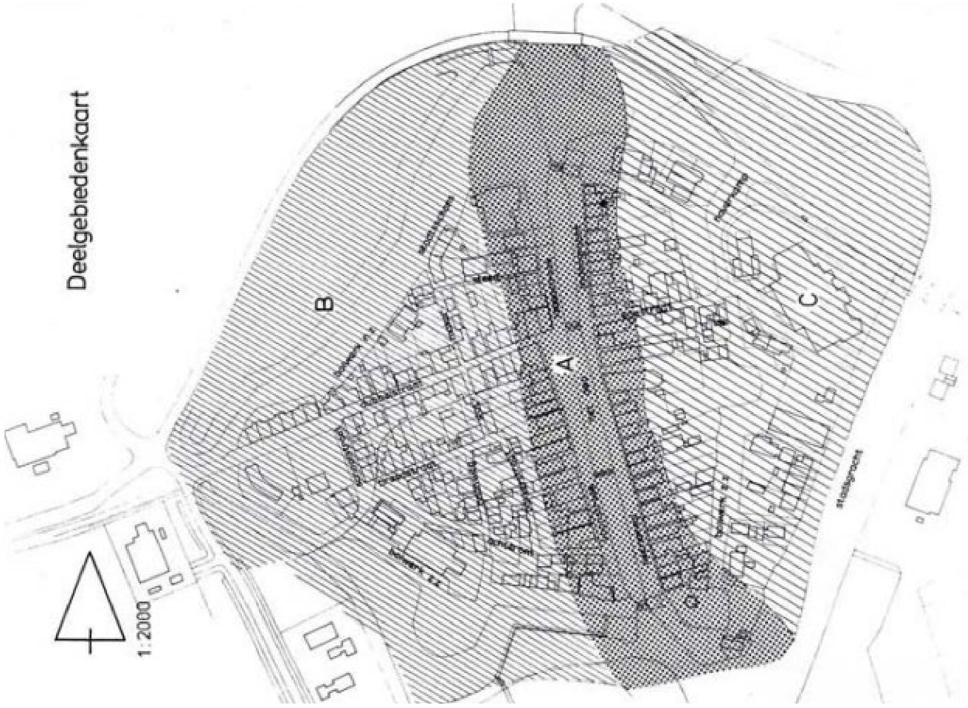



Figure 74. Sub-Areas of the Zoning plan (Pouderoyen Compagnons, 2012).

### 6.2.2 Available spatial datasets of Sloten

In addition to the regulation plans of Sloten, several digital maps are available for the selected area as structured spatial datasets. They were analysed, compared, and mapped to the domain ontology to enhance it by integrating with relevant parts of the data schemas (see next chapter, § 7.1.1).

Figure 75 shows an example of the *“PDOK, Publieke Dienstverlening Op de Kaart (Public Services on the Map) and BGT, Basisregistratie Grootschalige Topografie (Key Register Large-Scale Topography)”* data set available for Sloten.

Table 10 reports all the different spatial datasets available for case study I.

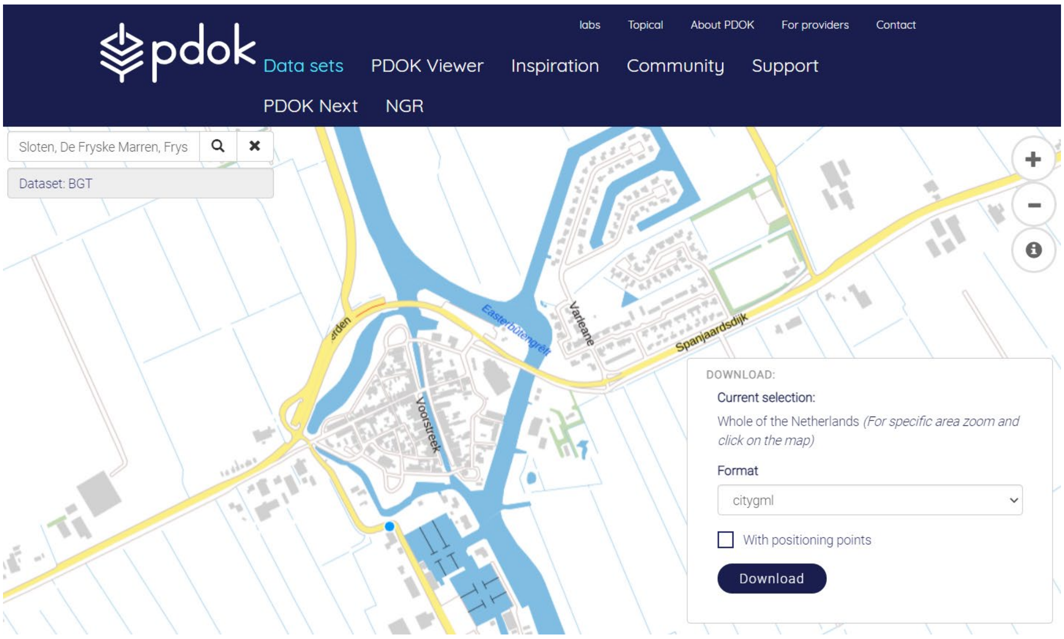



Figure 75. PDOK, BGT datasets download in CityGML[112].

Table 10. Available datasets of the case study.

| ***Data*** | ***Data Format*** | ***Author*** | ***LoD*** | ***Source*** |
|---|---|---|---|---|
| ***ZONING PLAN*** | GML | ruimtelijkeplannen | LoD0 | *https://www.ruimtelijkeplannen.nl/* |
| ***BGT*** *(Basisregistratie Grootschalige Topografie)* | CityGML | Kadaster PDOK | LoD0 | *https://www.pdok.nl/downloads/-/article/basisregistratie-grootschalige-topografie-bgt-* |
| ***BAG*** *(Basisregistratie Adressen en Gebouwen)* | CityGML (WFS service) | Kadaster PDOK | LoD0 | *https://www.pdok.nl/datasets* |
| ***3D BAG (BAG/PDOK, BGT, AHN)*** | CityGML/IMgeo | Kadaster/TUD3D | LoD 1.3 | *http://3dbag.bk.tudelft.nl/downloads* |
| ***PDOK 3D Basisbestand Gebouwen*** | CityJSON | Kadaster/TUD3D PDOK | LoD1-2 | *brt.kadaster.nl/basisvoorziening-3d/* |
| ***OpenStreetMap*** | OSM (Open Street Map) | OSM community | LoD0 | *https://www.openstreetmap.org/export#map=17/52.89449/5.64787* |

[112] https://app.pdok.nl/lv/bgt/download-viewer/

# 6.3 Ontology enrichment and population - *Sloten* data

## 6.3.1 Ontology enrichment (I)

*Ontology enrichment I*

The second step of the ontology development process of this thesis is *ontology enrichment*, subsequently to the specification of spatial concepts and their relations. To validate the methodology, the ontology enrichment aims to extract semantic concepts able to describe real MHC and their planning rules. For the case study of Sloten, the steps considered are:

- Selection and analysis of unstructured data. It consisted of semantic information analysis and formalisation from the documentation available in the regulations related to the historical core zoning plan of Sloten (Art. 5 and Art. 20);
- Addition of new concepts and relations to the ontology from the formalised unstructured knowledge;
- Ontology mapping. It regarded the mapping and comparison of concepts and relations of the MHC ontology (from national data models and existing ontologies, checking possible entities not considered in the first part of the ontology design);
- Ontology updating. It was aimed to revise and integrate the ontology (in Protégé) according to the previous mapping.

The *Historical core Zoning Plan of Sloten* has been analysed following different strategies selecting Art. 5 and Art. 20 (§ 6.1.1). This approach was performed using the analysis of documents by manually selecting possible classes and relations through a manual text interpretation and formalisation. The schemas deriving from the formalisation of the two articles were used according to two different aims:

- *Art. 5* would guide the selection of information necessary to check compliance to the rules there stated and represent information requirements;
- *Art. 20* contributes to build the available information about the village (as well as the other maps and spatial data), part of which will be selected according to Art.5.

The following paragraphs report some text excerpts with the extracted entities highlighted in grey, instances in dark yellow data properties in jade-green and object properties in red (as defined in Protégé) (Colucci et al., 2021). Entities have been highlighted only the first time that they appear in paragraphs.

*"Art. 5.1 Destination description*
*Art. 5.1.1 General destination description*
*The grounds designated for Mixed are intended for:*
*buildings and roofs for:*

*living, whether or not in combination with space for a professional or business activity at home;*
*living in combination with retail, services, social facilities, offices, craft businesses;*
*supporting catering industry;*
*with the accompanying:*
*yards and pavements;*
*facilities and structures, not being buildings.*
*Art. 5.1.2 Further details of the destination*
*The residential function is not permitted at the location of the indication 'housing excluded'".*

*"Art. 5.2 Building rules*
*Art. 5.2.1 Construction of buildings within a construction area*
*The following rules apply to the construction of buildings within the construction area:*
*the number of dwellings may not exceed the number existing at the time when the design of this plan was made available for inspection; otherwise, the rules as indicated in Art. 20.2.1 apply.*
*Art. 5.2.2 Construction of buildings and canopies outside a construction area. The rules as indicated in Art. 20.2.2 apply to the construction of buildings and roofs outside the construction area.*
*Art. 5.2.3 Construction of structures, not being buildings*
*For the construction of structures, not being buildings, the rules as indicated in Art. 20.2.3 apply." Art. 5.*

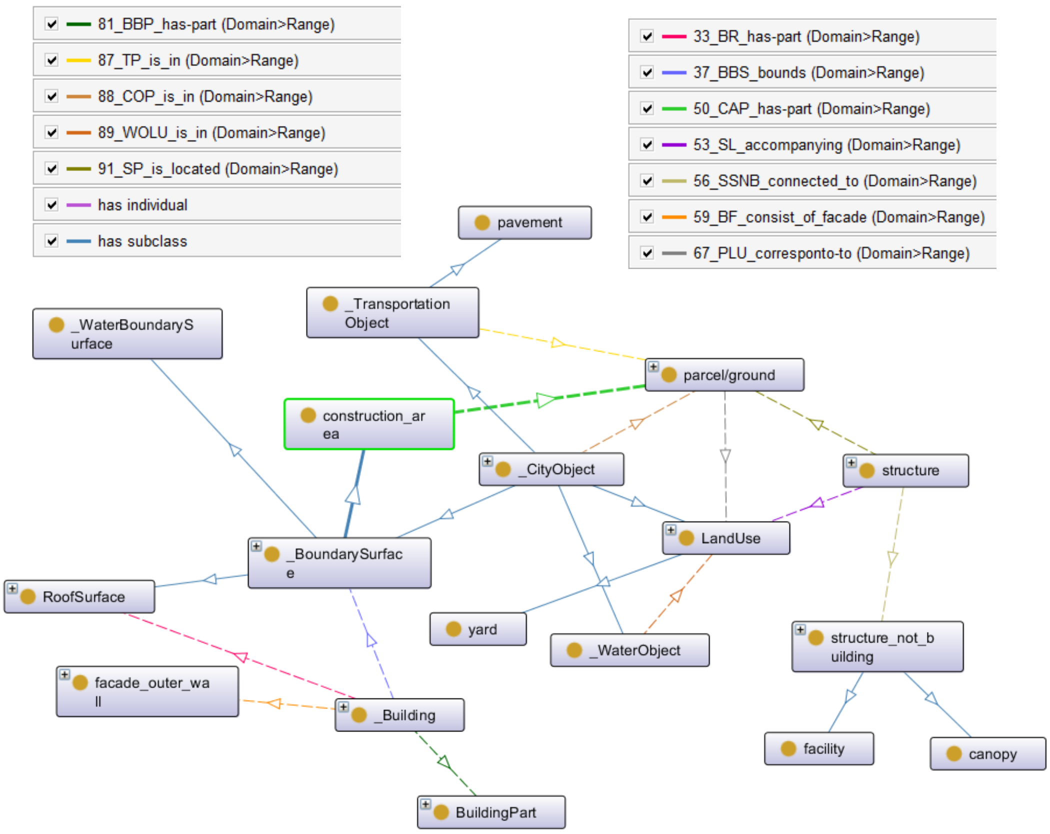



Figure 76. OntoGraf view of some concepts and relations extracted from Article 5.

Figure 76 reports some concepts and relations derived from Art. 5 and integrated into the MHC ontology in Protégé, following the ontology enrichment method. A similar procedure to enrich the ontology has been conducted for Art.20, Value and Cultural History.

Instances about Sloten village have been considered. It concerns the dual destination throughout the planning area (Areas A, B and C), intending to protect the cultural-historical values of the protected cityscape.

*"Art. 20.1.1 General destination description*

*The grounds designated for Value - Cultural History are, in addition to the other uses occurring there, also intended for the protection and maintenance of the cultural-historical values occurring within the protected cityscape or associated with it. All this by the further details of the destination included in Art. 20.1.2".*

*Art. 20.1.2 Further details of the destination*

*The cultural-historical values as referred to in Art. 20.1.1 are determined by the recognisability of the following characteristics:*

*The city has formed around the crosswise situated axes "Het Diep" and "Dubbelstraat-Koestraat" and within the city walls and city canal. The Diep (with the streets on either side) forms the central axis".*

***For a description of the characteristics present, the plan area can be divided into the following three sub-areas:***

*"Sub-area A.*

*Building characteristics:*

*Buildings mainly one storey with roof. Deviations are buildings with a special function;*

*The buildings have an angular design with a simple basic shape;*

*Parcel width usually allows for a facade layout with a door and 2 to 3 windows, the height of which is greater than the width;*

*The buildings are generally covered with a gable roof, the ridge direction of which is perpendicular to the road;*

*The facade wall predominantly shows a variety of - sometimes richly decorated - gables. An exception is a hipped roof at the front (usually with one centrally located characteristic dormer window), covered with black glazed tiles;*

*Facade walls usually consist of clean masonry of yellow or red bricks." Art.20.*

*"Sub-area B*

*The following characteristics apply in the west of Het Diep (Dubbelstraat with the adjacent parts).*

*Urban design features:*

*Virtually continuous façade walls along Dubbelstraat;*

*The Dubbelstraat has a narrow profile (4 - 6 meters) without further division;*

*Characteristic of the Dubbelstraat is the longitudinal or moulding facades in one building line, interrupted only by the Slotmakerssteeg;*

*The structure of the remaining buildings (Achterom, Breedstraat and Bakkerstraat) is characterized by an alternation of built-up and undeveloped plots;*

Breedstraat and Schoolstraat are built on two sides. The Bakkerstraat is built on one side (rear sides of the Voorstreek). For the rest, there is an alternation of buildings and gardens;

There is a clear view of the landscape from Bolwerk (south and north) and Stadsschans;

The structure is determined by the buildings along and on the Bolwerk (no closed façade walls, but clustered). The buildings on the south side are precious;

Cap shape is generally gable roof, with or without shields. The cutting direction varies.

Building characteristics:

The buildings usually consist of a storey with a varying gutter height (2.5 to 4 meters). At corners this can be up to two storeys (4 to 6 meters);

Outside the Dubbelstraat, the buildings have fewer common features;

The plot width and thus the cutting direction and shape vary;

The detailing of the buildings is generally more austere than at the location of sub-area A;

Facade openings have a greater height than width;

Facade walls usually consist of clean masonry of red or yellow brick, but plastered facades also occur;

The wooden dormers are particularly iconic.

Public space characteristics:

The buildings are located directly on the street with no front yard or sidewalk;

The roadway is indicated by clinker paving in stretcher bond;

The surroundings of the Bolwerk are open and public in character.

Trees, residential buildings and boundaries guide the roads across Bolwerk. In general, here is a clear view of the backyards and the surrounding landscape. Residents use the grass strips between the road and the water to dry the laundry".

"Sub-area C.

The following characteristics apply in the zone located to the east of Het Diep (animal feed factory area).

Urban design features:

In contrast to Dubbelstraat, Koestraat has no continuous corner buildings with Lindegracht / Heerenwal.

The urban development structure can still be seen in the course of the Bolwerk and the building structure of several buildings in the north of the sub-area and near the factory;

The image of the Bolwerk is determined mainly by the view of backyards with lots of greenery, outbuildings and fences. This statue can be characterized as valuable near the church;

The animal feed factory disrupts cultural-historical values due to its size and scale.

Building characteristics:

Except for a few buildings in the north of the sub-area (Haverkamp 1 to 4) and the cattle feed factory not taken into account, the structures are characterized by a single storey with hood (gable roof, with or without shields) ;

The plot width and thus the cutting direction and shape vary;

*The detailing of the buildings is generally more austere than in sub-area A;*
*Facade openings have a greater height than width;*
*Facade walls usually consist of clean masonry of red or yellow brick, but plastered facades also occur;*

*Public space characteristics:*
*In addition to the buildings on Koestraat and the immediate vicinity, buildings in this sub-area have a front and back yard;*
*The greenery on the Bolwerk is highly defining;*
*The sub-area has an informal pattern of streets and alleys".*

*"Art. 20.2.1 Construction of buildings within a construction area*
*On the grounds referred to in Art. 20.1, the following rules apply to buildings within a construction area, if these have been declared applicable in the underlying zoning:*
*the facades of a building facing the public road or public space may only be situated in the building boundary facing the public road or public space;*
*the gutter and construction height may not exceed the existing gutter and construction height; by way of derogation from this, the gutter and construction height at the location of the indication 'living' may not exceed 4 m and 9 m respectively;*
*the cutting shape, cutting direction and roof pitch may not deviate from the existing cutting shape, cutting direction and roof pitch; by way of derogation from this, for buildings at the location of the designation 'living', the roof pitch may not be less than 30 ° and not more than 60 °;*
*for the rest, the building regulations apply as included in the underlying zoning".*

*"Art. 20.2.2 Construction of buildings and canopies outside a construction area*
*The following rules apply to the construction of buildings and roofs outside the construction area if these have been declared applicable in the underlying zoning:*
*the built-up area of buildings and roofs, insofar as located outside the construction area, may not exceed 60 m² per building plot, on the understanding that the built-up percentage may not exceed 50% of the land located outside the building area;*
*the gutter height of buildings and roofs outside the construction area may not exceed 3 m;*
*the building or the covering must be covered with a roof, the roof slope of which is at least 35 ° and at most equal to the (maximum) slope of the roof of the main building located within the construction area".*

*"Art. 20.2.3 Construction of structures, not being buildings*
*The following rules apply to the construction of structures, not being buildings, if these have been declared applicable in the underlying purpose:*
*The construction height of structures, not being buildings, may not exceed 2 m".*

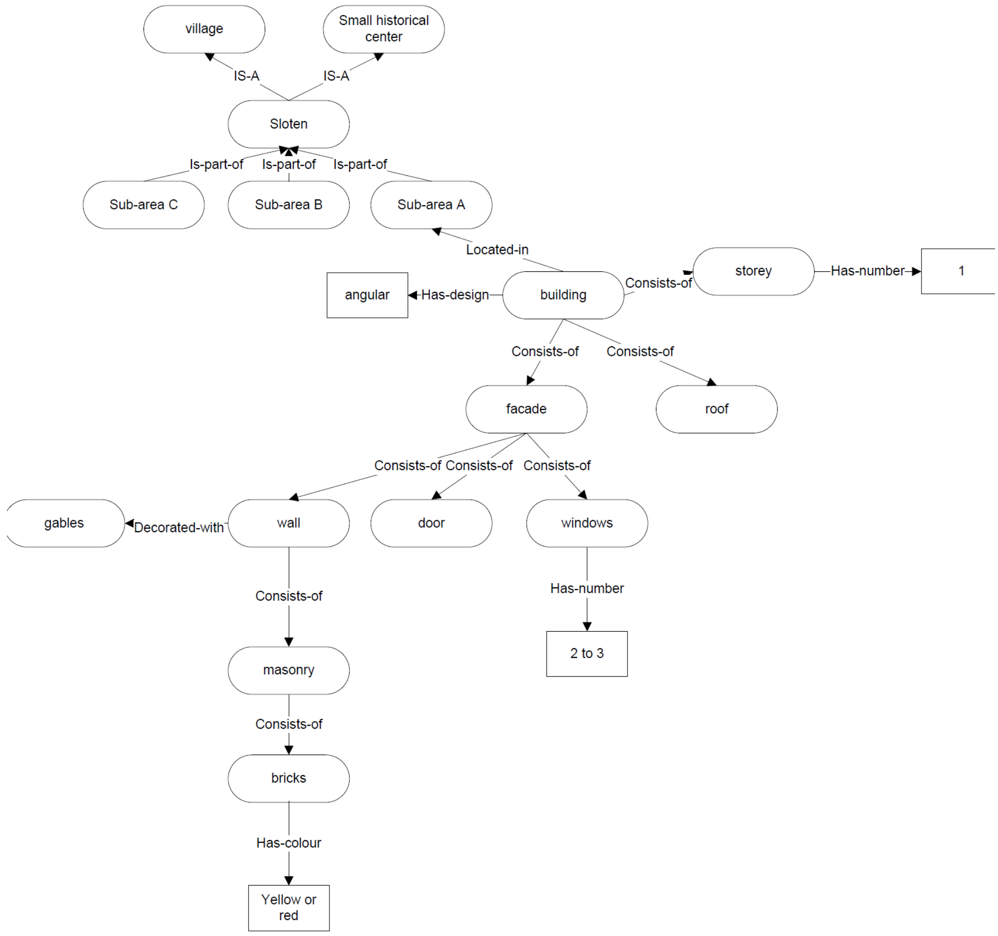



Figure 77. Excerpt of some classes and instances extracted from Article 20, Sub Area A (Colucci et al., 2021).

As reported in Colucci et al. (2021), the concepts and relations extracted from the regulation are used to enrich the ontology of MHC. Linking the semantic representation of MHC to the ontology will also enable its validation and enrichment with new concepts, relations, attributes, and values. Table 11 shows some explicative examples of triples developed linking classes with relations (predicate column).

Table 11. Triples of concepts were implemented during the ontology enrichment (Colucci et al., 2021).

| **Subject** | **Predicate** | **Object** |
|---|---|---|
| BUILDING | *consist of* | FAÇADE |
| BUILDING | *has part* | BUILDING ELEMENTS |
| HISTORICAL CENTRE | has | URBAN FEATURES |
| HISTORICAL CENTRE | has-part | PUBLIC SPACE |
| HISTORICAL CENTRE | has | CULTURAL VALUES |
| BUILDING | bounds with | BOUNDARY SURFACE |
| HISTORICAL CENTRE | has part | BUILDING |
| BUILDING | *consist of* | ROOF |

Following the ontology mapping and matching approaches, the MHC ontology has also been compared to Dutch national datasets (such as BGT and BAG), existing ontologies already considered in part (CityGML and CIDOC-CRM) and concepts extracted from articles of the regulation zoning plan. Specifically, these new entities derived from:

- relevant classes from data models of national datasets (such as the objects *house, vegetation* and *water* from the ADE of CityGML implemented for BGT datasets[113]);

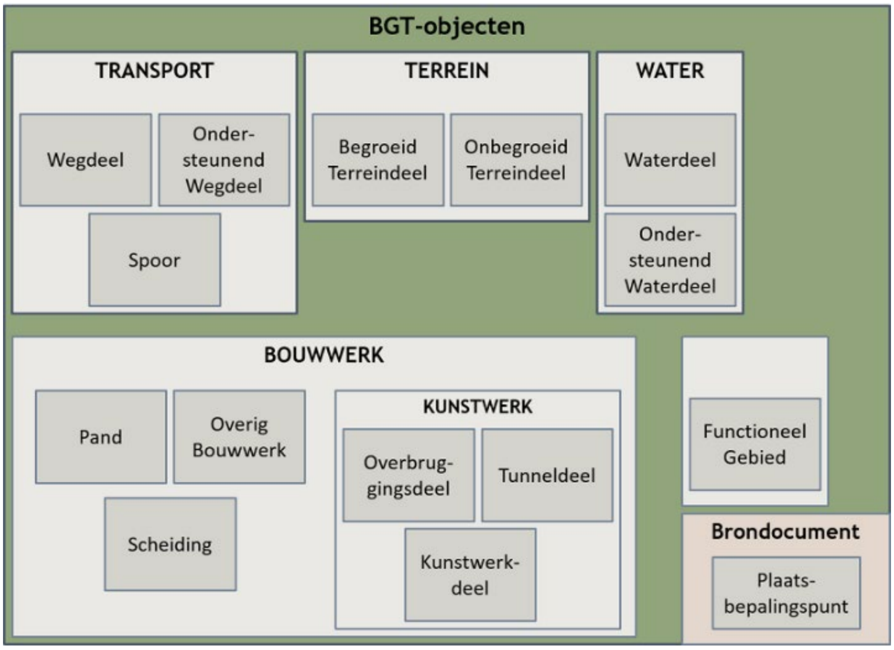



Figure 78. Overview BGT objects (*Basisregistratie Grootschalige Topografie Gegegevenscatalogus BGT 1.2*).

- the RDF classes and attributes of BAG object of the BAG data model[114] and descriptions from the BAG glossary (e.g., BagHouse "is a smallest, functional and architectural-structural independent unit that is directly and permanently connected to the earth and is accessible and lockable"[115]);
- relevant classes from existing ontologies, already considered in the first phases of the design (§ 5.2). For example, the OWL version of the CityGML v.2.0 data model developed by the University of Genova[116] (see concepts selected in Figure 79).

[113] https://docs.geostandaarden.nl/imgeo/catalogus/bgt/
[114] https://bag.basisregistraties.overheid.nl/datamodel
[115] https://bag.basisregistraties.overheid.nl/begrippenlijst
[116] http://cui.unige.ch/isi/onto//citygml2.0.owl

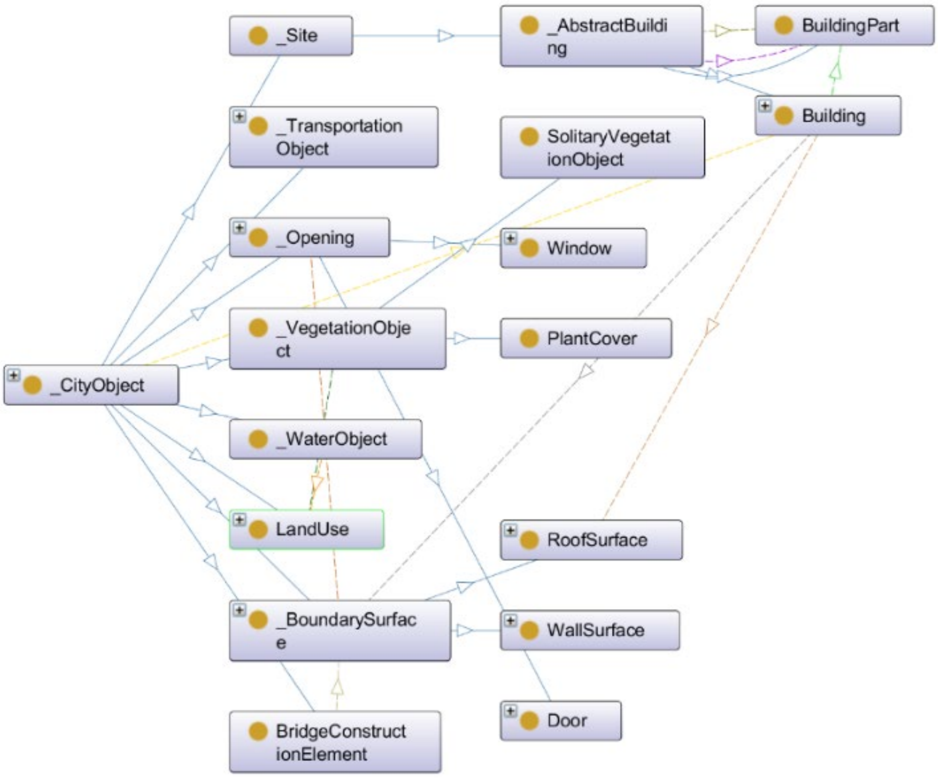



Figure 79. CityGML entities are considered for the ontology (OntoGraf viewer, Protégé).

- CIDOC-CRM ontology core relations/properties such as *"borders_with", "overlaps_with" and "contains"* (CIDOC CRM, 2021), not considered in the first phase of the ontology design, Figure 80.

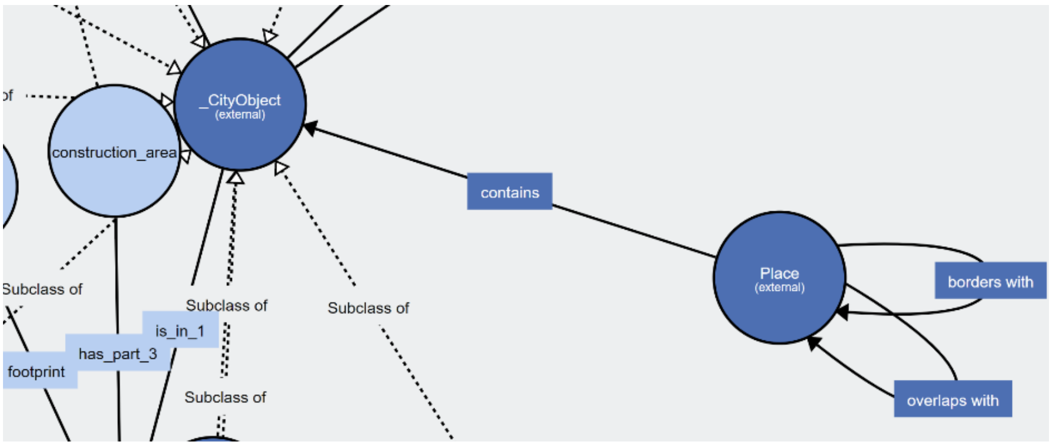



Figure 80. CIDOC-CRM ontologies relations were selected for the present study.

- Classes extracted from Art.5 of the regulation have been compared to concepts of existing ontologies (some examples in Table 12).

Table 12. Comparing concepts among regulations and ontologies.

| ***Entities form Art.5 – Rules Mixed*** | ***Existing concepts in ontologies*** |
|---|---|
| Roof | RoofSurface (CityGML) |
| Building | Building (CityGML) |
| Road | TransportationObject (CityGML) |
| Building boundary | BoundarySurface |
| Place | Place (CIDOC-CRM) |

A draft of the final output of this mapping is shown in Figure 81; green classes derive from the first version of the MHC ontology (shown in Chapter 5), blue and yellow from regulations (Art. 5 and Art. 20) and red text from CityGML ontology and national data models. In the ontology editor, semantic descriptions and relations (object properties) have been implemented.

### 6.3.2 Ontology population with instances (I)

*Ontology population I*

Since the ontology-based methodology aims to document historical centres and specify some information about regulations and building permits of villages, few instances have been added starting from the unstructured knowledge. It is important to underline that the main aim of the ontology developed in this thesis is to lay the foundation for creating a piece of knowledge to document HC. For this reason, there are not a lot of instances in the MHC ontology because they refer to a more specific level. Instances only provide practical examples of how the ontology can also be populated with data. This thesis chooses to remain on a more general level to favour the reuse of knowledge in other domains and for other purposes.

Some instances derive from the description of the historical village of Sloten[117] (such as “Frisian is the province of Sloten”) and others from the text reported in the Art. 20. For example, subarea A, B and C are parts of Sloten; the buildings of Area A have “mainly one storey with a gable roof”, “facade walls usually consist of clean masonry of yellow or red bricks”, and so on. These information represents relevant identity features, either not explicit or missing in the spatial datasets and related attributes.

Table 13 reports some instances of concepts and relations added to the ontology.

[117] https://www.sloten.nl/

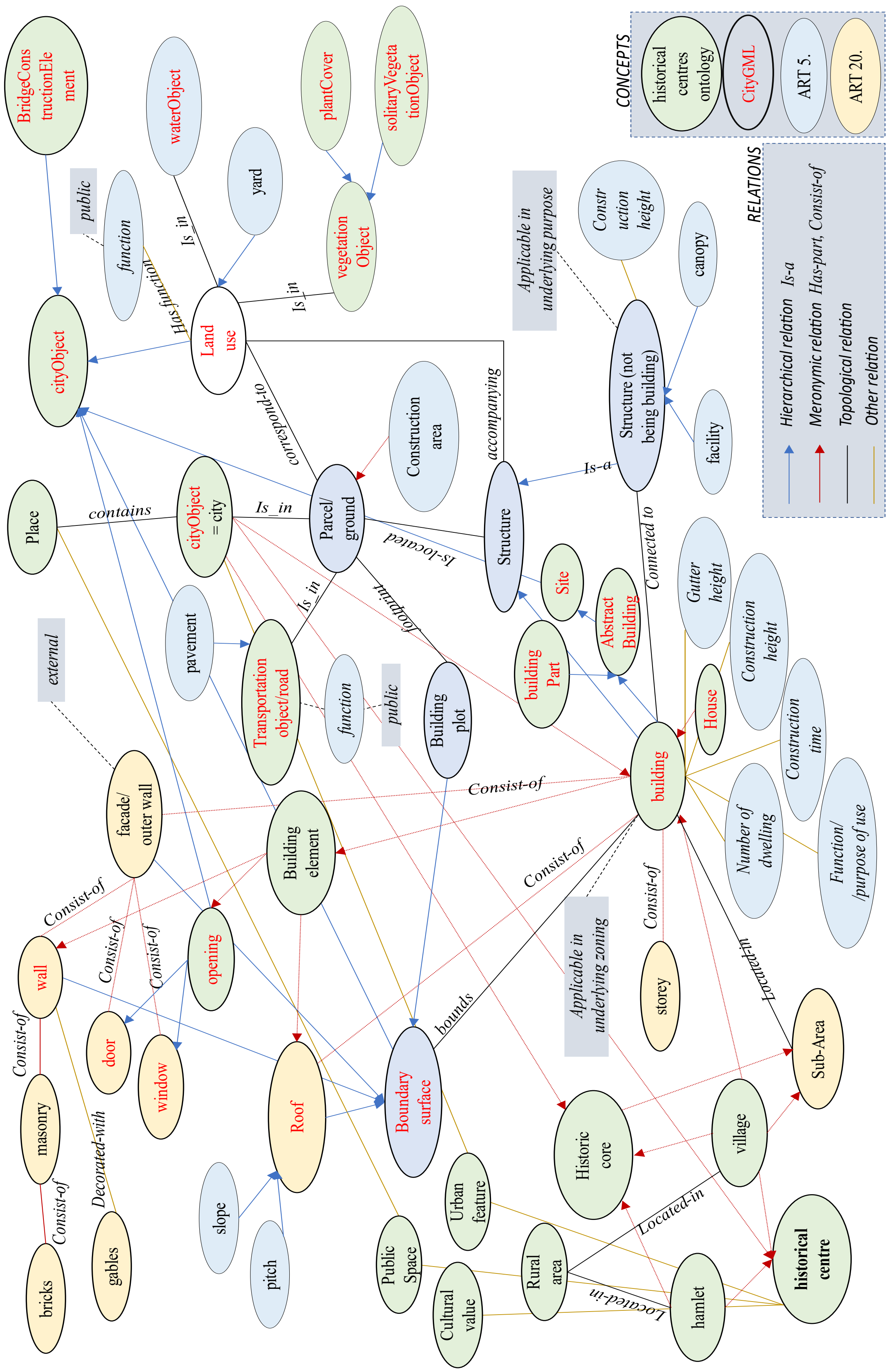



Figure 81. Ontological draft schema of classes and relations from Art.5, Art.20 of Zoning Plan of Sloten, the reference ontology of historical centres and the CityGML (Colucci et al., 2021).

Table 13. Some instances for Art. 20, Sub Area A (from general to specific) have been added during the ontology population (* Referred to data-property or class / Object property assertion in Protégé).

| **Subject** | **Predicate** | **Object** | **Properties*** |
|---|---|---|---|
| FRISIAN | *is the province of* | SLOTEN | Object property assertion |
| SLOTEN | *is a* | VILLAGE | type/toponym |
| SLOTEN | *is a* | HISTORICAL CENTRE | type/toponym |
| SLOTEN | *is municipality from* | 1984 | Object property assertion |
| SLOTEN | *is in the municipality of* | GAASTERLÂN-SLEAT | Object property assertion /toponym |
| SLOTEN | *is in the municipality of* | DE FRYSKE MARREN | Object property assertion /toponym |
| SLOTEN | *has* | SUBAREA(s) | Type: Sub-area |
| SLOTEN | *has* | CITYWALL | Object property assertion |
| SUBAREA A | *is part of* | SLOTEN | Sub-area |
| SUBAREA B | *is part of* | SLOTEN | Sub-area |
| SUBAREA C | *is part of* | SLOTEN | Sub-area |
| BRICK | *has colour* | YELLOW | Data property: colour |
| BRICK | *has colour* | RED | Data property: colour |
| WINDOW (Sub Area A) | *has number* | 2 to 3 | Data property: number |
| FACADE WALLS (Sub Area A) | *consist of* | CLEAN MASONRY | Object property assertion |
| STOREY (Sub Area A) | *has number* | 1 | number |
| | | | |
| CLEAN MANSORY (Sub Area A) | *has* | YELLOW or RED BRICKS | Object property assertion |

## 6.4 Case Study II - The hamlet of Pomieri

The Italian mountain hamlet of Pomieri is located in the municipality of Prali in the Piedmont Region. Its old name in dialect is "Li Poumie", which means "the apple trees". It is situated in a mountain area in the Germanasca Valley at 1511 m a.s.l. Lying at the foot of the mountain Punta Vergia (m 2998), it maintained the typical character of a small rural village. Its position allows inhabitants and visitors to enjoy an amazing view over a large part of the municipal area.


a.

b.

Figure 82 (a/b). Aerial view of the hamlet (a) and an old sketch (b, Private collection of Pierino Grill).

Case study II: Pomieri hamlet

Pomieri is also characterised by Waldensians migration and settlements for its position and some historical events. As in all the Waldensians Valley, culture and study have a long history. In the first half of the nineteenth century, the historical period named "religious awakening" took place. It is well known that before the spread of the so-called "Beckwith schools", the teaching of reading and writing, aimed primarily at learning biblical notions, was widespread and also practised in makeshift places such as stables, favoured by the warmth of the animals. The first "Beckwith schools" were founded in the villages of Ribba, Pomieri, Malzat, Orgere, Indritti, Ghigo, Cugno and Villa, thanks to the funding of the English Colonel Charles Beckwith (Società di Studi Valdesi, 2012).

As regards its morphology, Pomieri and the entire municipality of Prali are characterised by relatively steep slopes. Consequently, they are naturally exposed to snow slides. In the Maiera avalanche of 1832, there were victims of twelve pralines returning from work in the vineyards downstream of Ghigo, Orgiere and Pomieri. Due to its morphology, related natural risk, and historical and cultural value, the hamlet of Pomieri was chosen as another perfect suitable case study to enrich and populate the MHC ontology. In this case, it is possible to benefit from various structured and unstructured data. These information derive from many sources such as regional geoportal for spatial datasets, cadastral and landscape information from urban and territorial plans, and building permits documents for restoration or construction actions. For case study II, it is possible to consider a multiscale view of the hamlet, from the territorial plans of the mountain valley and the connection with cities to the building permits procedures.

### 6.4.1 Landscape plans and regulation documents

*PPR – Regional Landscape Plan*

The Italian territorial and landscape plans and the *building permits* have been analysed to enrich the ontology with other data of a hamlet case study. Different regulations of the Alps area, with a multiscale approach, have been considered. The first important document from the landscape values point of view is the Regional Landscape Plan[118] (*Piano Paesaggistico Regionale*, PPR). The PPR represents the primary tool to guarantee the quality of the landscape and sustainable environmental development of the entire regional territory. The main objective of the plan is the protection and enhancement of the landscape heritage, natural and cultural. It wants to strengthen the competitiveness and the attractiveness of the territory by improving the lives of the populations and their cultural identity. The PPR also provides thematic GIS maps for different areas (named *Ambiti*). For each area, the PPR offers a description of the landscape components and units. The Germanasca Valley and the related municipality of Prali are located in the “Ambito 41” of PPR. This thesis analyses the document of PPR by manually extracting significant new information to describe the territory and the hamlet. Moreover, the study considers spatial data, subdivisions and descriptions of geometric objects of the Plan. Some instances have also been extracted from the “*PPR, Schede degli ambiti di paesaggio”*, Landscape area sheets document (Regione Piemonte, 2008). Each sheet shows the cartographic map with the perimeter of the area and their municipalities, followed by a brief description of the context, which identifies the prevailing physical and historical-cultural traits.

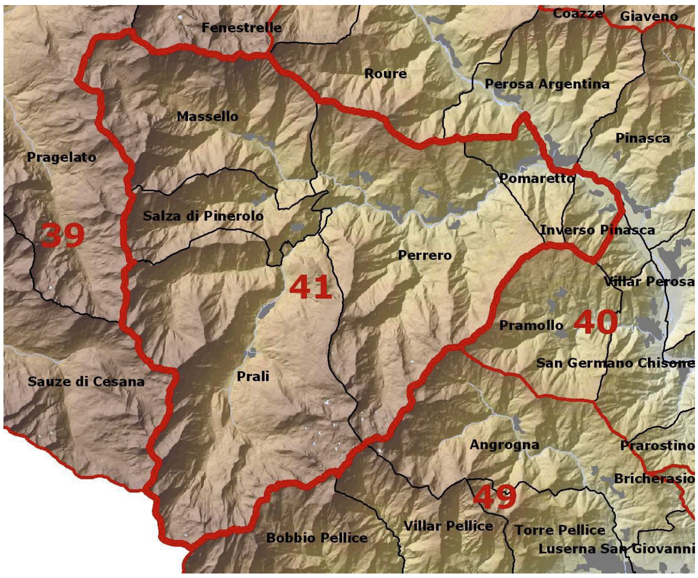



Figure 83. Val Germansca, Ambito 41, Schede degli Ambiti di Paesaggio, PPR.

118 https://www.regione.piemonte.it/web/temi/ambiente-territorio/paesaggio/piano-paesaggistico-regionale-ppr

Some essential documents to consider are:

*PTC - PdC - PRGCM - PRGI - Bulding Regulation of Germanasca Valley and Prali*

- the Provincial-Territorial Coordination Plan (*Piano Territoriale di Coordinamento*, PTC[119]),
  the Building Permits (*Permesso di Costruire*, PdC) descriptions, integrated into the ontology at the building level of detail.

In details, the specific existing documents for the municipality of Prali are:

- the General Plan of the Mountain Community of the Chisone and Germanasca Valleys *(Piano Regolatore Generale della Comunità Montana Valli Chisone e Germanasca*, PRGCM[120]*)*,
- the Intercomuncal general Regulatory Plan (*Piano Regolatore Generale Intercomunale, Unione Montana dei Comuni Valli Chisone e Germanasca*, *PRGI*),
- the Building Regulation of Prali (*Regolamento Edilizio del Comune di Prali*[121]).

From these plans, different spatial and administrative information have been considered. Section 6.5, the ontology enrichment and population with data from the Pomieri case study, reports the different information included in each plan.

## 6.4.2 Available Spatial datasets of Pomieri and Piedmont Region

In addition to the information contained in the landscape plans and regulations, some spatial datasets have been considered for case study II. The same approach followed for case study I has been adopted for Pomieri. These data were analysed, compared, and mapped to the MHC (see § 7.1.2).

### 6.4.2.1 The 3D metric survey by Geomatics Group and Team DIRECT

In the summer of 2019 (from the 26th to the 28th of June), I took part of a 3D integrated metric survey in the area of the municipality of Prali. The survey campaign has been organised by the geomatics group of Politecnico of Torino, and the student Team DiRECT (Disaster Recovery Team[122]) (Grasso, 2015). The team is devoted to acquiring spatial data with rapid systems techniques in damaged areas or places affected by natural hazards. Moreover, one of its targets is to enhance territorial and landscape plans in disadvantaged areas. The survey aimed to document and 3D represent these places to support planning activities and the

[119] http://www.cittametropolitana.torino.it/cms/risorse/territorio/dwd/urbanistica/schede_comunali/1202.pdf
[120] https://www.unionevallichisonegermanasca.it/archivio/pagine/PRGCM.asp
[121] https://www.comune.prali.to.it/cgi-bin/regolamenti/0612202091316_COMUNE_DI_PRALI.pdf
[122] https://www.g4ch.polito.it/wordpress/team-direct/

regeneration of alpine regions to figure out worthy landscape development actions (social, economic, cultural, tourism, etc.).

Different zones have been surveyed: the municipality of Prali and its central square, the hamlets of Pomieri and Ghigo di Prali and the buildings of the Agape Centre. Regarding the hamlet of Pomieri, the reasons that led to carry out the survey are various. Furthermore, the historical and identity values of the village as a whole to be preserved should be emphasized. One building represents cultural and historical values because it was a Becket school, and Pomieri was hit by a snowslide that damaged some buildings (Figure 85). Also, some of these old constructions require restoration due to their natural phenomena of degradation and the time and the climate of the area. The municipality of Prali was also considered as a case study of the MSc course "Riabitare le Alpi" (Rehianbit the Alps) of the Architecture for Sustainability Design degree of Politecnico si Torino (prof. Daniele Regis, Architectural and urban composition; prof. Cristina Cuneo, Documentation of local history; and prof. Antonia Spanò for Architecture and Environment Representation)[123].

The documentation process of a CH asset represents a complex task that should be designed according to several factors: the accuracy of the expected results, the time for the acquisition and processing, the portability of devices, the economic and human resources available, the environmental condition and the flexibility of techniques (Remondino, 2011). Different geomatics techniques can be applied adopting various sensors, as reported in Figure 84 (Nex & Remondino, 2014).

Concerning the case study of this research, the first acquisition phase regarded the creation and measurement of the topographic network (using traditional topographic techniques such as total station (TS) (Figure 86) that was then used to refer all the other acquisitions in the same global coordinate system. Then, close-range photogrammetry (CRP) and UAV (ASPRS, 1980; Kraus et al., 1997) were applied by means of Unmanned Aerial Vehicle (UAV) and digital single-lens reflex cameras (DSLR). The Mavic Pro and Phantom4 Obsidian drones by DJI were used for aerial photogrammetry. The first one was used to acquire the damaged building with a flight height of 15 meters and a mean Ground Sample Distance (GSD) of 8 mm/pix, which "is the pixel size expressed in ground units by reference to the image scale" (Granshaw, 2016). The second drone sensor acquired images of the entire hamlet with a flight height of 60 meters and a mean GSD of 2 cm/pix (Figure 86). Finally, range-based techniques were adopted as well performing some TLS (Terrestrial Laser Scanning) and MMS (Mobile Mapping System) acquisitions (Gomarasca, 2009).

For the TLS acquisition, a Faro FOCUS$^{3D}$ by CAM2 was used, while the MMS acquisitions were achieved with the handheld laser ZEB Revo RT system by GeoSLAM and the Stencil KAARTA®; both based on SLAM algorithms (Simultaneous Localisation and Mapping). All these techniques were deployed in

[123]https://didattica.polito.it/pls/portal30/gap.pkg_guide.viewGap?p_cod_ins=01QJJQN&p_a_acc=2020&p_header=S&p_lang=IT

an integrated approach to achieve a multi-scale and multi-sensor documentation of the heritage asset considered, as reported in Patias.

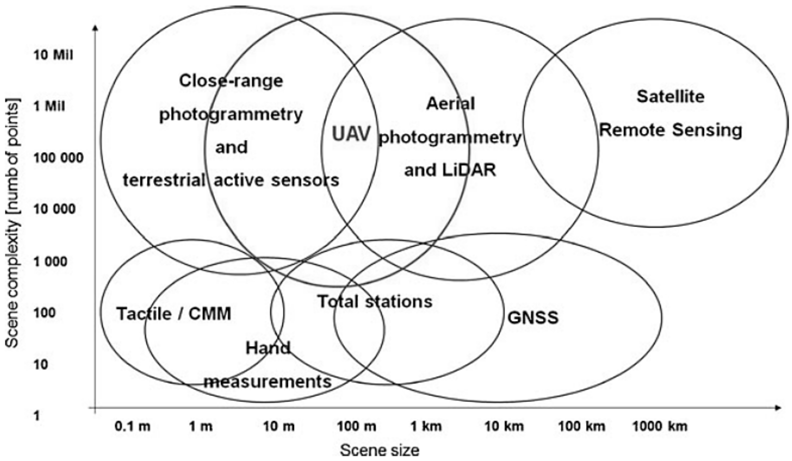



Figure 84. Available geomatics techniques, sensors, and platforms for 3D recording purposes, according to the dimensions and complexity of the scene (Nex & Remondino, 2014).

Figure 85. Damaged building of the hamlet of Pomieri (photo by drones).

Figure 86. Frame acquired during the photogrammetric UAV acquisition (on the right) and GPS/GNSS acquisition on the vertex (on the right).

After the acquisition phase, the data have been processed following consolidated approaches to generate 3D models in the form of point clouds (PC) and meshes. The first step was connected with the computation of the measured topographic network to obtain the vertices coordinates in the reference system WGS84 - ETRF2000. LiDAR data can be processed with different registration solutions, cloud to cloud or by using targets measured by TS or GPS/GNSS. The software SCENE, by CAM2 Faro® technologies, was used. In the registration of scans (in which different datasets were located in a unique reference system, RS), ICP-algorithms (Iterative Closest Point) can be used (Bae, 2006; Gressin et al., 2013), and residual errors were checked. Then, references (coordinates points named Tie Points, TPs) were considered for the final registration. The procedure is called "target-based rigid registration", and it allows the rototraslation of point clouds of scans on coordinates points to georeferenced the model.

Then, MMS data have been post-processed following various approaches (as reported in Bronzino et al., 2019; Calantropio et al., 2019; Sammartano & Spanò, 2018). PCs have been aligned, registered and merged with the final point cloud of TLS (in Cloud Compare).
Successively, photogrammetric data have been post-processed with image-matching techniques and algorithms based on Structure-from-Motion (SfM) approach (Luhmann et al., 2006b; Remondino et al., 2014, 2013; Westoby et al., 2012). In this way, it is possible to obtain sparse and dense point clouds representing the object of interest (Figures 87 and 88). Then, it is possible to generate and export orthophotos (orthomosaics) and digital surface models. Some examples of DSM (Digital Surface Model) and orthophotos are shown in the images below (Figure 89). A similar workflow has been followed for the CRP acquisition. The SW used for the post-processing of photogrammetric data is Agisoft Metashape. Summary details of the process are reported in Table 14.

Table 14. Details of the photogrammetric process (Phantom4).

| ***Number of images*** | ***Flight height*** | ***GSD*** | ***N. of Ties points*** | ***N. of Dense cloud point*** |
|---|---|---|---|---|
| 455 | 85.8 m | 1.85 cm/px | 3,647,650 | 49,916,670 |

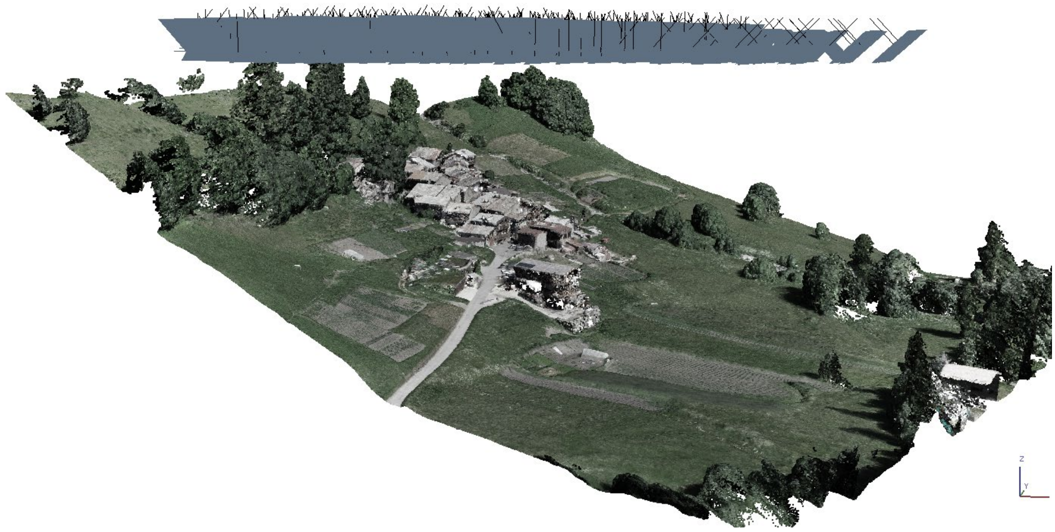


Figure 87. Post-processing of UAV images acquisition in Metashape SW (Phantom4).

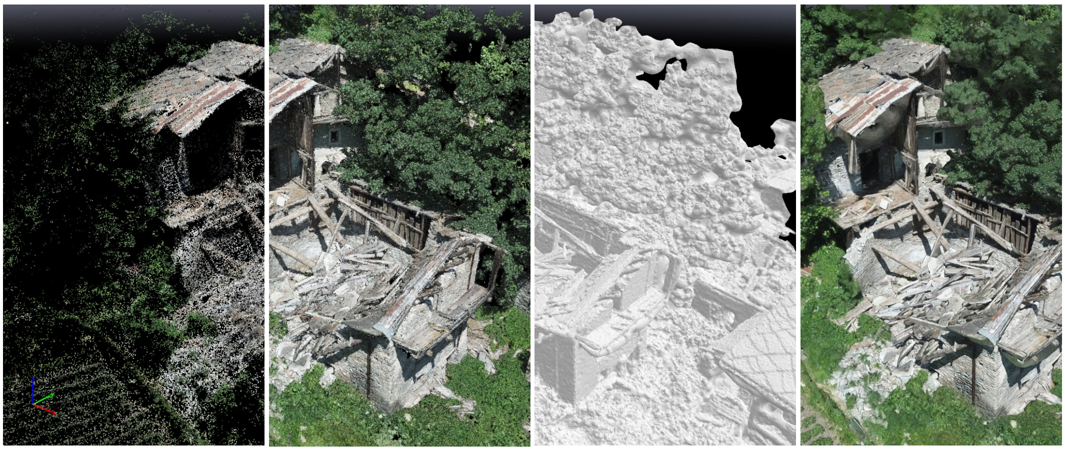


Figure 88. Sparse cloud, dense cloud and mesh of the photogrammetric process.


Figure 89. Orthophoto and DSM of Pomieri generated in the photogrammetric post-process (Mean errors on GCPs, RMSE GCPs = 0.029 m).

These output data can be used to generate 2D maps (in CAD environment or for parametric modelling) and in the GIS domain. Vector or raster data could be imported to vectorised geometries of the hamlet (see Figure 90) and to create a 3D building model. Some data have been integrated into the GIS project (see § 7.1.2), and various information derived from this survey have been inserted into the attribute tables. Moreover, thanks to the data post-processed, it was possible to enrich the level of details of the Pomieri case study (LoD1). The footprints on the ground and the roofs have been vectorised in GIS by adding the DSM and the orthophoto in the project. The 3D polygons of roofs have been designed in a CAD environment by querying the DSM. Thus, a potentiality of the work consists of a possible future WebGIS with 3D accurate data from the 3D metric survey. The 3D app could be queryable, and semantic information could be gathered directly from 3D models.

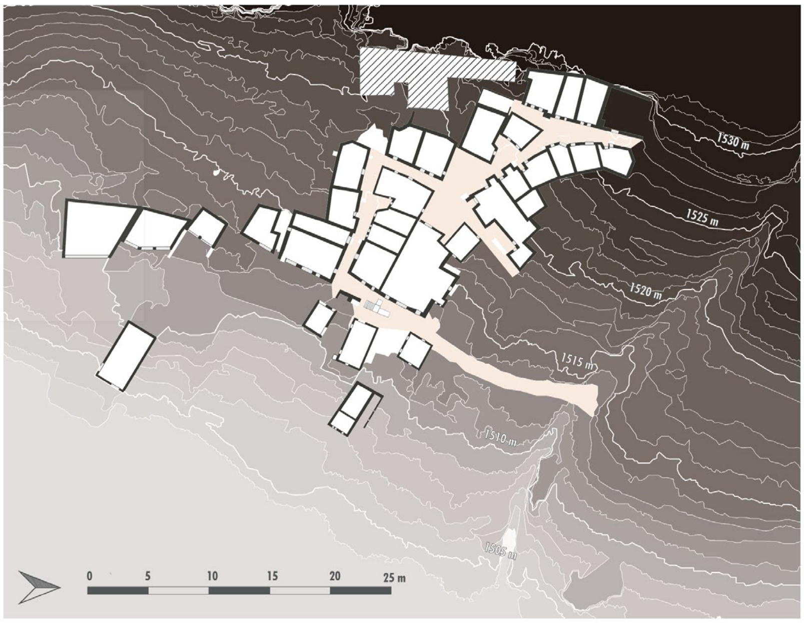



Figure 90. Example of data output derived from the data post-processed, section of Pomieri hamlet buildings (Msc Course "Riabitare le Alpi" 2019, Student Group 4, Biffanti Deborah - Crivelli Arianna - Caiazzo Carla - Dello Vicario Giulia).

#### 6.4.2.2 The Piedmont Geoportal and the BDTRE

REGIONE PIEMONTE

GEO PIEMONTE geoportale regionale

In the Piedmont Geoportal, GEOPIEMONTE[124], is it possible to visualise and query spatial data of the Region. The Region has collaborated to harmonise and disseminate a geographic standards structure by creating the Piedmont GeoPortal. This initiative is in line with the INSPIRE Directive, its national implementation (Legislative Decree no. 32/2010) and the National Territorial Data Directory (RNDT, Repertorio Nazionale Dati Territoriali). There are various services such as data search, download (WFS service, shapefiles and raster data) and consultation. The *BDTRE*[125] (Base Dati Territoriale di Riferimento per gli Enti Piemontesi) represents all the technical cartography of the region, structured according to the national "Technical rules for the definition of the content specifications of geotopographic databases". It aims to support planning, governance and protection activities. The WebGIS interface[126] makes it possible to navigate the catalogue and visualise data in the 2D map. Available data used for case study II are in the cartographic RS WGS84- UTM zone 32N, ETRF 2000, EPSG:32632.

Moreover, in the Geoportal, it is possible to download spatial data related to the PPR. It offers a set of spatial datasets representing objects such as landscape areas, peaks, ridges, lakes, etc[127]. All the datasets downloaded for the ontology validation and the WebGIS project creation are listed in Table 15.

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[124] https://www.geoportale.piemonte.it/cms/
[125] https://www.geoportale.piemonte.it/cms/bdtre/specifiche-per-cartografia-di-base
[126] http://www.geoportale.piemonte.it/geocatalogorp/?sezione=mappa
[127] https://www.geoportale.piemonte.it/cms/images/Ppr_elenco_shape_tavole.pdf

Table 15. Available spatial data from regional geoportal and datasets.

| ***Data description*** | ***Scale of representation and resolution*** | ***Spatial data type*** | ***Source/link*** |
|---|---|---|---|
| Technical Regional Map, the BDTRE 2019 representing toponym, hydrography, borders (of valley and municipalities), buildings, cities, roads, etc. | 1:10000 | Vector, raster, WMS | *https://www.geoportale.piemonte.it/cms/bdtre/specifiche-per-cartografia-di-base* |
| PPR datasets of mountain areas, paths, peaks, ridges, etc. tables P4 and P5 of PPR represent paths network and roads map of forest-pastoral interest (Club Alpino Italiano - CAI paths, village paths, panoramic path) | 1:50000 | vector | *https://www.regione.piemonte.it/web/temi/ambiente-territorio/paesaggio/piano-paesaggistico-regionale-ppr* |
| Map of forest (2016) for the land use (based on the orthophoto AGEA 2012) | 1:10000 | raster | |
| The lithological unit map | 1:10000 | Vector, raster, WMS | *http://map.chisone-germanasca.torino.it/web/images/ValGermanasca/AdeguamentoPAI/Perrero/4.3_Carta%20caratteri%20litotecnici%20e%20idrogeologici.pdf* |
| Avalanches, floods and landslides derive from Arpa Piemonte maps, Avalanche Information System (SIVA) | Max scale 1:5000 | vector | *https://WebGIS.arpa.piemonte.it/Geoviewer2D/index.html?title=Arpa+Piemonte+-+Sistema+Informativo+Valanghe+-+SIVA&resource=agsrest%3Ahttps%3A%2F%2FWebGIS.arpa.piemonte.it%2Fags101free%2Frest%2Fservices%2Fgeologia_e_dissesto%2FSIVA%2FMapServer* |
| DTM of the south-western Piedmont – CTRN 1:10000 | Res. 10m | raster | *http://www.datigeo-piem-download.it/direct/Geoportale/RegionePiemonte/DTM10/DTM10.zip* |
| DTM 2009-2011 ICE, CTR FOGLIO 50-172 | Res. 5m | raster | *http://geomap.reteunitaria.piemonte.it/ws/taims/rp-01/taimsgriwms/wms_griglie?* |
| Historic cartography of IGM (Istituto Geografico Militare) of 1880, 1930, 1960 years | 1:50000, 1:25000 | raster | *https://www.igmi.org* |

## 6.5 Ontology enrichment and population - *Pomieri* data

As performed for the Sloten case study, the *ontology enrichment* and *population* processes have been adopted for case study II. In this case, the approach extracted semantic information (concepts and relations) from the plans and regulations mentioned above. These steps aimed to validate the ontology structure and demonstrate the possible reuse of the knowledge base in the domain of alpine settlements.

For this purpose, some stages (similar to case I, see § 6.3) have been followed. They are reported in Figure 91. The workflow started by selecting existing regulations and plans with a multiscale approach, from the landscape and territorial characteristics of the Germanasca Valley to the Building Permits rules for the municipality of Prali. Then, other unstructured data have been extracted from various sources (historical, risk-related and charters). These documents have been analysed by manually extracting information from the text. In the ontology population phase, practical examples (instances) describing the Pomieri hamlet and its context have been added to the MHC ontology. Moreover, structured data, such as spatial datasets from Regional Geoportal and National databases, have been mapped (see § 7.1).

The methodology application workflow phases were performed to develop a knowledge base in different domains. Chapter 7 shows the connection among spatial data (harmonised and integrated) and semantic concepts of the ontology to prove the practicality of an ontology structure developed for the MHC domain.

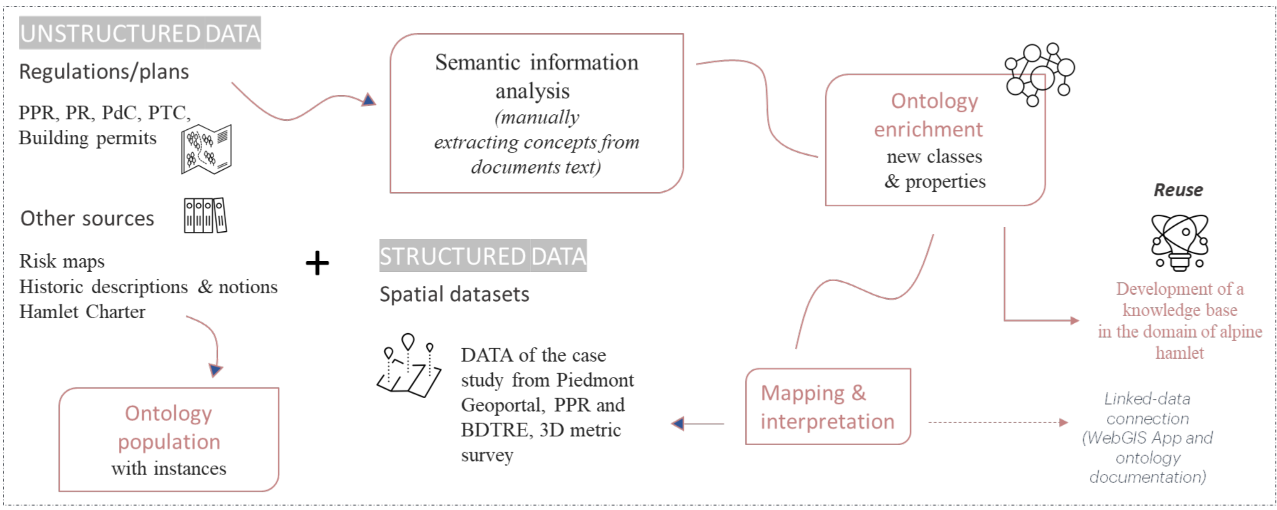



Figure 91. Ontology enrichment and population workflow with data from case study II, Pomieri.

### 6.5.1 Ontology enrichment (II)



This part of the ontology enrichment approach analysed landscape plans and regulation documents (§ 6.4.1) by manually extracting some new classes and relations for the spatial and temporal documentation of alpine hamlets. Below various texts from regulation are reported. Concepts to be integrated into the MHC ontology are highlighted in grey, instances in dark yellow (described in next section), data properties in jade-green, and object properties in red (as done for case study I). These concepts have been mapped to the existing ontology in Protégé to check if some definitions already exist or are equal to others. The first class added to the ontology are "***mountain hamlet***" and ***"alpine settlement",*** a subclass of "***hamlet***".

Excerpt of texts of *Landscape Areas Sheets* and *Implementation Rules* of ***PPR*** documents are reported below (Regione Piemonte, 2008, p.287; 2017, p. 151).

*"The Ambito/Area 41 includes the Val Germanasca with municipality of Inverso Pinasca (40-41), Massello (41), Perrero (41), Pomaretto, (41), Prali (41), Salza di Pinerolo (41)."*

*"The municipality of Prali is identified in the documents of the PPR with the numeric codes 4104, 4105, 4106.*

*Area 41 is essentially defined by the basin of the Germanasca stream with its tributaries (Massello, Salza, Prali), from its sources to the confluence with the Chisone stream at Pomaretto (To)".*

*"The area is characterized by:*

*- the presence, in the high-alpine area, of a system of roads and mule tracks that connected the various military structures, now being abandoned, but with a significant impact on the landscape. These infrastructures allow access to some panoramic points, such as the vast plateau of 13 lakes, of glacial origin;*

*- the talc mines (Prali) are still mined and processed today in one of the most important mining complexes in Italy;*

*- the SIC Val Troncea and the Conca Cialancia Natural Park are linked to the subalpine forest and alpine environments of naturalistic and landscape value."*

*"The main components of the historical rural heritage that concern the territory and the villages of the municipality of Prali are:*

*- SS35 Alpine core connected to agro-silvopastoral uses*

*- SS52 Poles of religiosity (art. 28) Shrines and works "of commission" of territorial value*

*- SS62 Fortification lines*

*- SS71 holiday resorts and leisure centres*

*- SSC2 Visual relationships between settlement and context (art.31)"*

The Implementation rules document also reported some objectives of Area 41:

- "The first mission is to revitalise and innovate functions for Alpine settlement systems in an integrated way between new functions and

> protection of the characterizing elements. Then, another objective is to enhance the system of alpine settlements, in abandonment or at risk of dismissal or collapse, and of the related rural and wooded context, with guidelines for the recovery and architectural transformations."

The PPR also defines classes of *Landscape Unity, Historic-natural theme* and *Urbanistic theme.* Finally, from the table of the Landscape Areas Sheets, "rural architectural typology, techniques and construction material (used in Area 41)"[128], it is also possible to notice other two concepts: *Forni (=ovens)* and *Case in pietra (=stone house).*

The ***PTC,*** Provincial-Territorial Coordination Plan (Provincial Territorial Coordination Plan, Provincia di Torino et al., 2015) of the municipality of Prali, reports various statistical data related to the population (from the Italian ISTAT, Istituto Nazionale di Statistica), the physical and morphological conformation, the agriculture, the history, and so on. Some of these data are, for example:

- Istat code: 1202 (1)
- Municipal area (ha): 7.261,2 (1)
- Morphology, mountain area (ha): 7.261,0 (2.a)
- Wood Area Surface (ha): 2.821,3 (4.b)
- Homes, dwellings occupied by resident person: 1.149 (5.b)
- Historical and cultural values: type D, total assets 5 (pole of religiosity) (6)
- Infrastructure and mobility: SP 169, Val Germanasca, 8.21 km – SP 260, Rodoretto, 0.70 km (8)
- The municipality is not served by the Metropolitan Railway System (SFM)
- Avalanche length: linear, 28.2 km; areal, 1.647,9 ha
- Public water: Rio Dei 13 Laghi, Rio Di Ghigo, Rio Vallon, Torrente Germagnasca, Torrente Germagnasca Di Mossello (B), Torrente Germagnasca Di Rima (A)

Some of these data are already present as attributes of the spatial object downloaded from the Regional Geoportal. For this reason, they have not been included in the ontology structure as classes or instances to avoid repetition.

The other documents considered for the semantic information analysis are related to the ***PRGCM*** and the ***PRGI.*** Different texts are available on the Unione Montana Chisone e Germanasca official website[129] or the web page of the "Map" project[130]. Among them, three have been selected (1-3).

1) The first one is the document "Relazione, tav 7.11" (UNIONE MONTANA DEI COMUNI VALLI CHISONE E GERMANASCA et al., 2013). For the hamlet of Pomieri it reports the Avalanche Phenomena of winter 2008-2009 with a map (Figure 92).

[128] Regione Piemonte, "Ppr. Schede degli ambiti di paesaggio", p. 291.
[129] https://www.unionevallichisonegermanasca.it/ita/elenco_servizi.asp
[130] http://map.chisone-germanasca.torino.it/web/index.php?option=com_content&view=article&id=50&Itemid=57

*"In the Municipality of Prali, the main damage is mainly related to the torrential activity of some tributaries of the Germanasca stream, near the Pomieri hamlet".*
*"Pomieri was also involved in different landslide phenomena in 2000 and 2008".*

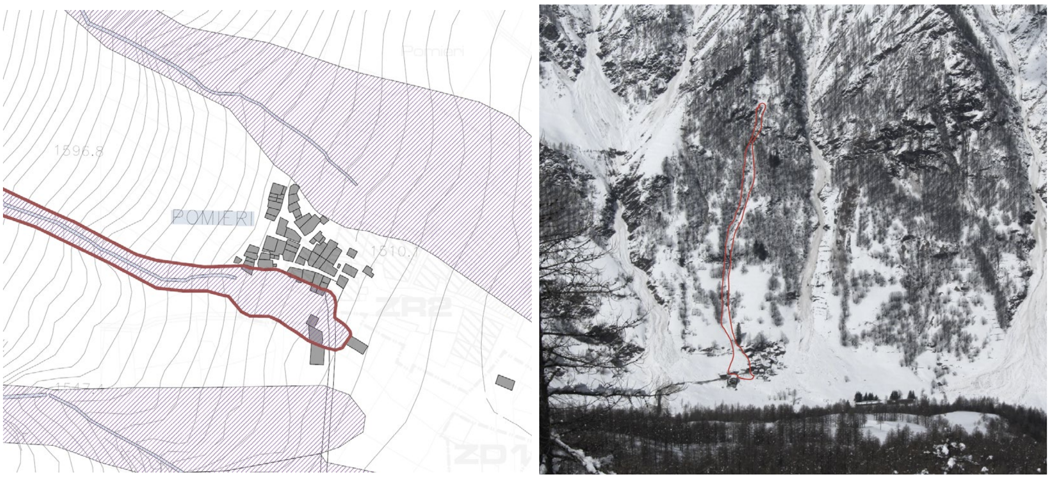


Figure 92. Avalanche area of winter 2008-2009 damaging the building in Figure 87.

2) The second one is the "Zone di Recupero e Sviluppo", Recovery and developments area, scale 1:1000 (COMUNITA' MONTANA DEL PINEROLESE, 2012); PRGI - Structural variant of adaptation to the P.A.I.. From the map (Figure 93) of this document, it is possible to extract information related to the buildings needing mandatory interventions of:

   - restoration (philological and conservative restoration and conservative renovation) and some other objects of the hamlet (such as fountains, architectural elements, sundials, votive towers, frescoes, decorations, newsstands, fountains and ovens).

Figure 93. Recovery and developments area of Pomieri (scale 1:1000), ZR2 express Recovery areas and ZD1, development zone, * are fountains or ovens. Buildings on the north need philological restoration, and buildings in the south of the hamlet need conservative renovation activities.

3) The document "Schede e Tabelle di Zona", Zone Cards and Tables, (COMUNITA' MONTANA DEL PINEROLESE, 2013), reports the zone ZR2 of Pomieri (p .30). It indicates some urbanistic and construction indicators and some norms. The *destination land use* is primarily *residential* with a territorial surface of *4026* sqm. Specific rules are reported:

   - *"It is forbidden to modify the environmental characteristics of the road and building plot and the artefacts, even isolated ones, which constitute historical, cultural and traditional evidence (...).*
     *The area is affected by the following suitability classes: II, IIIa1, IIIa2, IIIb3, IIIb4.*
     *The timetable of interventions for the areas in Class IIIb: for the sectors falling into Class IIIb3 and IIIb4 affected by the distal sector of the avalanche arrest zone, interventions are necessary to ensure the safety of the impluvium against the underlying buildings. In particular, a study must be envisaged aimed at defining the areas at different levels of danger according to the impact pressures, using the methodologies defined by the AINEVA (Interregional Snow and Avalanche Association) to determine any interventions to be carried out."*

The **Building Regulation** of Prali , "Regolamento edilizio" (Comune di Prali & Città Metropolitana Torino, 2018) reports some rules concerning building construction and materials.

> *"In the Villages Villa, Malzat, Orgere, Pomieri, Ghigo ed Indiritti is allowed only the construction of the roofs of the buildings in stone lose or wood shingles."*

The abovementioned sources describe plans, building permit procedures, risk phenomena, and restoration actions. Adding to the ontology these information can be helpful to create a unique structure in which it is possible to store various regulations data. In this way, common semantic knowledge is shared among administrations, municipality bodies, civil protection, architects, and restorers to reach common aims. These documents of the historical centre of Pomieri have been reported as examples of possible classes, relations and instances that could be added to the ontology to enrich the MHC knowledge domain for several purposes. Some other sources could be considered to improve the knowledge of the hamlet of Pomieri. The following paragraph lists some of them:

- The text of Società di Studi Valdesi (2012) has been analysed. ***Historical descriptions and notions*** related to Waldensian settlements, partisans in the second world war, natural disasters (such as landslides and avalanches) and interventions for the ski lifts are reported. Classes and instances such as Beckwith schools, Waldesian valley, partisans, ski areas, chairlift and so on can be implemented in the ontology for possible historical documentation purposes.

- Other information are related to some statistics of ISTAT or Eurostat[131] datastets on families or inhabitants, such as (surname, number of families, population, language, idiom).
- Information related to ***tourism*** could be handy to investigate turnout flows linked to the different seasons and villages. Tourist activities in Prali are related to the museums (Waldesian Museum[132], Ecomuseum of Mines and Germanasca Valley[133]) and the Prali sky area[134].
- In addition to the ***risk*** classes reported in the PRGI and in the PRG it is possible to add classes of "man-made hazard" and "natural hazard" (such as landslide, earthquake, avalanche) as subclasses of risk. A classification of risks is available in The International Disaster Database developed by Centre Research of Epidemiology Disaster (CRED)[135].
- The last domain of interest of the mountain area of Prali regards its ***networks.*** For this field, transport classes for the connections with the lower valley and the city of Turin, wireless nets *(such as WiFi and broadcast network)* and energy (renewable, solar, biomass, hydric, wind and geothermal) nets could be considered as subclasses of "net".

*Ontology mapping and updating*

Finally, the ***ontology updating*** was aimed to revise and integrate the ontology according to the previous ***mapping***. The ontology structure has been implemented by adding classes and relations in Protégé after having analysed documents and texts related to different activities in which the municipality of Prali and the hamlet of Pomieri are involved. The schema below (Figure 94) reported the different thematic areas and domains of the entities added in various colours (legend in the bottom right of the image). In grey, existing classes already implemented into the version 1 of the ontology are highlighted.

## 6.5.2 Ontology population with instances (II)

*Ontology population II*

This section presents examples of *instances* extracted from the texts and documents analysed in the ontology enrichment steps. Only a few have been added to the MHC ontology to prove the possibility of reusing such knowledge in various fields such as restoration actions, historical documentation, regional and city plans, and building permits processes. Further studies on historical documentation, risk description and restoration or planning activities can add many other instances from existing sources. Table 16 shows some examples of triples with instances, classes (C) and predicates from case study II sources.

[131] https://ec.europa.eu/eurostat/web/cities/data/database
[132] https://museovaldese.org/museo-valdese-prali/
[133] https://www.ecomuseominiere.it/territorio/musei/
[134] https://www.praliskiarea.com/
[135] https://www.emdat.be/classification

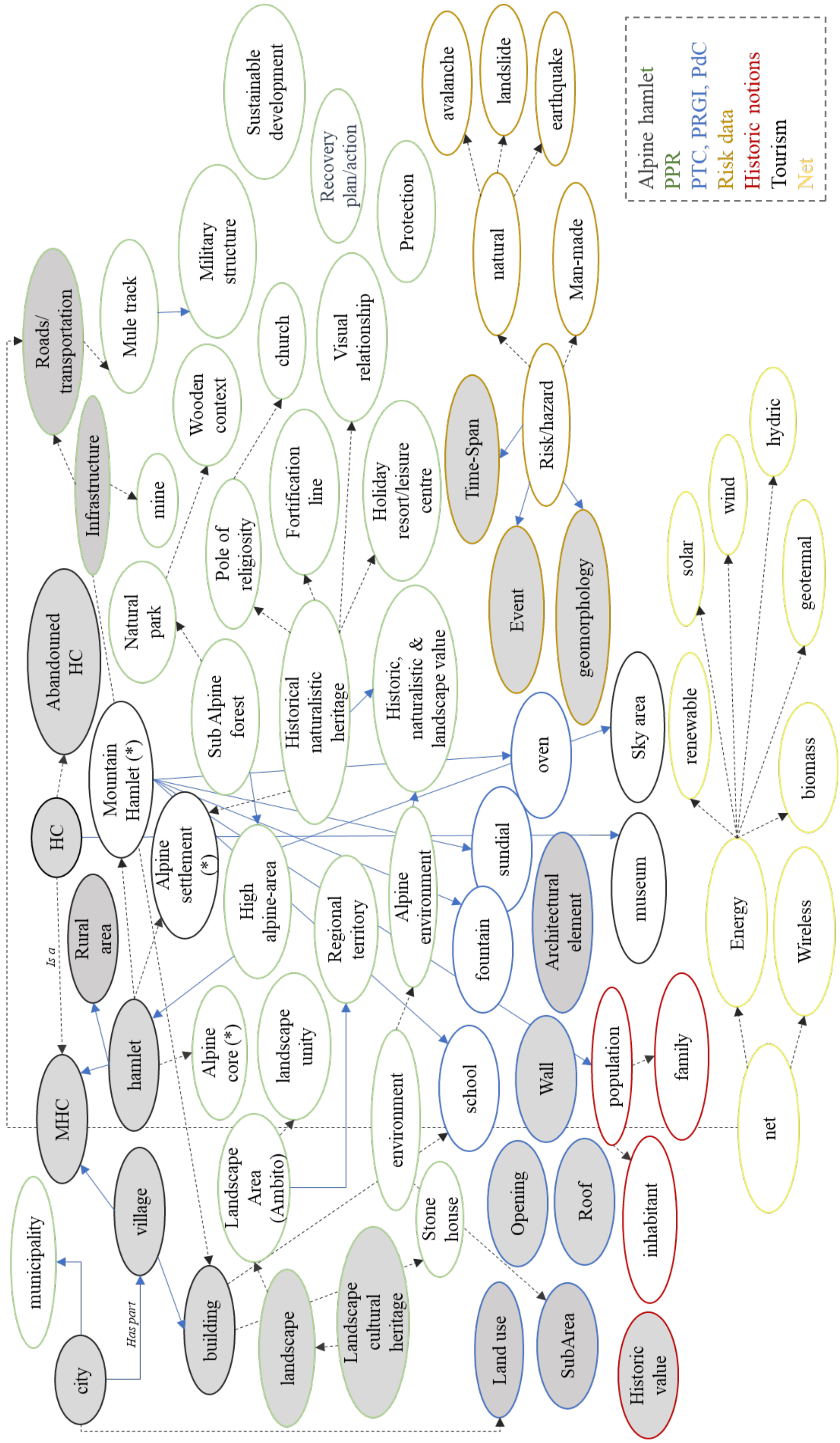



Figure 94. Classes and relations added into the ontology after the data enrichment from the Pomieri hamlet case study.

Table 16. Examples of triples of instances, classes and properties from case study II sources and documents (* Referred to data-property or class / Object property assertion).

| Subject | predicate | Object | Properties* |
|---|---|---|---|
| Ambito/Area 41 of PPR | *includes* | Val Germanasca | Object property assertion / toponym |
| Prali | *is located in* | Val Germanasca | Object property assertion/ toponym |
| Pomieri | *is in the municipality of* | Prali | Object property assertion/ toponym |
| Pomieri | *is a* | Minor historical centre (C) | Object property assertion |
| Prali | *is in the region* | Piedmont | Object property assertion |
| Prali | *is in the province of* | Turin | Object property assertion/ toponym |
| Pomieri | *is a* | Mountain hamlet (C) | Type (of hamlet) |
| Prali | *is identified with* | Numeric code | Object property assertion |
| Numeric code | *has number* | 4104 – 4105 – 4106 | Data property: number |
| Val Germanasca | *borders with* | Val Chisone | Object property assertion/ toponym |
| Val Germanasca | *borders with* | Val Pellice | Object property assertion/ toponym |
| Area 41 | *is characterized by* | Panoramic point | Object property assertion |
| Panoramic point | *is* | Plateau of 13 lakes | Object property assertion/ toponym |
| Prali | *has istat code* | 1202 | Data property: number |
| Wood Surface area | *has dimension (ha)* | 2821,3 | Data property: number |
| Recovery area of Prali | *is identified with the code* | ZR2 | Data property: code |
| Development area of Prali | *is identified with the code* | ZD1 | Data property: code |
| Pomieri | *has* | Becket School | Object property assertion |
| Becket school | *is a* | School (C) | Object property assertion |
| Prali | *has* | Waldesian Museum | Object property assertion |
| Prali | *has* | Ecomuseum of mines | Object property assertion |

## 6.6 Resulted final application ontology

*Application Ontology of MHC*

This section presents the main result of this thesis: the application ontology, the updated version of MHC ontology version 1 (explained in the previous chapter 5). After the ontology creation and integration from existing standards and conceptualisations, it was enriched and populated with classes, relations, and instances from the two case studies. In the Protégé ontology editor, the reasoner HermiT (version 1.4.3.456) has been applied, and all the inconsistencies have been checked and solved. Moreover, by using the Ontology Debugger Plug-In[136], it is possible to validate the ontology.

After starting the process, the result shows: “the ontology is coherent and consistent” (Figure 95). Then, the OntoGraf tool was launched to query classes and to graphical visualise them. Below, some images report possible queries of entities containing the semantic “historical”, “building”, and “heritage” (Figure 96, Figure 97, Figure 98).

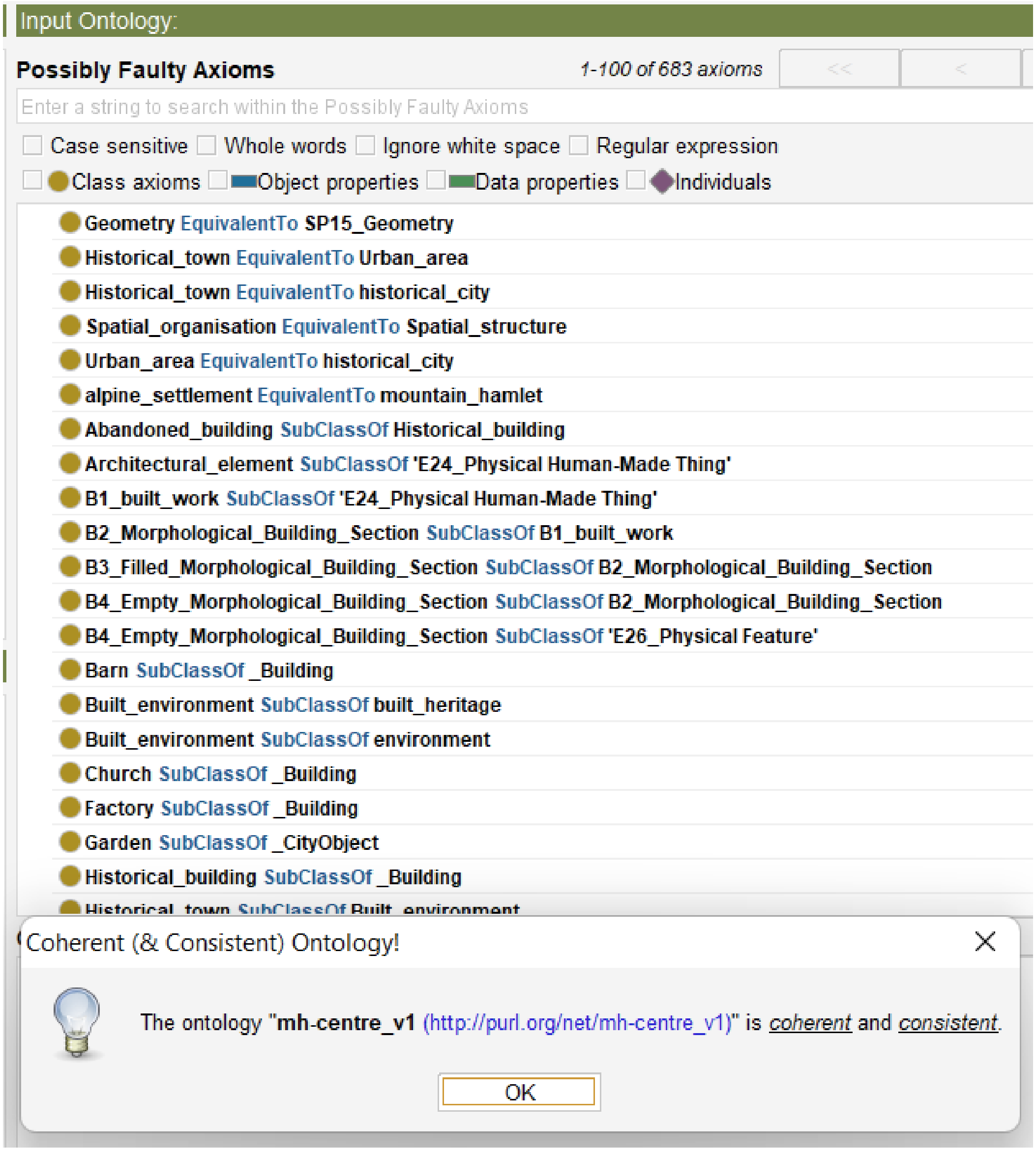



Figure 95. Ontology Debug Plug-In, the screenshot of the software shows that the MHC ontology is consistent and coherent.

[136] http://isbi.aau.at/ontodebug/Plug-In

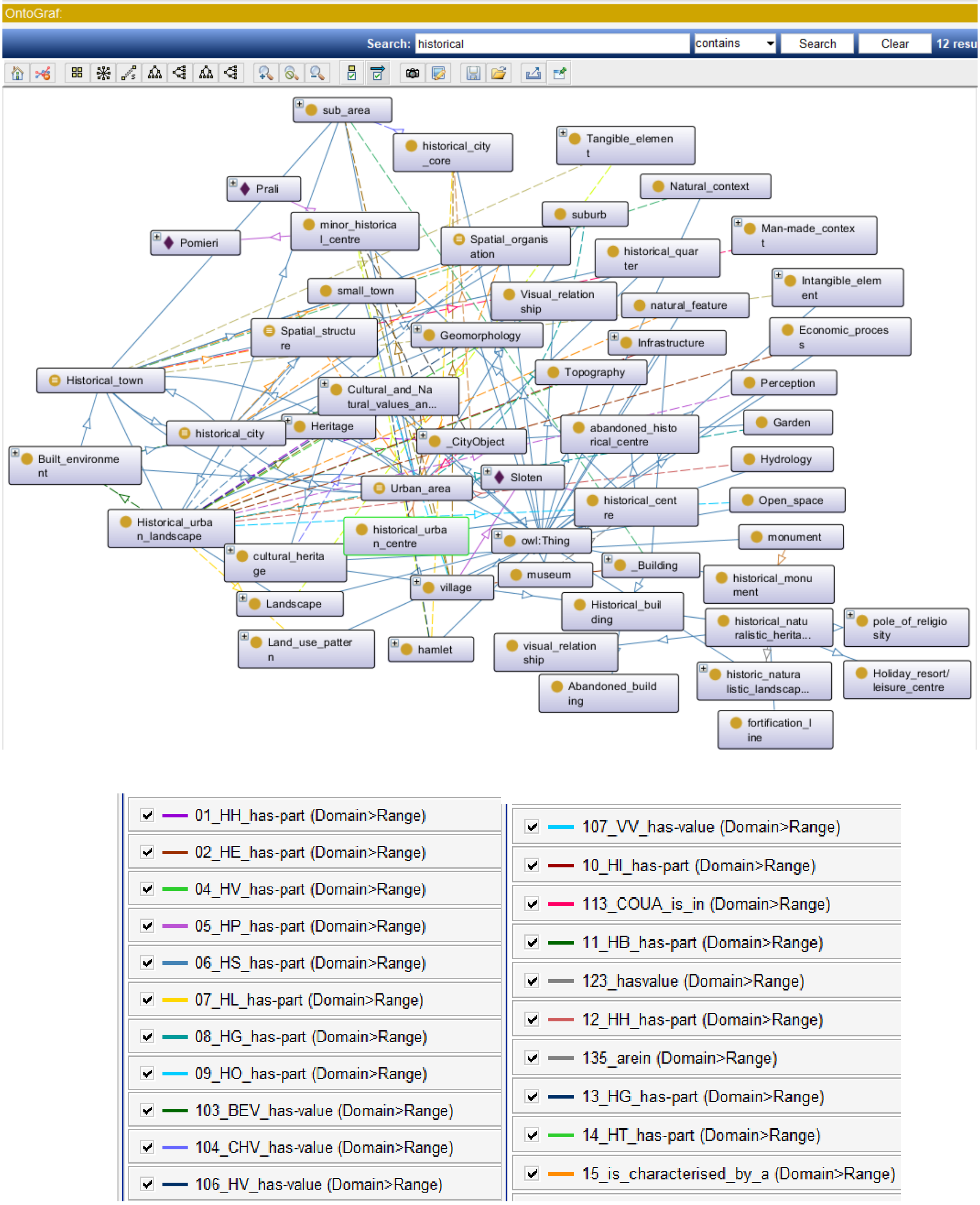



Figure 96. OntoGraf query of entities containing "historical" semantics. On the right, properties with different colours are listed.

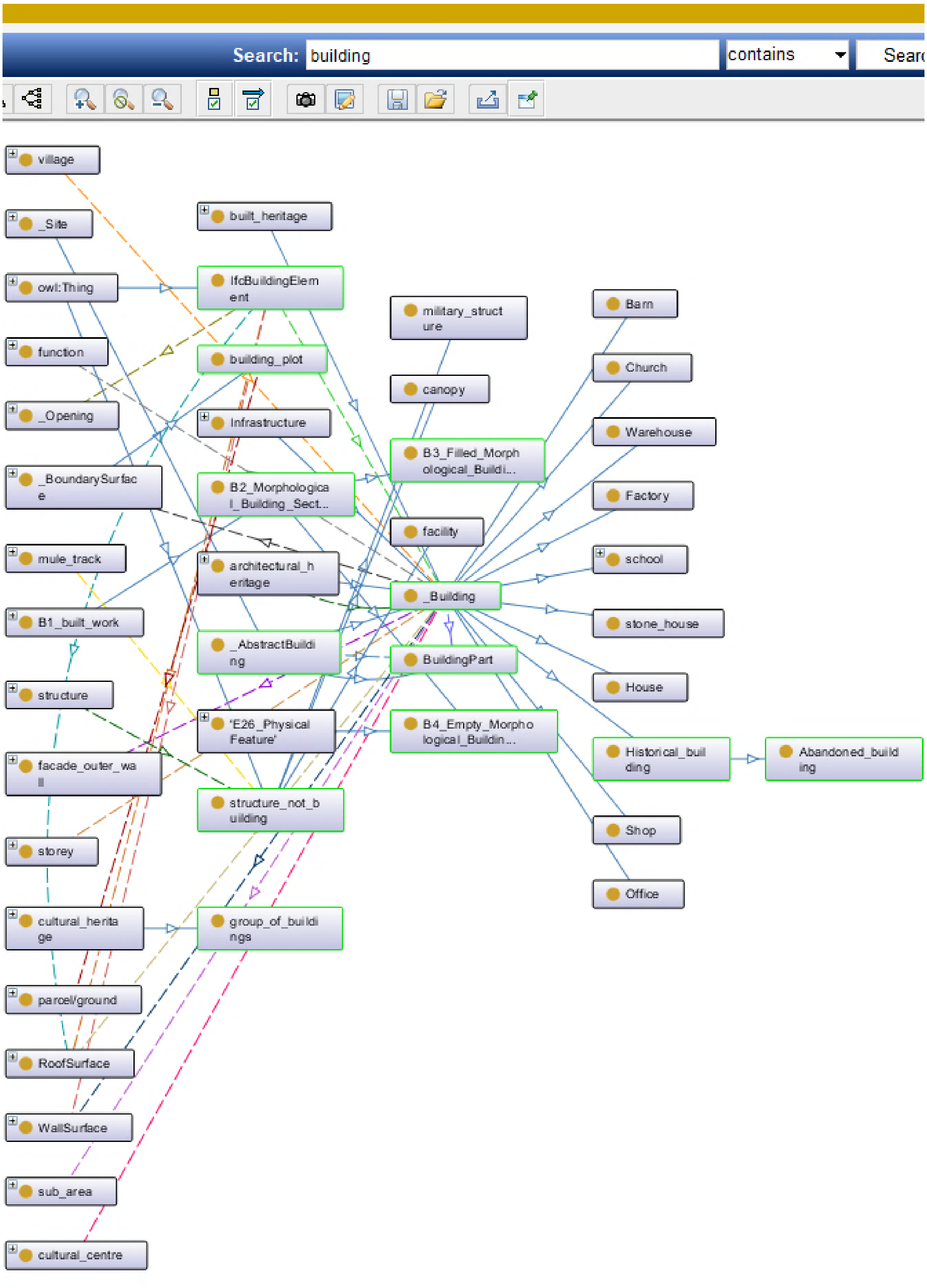



Figure 97. OntoGraf query of entities containg "building".

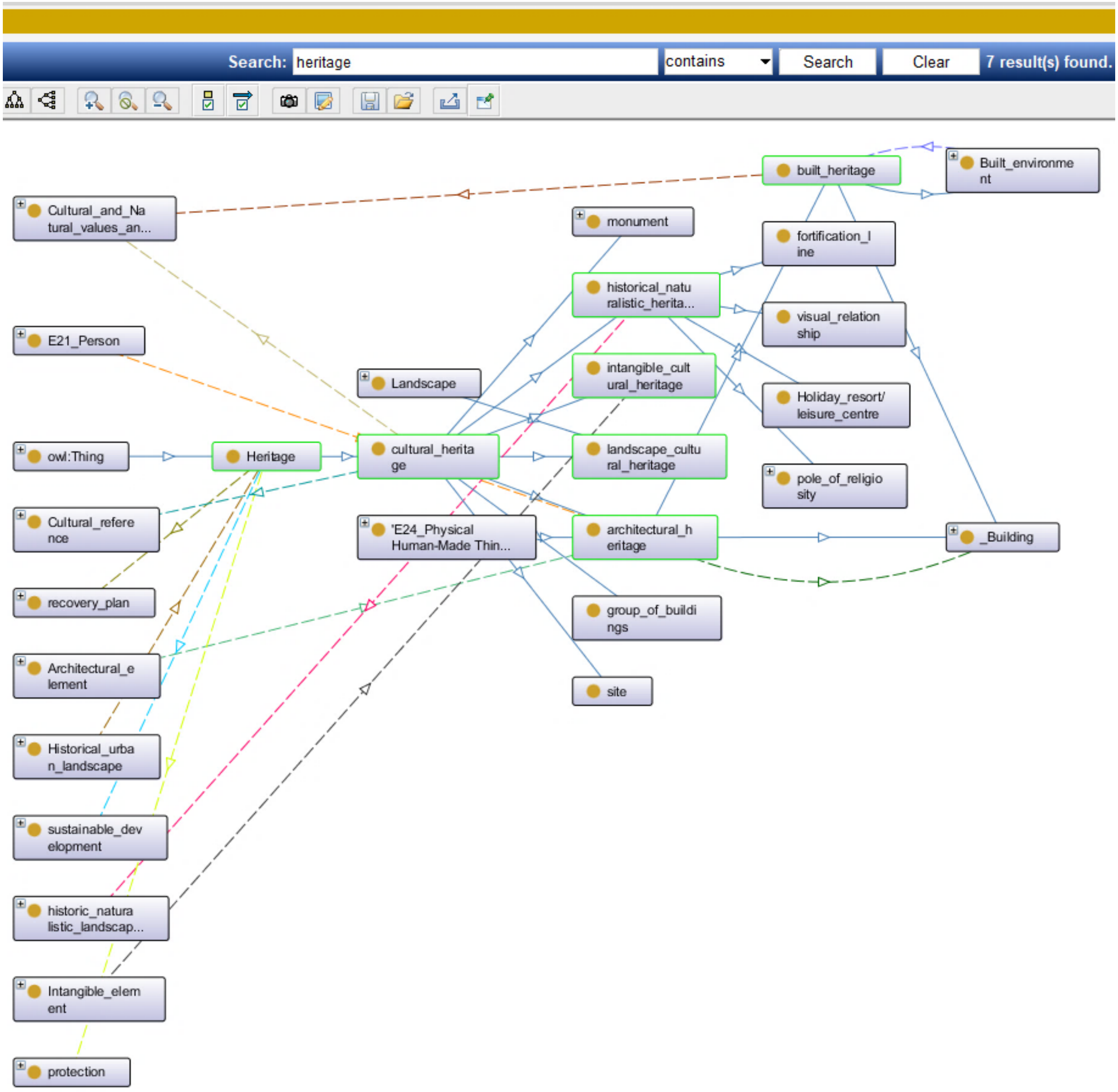



Figure 98. OntoGraf query of entities containing "heritage".

The new VOWL Plug-In, implemented in Protégé 5 (version Beta 0.4.1.49[137]), has been added to visualise entity and relations graphically. On the right of Figure 99, it is possible to notice the URI of selected entities. By clicking on these URIs, the OWL2 source of the class is visualised.

[137] http://vowl.visualdataweb.org

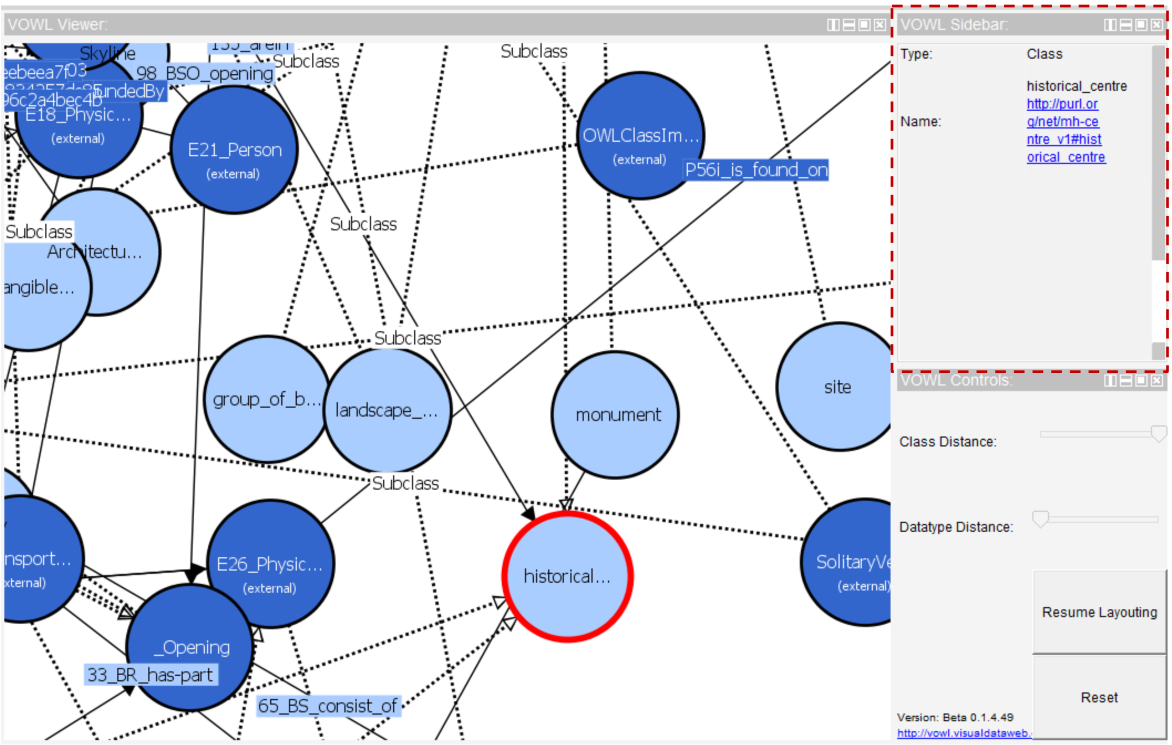



Figure 99. VOWL Plug-In in Protégé, historical city entity selected, https://raw.githubusercontent.com/elicolu/mh-centre_v1/gh-pages-branch/mh-centre_v1.owl#historical_city.

Below, it is possible to see some OWL2 excerpts of the ontology. Following texts report Annotations, “Historical centre” and “Abandoned Historical Centre classes” in OWL2.

- Ontology descriptions:

```
<?xml version="1.0"?>
<Ontology xmlns="http://www.w3.org/2002/07/owl#"
     xml:base="http://purl.org/net/mh-centre_v1"
     xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
     xmlns:xml="http://www.w3.org/XML/1998/namespace"
     xmlns:xsd="http://www.w3.org/2001/XMLSchema#"
     xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
     ontologyIRI="http://purl.org/net/mh-centre_v1"
     versionIRI="http://purl.org/net/mh-centre_v1">
    <Prefix name="" IRI="http://purl.org/net/mh-centre_v1"/>
    <Prefix name="g"
IRI="http://www.semanticweb.org/betti/ontologies/2020/5/minor_hist
orical_centres_v1/"/>
    <Prefix name="dc" IRI="http://purl.org/dc/elements/1.1/"/>
    <Prefix name="owl" IRI="http://www.w3.org/2002/07/owl#"/>
    <Prefix name="rdf" IRI="http://www.w3.org/1999/02/22-rdf-
syntax-ns#"/>
    <Prefix name="xml"
IRI="http://www.w3.org/XML/1998/namespace"/>
    <Prefix name="xsd" IRI="http://www.w3.org/2001/XMLSchema#"/>
```

```
    <Prefix name="rdfs" IRI="http://www.w3.org/2000/01/rdf-
schema#"/>
    <Prefix name="skos"
IRI="http://www.w3.org/2004/02/skos/core#"/>
    <Prefix name="Sloten_casestudy"
IRI="http://www.semanticweb.org/elisabetta/ontologies/2021/3/Slote
n_casestudy#"/>
    <Prefix name="minor_historical_centres_v1"
IRI="http://www.semanticweb.org/betti/ontologies/2020/5/minor_hist
orical_centres_v1#"/>
    <Annotation>
        <AnnotationProperty
IRI="http://ainf.aau.at/ontodebug#testCase"/>
        <AnonymousIndividual nodeID="_:genid2147483648"/>
    </Annotation>
    <Annotation>
        <AnnotationProperty
IRI="http://ainf.aau.at/ontodebug#testCase"/>
        <AnonymousIndividual nodeID="_:genid2147483649"/>
    </Annotation>
    <Annotation>
        <AnnotationProperty abbreviatedIRI="dc:contributor"/>
        <Literal>Margarita Kokla
Andrea Maria Lingua
Antonia Spanò</Literal>
    </Annotation>
    <Annotation>
        <AnnotationProperty abbreviatedIRI="dc:date"/>
        <Literal>07/04/2021
16/06/2021
24/08/2021
13/09/2021
27/10/2021
25/11/2021
12/01/2022 --&gt; instances</Literal>
    </Annotation>
    <Annotation>
        <AnnotationProperty abbreviatedIRI="dc:description"/>
        <Literal>Elisabetta Colucci PhD thesis</Literal>
    </Annotation>
    <Annotation>
        <AnnotationProperty IRI="#Description"/>
        <Literal
datatypeIRI="http://www.opengis.net/ont/geosparql#gmlLiteral">Geos
patial ontology to support the documentation of Minor Historical
Centres (MHC)

PhD thesis in Urban and Regional Development (URD) - Politecnico
di Torino - 34th cycle</Literal>
    </Annotation>
<Annotation>
        <AnnotationProperty abbreviatedIRI="rdfs:comment"/>
        <Literal>First version of minor historical centres
ontology for spatial documentation</Literal>
    </Annotation>
    <Annotation>
        <AnnotationProperty abbreviatedIRI="rdfs:label"/>
        <Literal></Literal>
    </Annotation>
    <Annotation>
        <AnnotationProperty abbreviatedIRI="owl:versionInfo"/>
        <Literal></Literal>
```

- "historical centre" class:

```
<Declaration>
        <Class IRI="# historical_centre"/>
    </Declaration>

<AnnotationAssertion>
        <AnnotationProperty IRI="#Source"/>
        <IRI>#historical_centre</IRI>
        <Literal>equivalent to Ecpm 30 Historical centre -
Acierno, Fiorani</Literal>
    </AnnotationAssertion>
    <AnnotationAssertion>
        <AnnotationProperty abbreviatedIRI="rdfs:comment"/>
        <IRI>#historical_centre</IRI>
        <Literal>_An urban center, both old and new, in fact
represents an entity with life (in the broadest sense that can be
attributed to this expression.
 _A historical centre, however, as well as the neighbourhoods of
the new city connected to it, continues to live; it has its own
population which often carries out its work activities within the
center itself, maintains social and political relationships and
cultural exchanges; has its own face validly expressed through the
architectures and the environment formed by them. A historical
centre is the place of people traditions and culture. Fano, G.
(1974)
_historic centre represents the oldest part of an urban
settlement, generally the richest in historical evidence; in urban
planning (Dizionario Treccani).
_historic city is the one that, with the stratification of its
monuments and the entire urban fabric, exemplary reflects the
historical, anthropological, cultural and artistic evolutionary
process of which it was the protagonist (Dezzi Bardeschi).
- An historical centre is "a place more or less configurable
within a perimeter/boundary, where citizenship has traditionally
carried out (and continues to carry out) the main activities, and
the most representative offices for these functions have long
since consolidated" (Di Gioia, 1975).
- Today, on the basis of this long debate, an historical centre,
therefore understood as a cultural, economic and social asset,
constitutes an extremely sensitive geographical area, with a
specific urban identity and a high historical value and
testimonial referable both to the urban fabric that to elements of
the building heritage, both with notable that with minor
importance (Cerasoli, 2010).</Literal>
    </AnnotationAssertion>
```

- "abandoned historical centre" class:

```
<Declaration>
        <Class IRI="#abandoned_historical_centre"/>
    </Declaration>

   <AnnotationAssertion>
        <AnnotationProperty abbreviatedIRI="rdfs:comment"/>
        <IRI>#abandoned_historical_centre</IRI>
        <Literal>The concept of minor historical centres is
introduced by Alberto Predieri, in his report for the "VI Convegno
A.N.C.S.A."- Bergamo, 1971.Abandoned Minor historical centres are
those in which the physical and technological deterioration of
buildings finds its origin in the demographic exodus.
In 1975 the European Charter of Architectural Heritage defined
"abandoned places".</Literal>
    </AnnotationAssertion>
```

7

Chapter 7

# From ontology to spatial data



This chapter investigates how classes, relations, instances and data properties added to the minor historical centres ontology could answer the main aim: the spatial and temporal documentation of the MHC domain. Different methodology validation methods have been adopted in this part of the research. Firstly, various datasets of case studies from data models, national and regional geoportal or SDIs, have been selected, mapped and harmonised. The process aimed to create new geodatabases storing geometries and their properties (attributes). Then, the final results consist of linking spatial data objects with their semantics, developed and defined into the MHC ontology. For this purpose, WebGIS apps were created relating geometries to semantic classes published into *ad-hoc* ontology documentation online.

This final step is crucial for shared spatial documentation purposes. Creating a unique and standard web tool, user-friendly, open and available online allows different actors and stakeholders involved in MHC activities to use an ontology-based instrument (sharing common knowledge and language). The methodology application shows different scenarios in which it is possible to benefit from the developed geospatial ontology structure. The two case studies selected also demonstrate the possibility to apply the methodology with different levels of detail.

The following paragraph (§ 7.1) described the comparison of spatial datasets and their harmonisation after mapping and translation in the GIS environment. Then, the process to publish online the ontology documentation is reported (§ 7.2.1) followed by the WebGIS App publication (§ 7.2.2). Finally, Linked Data connections and querying of geometries are described (§ 7.2.3).

## 7.1 Mapping of case studies datasets

... to spatial data

Different methods are available to develop conceptual model ontology-driven from developed ontologies (El-Ghalayini et al., 2004; Fonseca et al., 2019). In the presentation of Guarino & Welty (2000), the approach that leads "from ontology to data" is reported. After defining fundamental notions from formal ontology, establishing a set of properties and constraints and designing a top-level ontology, it is possible to drive the conceptual modelling (Figure 100).

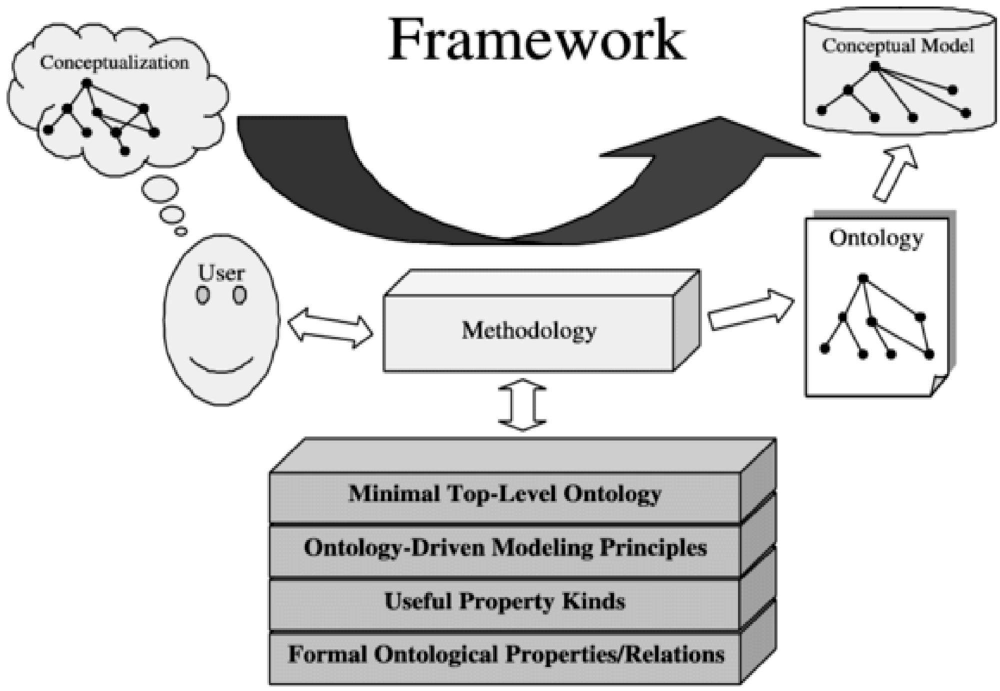



Figure 100. The framework of the Ontology-driven conceptual model (Guarino and Welty, 2000).

Moreover, to design an ontology-driven database, it is necessary to primarily define a reference ontology, then enrich it, focus on particular domain studies (application ontology), and finally describe constraints between terms. In this way, Knowledge Base can be defined.

This research decided to skip the phase of conceptual model definition from ontology-based systems to connect spatial data with their semantics directly. The different datasets of specific case studies have to be mapped, analysed, and harmonised to reach this aim. The final scope is the creation of a shared GDB.

Data harmonisation "aim is to transform different data sets in such a way that they fit together, both concerning geometry and semantic" (INSPIRE[138]). The data harmonisation allows the integration of further national and international datasets. This thesis has followed similar procedures for case studies I and II. Different datasets were downloaded, and firstly they and their attributes were manually

[138] https://inspire.ec.europa.eu/training/data-harmonisation

mapped. This process has been carried out by comparing the attributes table in a spreadsheet software program (such as Office Excel) and in the GIS environment (QGIS and ESRI ArcGIS Pro[139] software were used). Parameters with the same meanings and contents have been merged into a unique raw after careful comparison, mapping and translation (from Dutch and Italian to British English) of data.

The next sub-paragraphs describe datasets contents for case studies I and II and their integration and harmonisation to create complete and representative GIS projects. For each case study, suitable spatial entities to represent MHC and connect them to the developed semantic have been selected.

### 7.1.1 Data harmonisation of Sloten village (I)

#### 7.1.1.1 Case study I – Sloten village, spatial data mapping and interpretation

*Datasets harmonisation of Sloten*

The different datasets presented in the previous chapter (§ 6.2.2) in GML, CityGML, OSM formats and their attributes have been investigated and compared to integrate them. Spatial entities have been studied by downloading different datasets from the official website, geoportal or WebGIS apps. They have been uploaded in a GIS environment and analysed by querying their attribute and properties tables. The investigation on "how" spatial datasets have been created and populated with attributes will help link – through Linked Data - similar information or values to the same semantic concepts defined in the ontology. This step aims at setting a basis for future ontology querying and inferencing (§ 7.2.3). This is necessary to connect spatial data and semantic concepts and create semantic links between the data and the ontology. This also regards the semantic data integration process of the ontology-based approach (Stoter et al., 2006). Datasets and attributes have been inspected and compared manually in GIS. This preliminary operation is essential to individuate familiar or equivalent classes and attributes among different datasets of the same area or connect them to the same semantic concepts of the ontology.

Figure 101 and Table 17 show different or similar values of attributes. Figure 102 illustrates the three datasets selected and analysed for the village of Sloten in the software QGIS. For each source, the same building or construction area has been queried. On the right in the figure, we notice that different attribute values are referred to corresponding geometries.

[139] https://pro.arcgis.com/en/pro-app/latest/get-started/get-started.htm


Figure 101. Comparison of attributes of the same building geometries of BGT and BAG datasets.

Table 17. Example of comparison and investigation of the *building* selected in Figure 101, to check attribute and value similarities (in bold attributes with the same meaning, highlighted in blue the attribute referred to existing Linked Data).

| ***Historic Core Locks Construction area*** | | ***BGT IMGEO PDOK building*** | | ***BAG Kadaster building (WFS service) INSPIRE harmonised*** | |
|---|---|---|---|---|---|
| *attributes* | *values* | *attributes* | *values* | *attributes* | *values* |
| identification | *NL.IMRO.10* | gml_id | gml_id: bf9c00ceb-0e68-6a96-bb55-7142a9ba7550 | identification | *4650370* |
| name | *Construction area* | creationDate | *2016-12-07* | construction year | *1958* |
| type Plan object | *Construction area* | **bgt status** | ***existing*** | **status** | ***Building in use*** |
| | | relative Altitude | *0* | purpose of use | *meeting function* |
| | | time of registration | *2016-12-07T14:11:14.000* | area_min | *211* |
| | | LV publication date | *2017-01-05T18:48:21* | area_max | *273* |
| | | Namespace/source | *NL.IMGeo* | number_residence objects | *2* |
| | | | | rdf_seealso | *http://bag.basisregistraties.overheid.nl/bag/id/pand/*0653100000148072 |

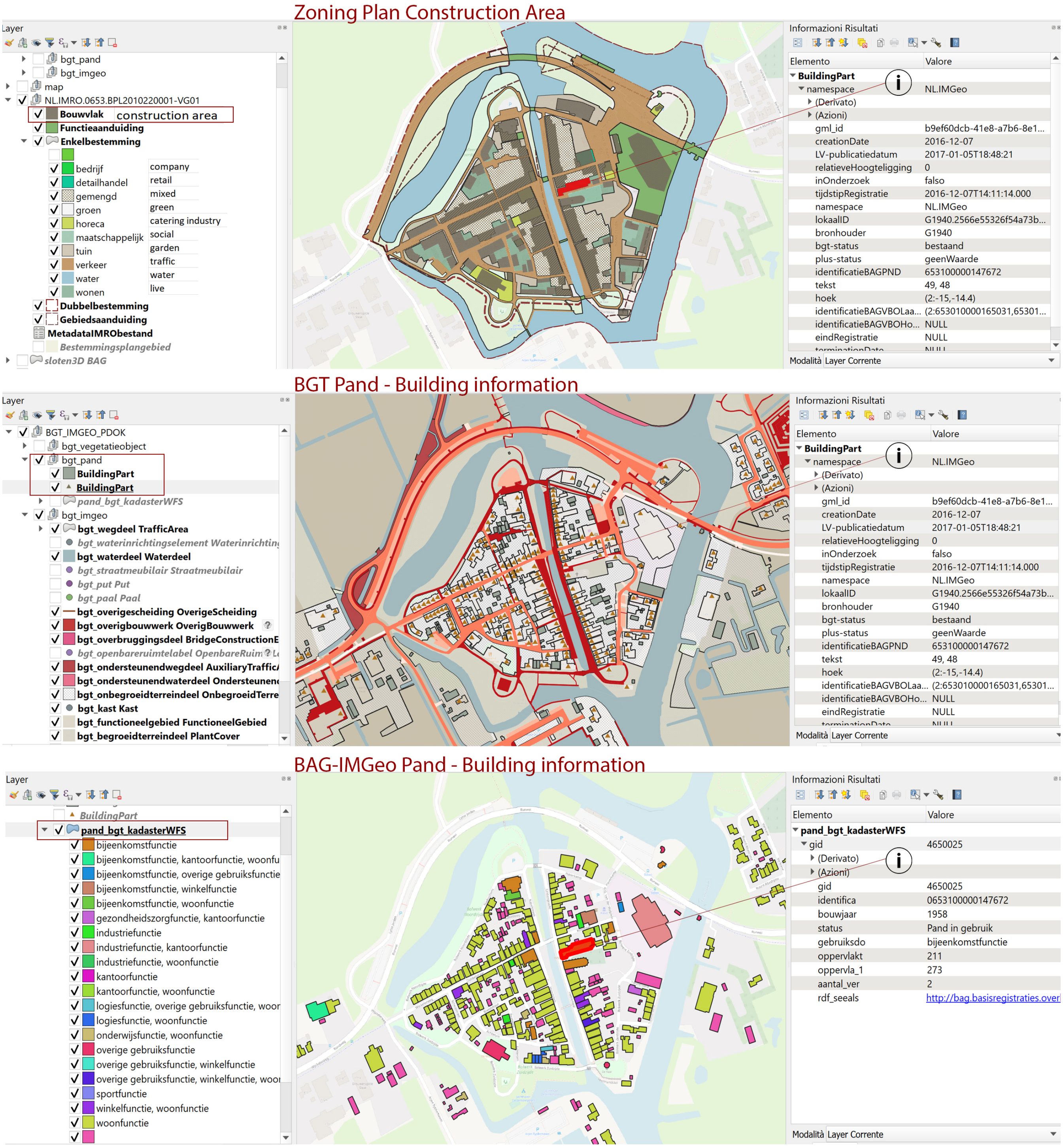



Figure 102. Datasets comparison of BGT, BAG-IMGeo and Zoning Plan entities Building and Construction Area in QGIS.

After investigating the different attributes tables of various datasets, some entities have been selected to spatial document the village of Sloten. These are: buildings, water, traffic area, functional area, terrain, plant cover and building area, function designation, and single area from the Zoning Plan regulation analysed in the present methodology.

Spatial objects are listed in Table 18. The column “sources” describes the different datasets. The attributes tables have been mapped and compared in GIS environment. Entities attributes with the same geometries have been merged to obtain a unique “spatial object”. Names of entities have been translated, without using gazetteers, from Dutch to English.

Table 18. Objects considered to spatial document the village of Sloten in its GIS.

| ***Spatial Object of the Geodatabase*** | ***Geometry Type*** | ***Sources*** | ***Original Name of Layers*** | ***English Translation*** |
|---|---|---|---|---|
| *Building* | Multipolygon (2.5D) | BGT_IMGEO<br>BGT KADASTER<br>3DBAG<br>OSM | Bgt_PAND<br>buildingPart<br>pand3Dbag<br>building | building |
| *Traffic Area* | curvepolygon | BGT_IMGEO | Bgt_weegdeel<br>TrafficArea | traffic |
| *Water* | curvepolygon | BGT_IMGEO | Bgt_waterdell<br>Waterdell | water |
| *Functional Area* | polygon | BGT_IMGEO | Bgt:functioneelgebi ed<br>FunctioneelGebied | Functional area |
| *Terrain* | curvepolygon | BGT_IMGEO | Bgt_onbegroeidterr eindell<br>OnbegroeidTerreind ell | terrain |
| *Plantcover* | curvepolygon | BGT_IMGEO | Bgt_begroeidterrein dell PlantCover | Plant cover |
| *Building Area* | polygon | NL.IMRO.0653.BPL 2010220001-VG01 | bouwvlak | buildingarea |
| *Function Designation* | polygon | NL.IMRO.0653.BPL 2010220001-VG01 | functieaanduiding | Function designation |
| *Single Destination* | polygon | NL.IMRO.0653.BPL 2010220001-VG01 | enkelbestemming | Single area |

Table 19 shows the different “buildings” entities from various data sources, analysed and compared mapping attributes and types. The tables below (Tables 20, 21, 22, 23, 24, 25) report some examples of different spatial entity attributes considered for the GDB of Sloten with their English translation. Figure 103 shows the “fields” of the Functional area entity and the column “Alias”, in which it is possible to add the English translation of Field Name. Table 24 reports the typology of the “function” of the "traffic area" spatial object.

Table 19. Comparison of the entities representing "buildings" in different sources with many attributes.

| ***Source*** | ***Entity Name*** | ***Data Format & Geometry Type*** | ***LoD*** | ***RF*** | ***Attributes Information*** | | |
|---|---|---|---|---|---|---|---|
| | | | | | ***DUTCH*** | ***ENGL*** | ***Type*** |
| ***3DBAG - (BAG/PDOK, BGT, AHN) -*** *http://3dbag.bk.tudelft.nl/downloads* | *BUILDING from BAG dataset* | CityGML, geopackage, WMS, WFS, CSV, CITYGML<br><br>created with 3dfier (BAG + Actueel Hoogtebestand Nederland (AHN) , Digital Elevation Model of the Netherlands) - Polygon (MultiPolygonZ) | LoD1.3 | *EPSG:28992 - Amersfoort / RD New - Proiettato* | *gid* | *gid* | *Real* |
| | | | | | *identifica* | *identification* | *String* |
| | | | | | *aanduiding* | *indication* | *Integer* |
| | | | | | *aanduidi* | *designator* | *Integer64* |
| | | | | | *officieel* | *official* | *Integer* |
| | | | | | *inonderzoe* | *in research* | *Integer* |
| | | | | | *documentnu* | *document now* | *String* |
| | | | | | *documentda* | *Document date* | *Date* |
| | | | | | *bouwjaar* | *construction year* | *Date* |
| | | | | | *begindatum* | *starting date* | *String* |
| | | | | | *einddatumt* | *end date* | *String* |
| | | | | | *gemeenteco* | *Municipal code* | *String* |
| | | | | | *ground-0.0* | *ground-0.0* | *Real* |
| | | | | | *ground-0.1* | *ground-0.1* | *Real* |
| | | | | | *ground-0.2* | *ground-0.2* | *Real* |
| | | | | | *ground-0.3* | *ground-0.3* | *Real* |
| | | | | | *ground-0.4* | *ground-0.4* | *Real* |
| | | | | | *ground-0.5* | *ground-0.5* | *Real* |
| | | | | | *roof-0.25* | *roof-0.25* | *Real* |
| | | | | | *rmse-0.25* | *rmse-0.25* | *Real* |
| | | | | | *roof-0.50* | *roof-0.50* | *Real* |
| | | | | | *rmse-0.50* | *rmse-0.50* | *Real* |
| | | | | | *roof-0.75* | *roof-0.75* | *Real* |
| | | | | | *rmse-0.75* | *rmse-0.75* | *Real* |
| | | | | | *roof-0.90* | *roof-0.90* | *Real* |
| | | | | | *rmse-0.90* | *rmse-0.90* | *Real* |
| | | | | | *roof-0.95* | *roof-0.95* | *Real* |
| | | | | | *rmse-0.95* | *rmse-0.95* | *Real* |
| | | | | | *roof-0.99* | *roof-0.99* | *Real* |
| | | | | | *rmse-0.99* | *rmse-0.99* | *Real* |
| | | | | | *roof_flat* | *roof_flat* | *Integer* |
| | | | | | *nr_ground_* | *nr_ground_* | *Integer64* |
| | | | | | *nr_roof_pt* | *nr_roof_pt* | *Integer64* |
| | | | | | *ahn_file_d* | *ahn_file_d* | *String* |
| | | | | | *ahn_versio* | *ahn_versio* | *Integer64* |
| | | | | | *height_val* | *height_val* | *Integer* |
| | | | | | *tile_id* | *tile_id* | *String* |

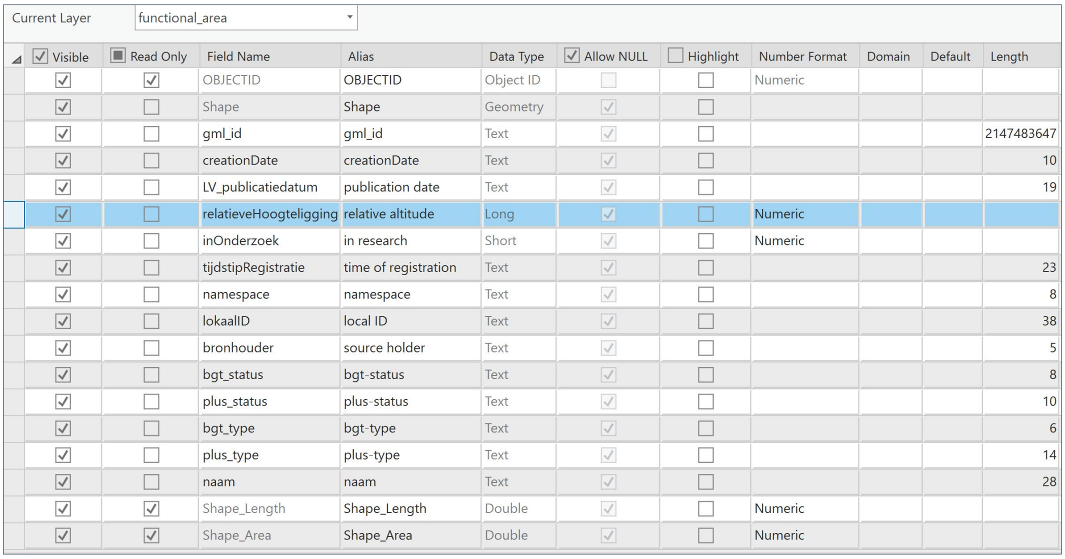
| ***Source*** | ***Entity Name*** | ***Data Format & Geometry Type*** | ***LoD*** | ***RF*** | ***Attributes Information*** | | |
|---|---|---|---|---|---|---|---|
| ***OSM OPEN STREET MAP -*** *https://www.openstreetmap.org/history#map=17/52.89449/5.64600* | BUILDING from OSM | .osm - Polygon (MultiPolygon) | LoD 0 | WGS84 | | *building* | *String* |
| ***Basisregistratie Grootschalige Topografie (BGT) - kadaster pdok -*** *https://www.pdok.nl/downloads/-/article/basisregistratie-grootschalige-topografie-bgt-* | Bgt_pand = edifici | CITYGML - POLYGONS, POINTS 2D | LoD 0 | *EPSG:28992 - Amersfoort / RD New - Proiettato* | *gml_id* | *gml_id* | *String* |
| | | | | | *creationDate* | *creationDate* | *String* |
| | | | | | *LV-publicatiedatum* | *LV publication date* | *String* |
| | | | | | *relatieveHoogteligging* | *relative Altitude* | *Integer* |
| | | | | | *inOnderzoek* | *in research* | *Boolean* |
| | | | | | *tijdstipRegistratie* | *time of registration* | *String* |
| | | | | | *namespace* | *namespace* | *String* |
| | | | | | *lokaalID* | *localID* | *String* |
| | | | | | *bronhouder* | *source holder* | *String* |
| | | | | | *bgt-status* | *bgt status* | *String* |
| | | | | | *plus-status* | *plus status* | *String* |
| | | | | | *identificatieBAGPND* | *identification BAGPND* | *Integer64* |
| | | | | | *tekst* | *text* | *StringList* |
| | | | | | *hoek* | *angle* | *RealList* |
| | | | | | *identificatieBAGVBOLaagsteHuisnummer* | *identification BAGVBOLowest House number* | *Integer64List* |
| | | | | | *identificatieBAGVBOHoogsteHuisnummer* | *identification BAGVBO Highest House number* | *Integer64List* |
| | | | | | *eindRegistratie* | *end registration* | *String* |
| | | | | | *terminationDate* | *terminationDate* | *String* |
| ***BAG KADASTER -*** *https://bag.basisregistraties.overheid.nl/resource?subject=https://bag.basisregistraties.overheid.nl/bag/doc/2009102700000100/pand/06531000000147672* | pand | citygml - OGC WFS (Web Feature Service) - polygon | LoD 0 | *EPSG:28992 - Amersfoort / RD New - Proiettato* | *gid* | *gid* | *long* |
| | | | | | *identificatie* | *identification* | *string* |
| | | | | | *bouwjaar* | *construction year* | *integer* |
| | | | | | *status* | *status* | *string* |
| | | | | | *gebruiksdoel* | *purpose of use* | *string* |
| | | | | | *oppervlakte_min* | *area_min* | *integer* |
| | | | | | *oppervlakte_max* | *area_max* | *integer* |
| | | | | | *aantal_verblijfsobjecten* | *number_residence objects* | *integer* |
| | | | | | *rdf_seealso* | *rdf_seealso* | *string* |

Table 20. Attributes of "water" spatial object.

| *Bgt WATER – WATERDEEL attributes* | | |
|---|---|---|
| *gml_ID* | *gml_ID* | |
| *creationDate* | *creationDate* | *String* |
| *LV-publicatiedatum* | *publication date* | *String* |
| *relatieveHoogteligging* | *relative Altitude* | *String* |
| *inOnderzoek* | *in research* | *Integer* |
| *tijdstipRegistratie* | *time of registration* | *Boolean* |
| *namespace* | *namespace* | *String* |
| *lokaalID* | *localID* | *String* |
| *bronhouder* | *source holder* | String |
| *bgt-status* | *bgt status* | String |
| *plus-status* | *plus status* | String |
| *class* | *class* | String |
| *Plus_type* | *Plus type* | String |
| *eindRegistratie* | *end registration* | Integer64List |
| *terminationDate* | *terminationDate* | String |
| *creationDate* | *creationDate* | String |

Table 21. Attributes of "functional area" spatial object.

| *Bgt FUNCTIONAL AREA - FUNCTIONEEL GEBIED attributes* | | |
|---|---|---|
| *gml_ID* | *gml_ID* | |
| *creationDate* | *creationDate* | *String* |
| *LV-publicatiedatum* | *publication date* | *String* |
| *relatieveHoogteligging* | *relative Altitude* | *String* |
| *inOnderzoek* | *in research* | *Integer* |
| *tijdstipRegistratie* | *time of registration* | *Boolean* |
| *namespace* | *namespace* | *String* |
| *lokaalID* | *localID* | *String* |
| *bronhouder* | *source holder* | String |
| *bgt-status* | *bgt status* | String |
| *plus-status* | *plus status* | String |
| *Plus_type* | *Plus type* | String |
| *naam* | *name* | String |



Current Layer: functional_area

| Visible | Read Only | Field Name | Alias | Data Type | Allow NULL | Highlight | Number Format | Domain | Default | Length |
|---|---|---|---|---|---|---|---|---|---|---|
| ☑ | ☑ | OBJECTID | OBJECTID | Object ID | ☐ | ☐ | Numeric | | | |
| ☑ | ☐ | Shape | Shape | Geometry | ☑ | ☐ | | | | |
| ☑ | ☐ | gml_id | gml_id | Text | ☑ | ☐ | | | | 2147483647 |
| ☑ | ☐ | creationDate | creationDate | Text | ☑ | ☐ | | | | 10 |
| ☑ | ☐ | LV_publicatiedatum | publication date | Text | ☑ | ☐ | | | | 19 |
| ☑ | ☐ | relatieveHoogteligging | relative altitude | Long | ☑ | ☐ | Numeric | | | |
| ☑ | ☐ | inOnderzoek | in research | Short | ☑ | ☐ | Numeric | | | |
| ☑ | ☐ | tijdstipRegistratie | time of registration | Text | ☑ | ☐ | | | | 23 |
| ☑ | ☐ | namespace | namespace | Text | ☑ | ☐ | | | | 8 |
| ☑ | ☐ | lokaalID | local ID | Text | ☑ | ☐ | | | | 38 |
| ☑ | ☐ | bronhouder | source holder | Text | ☑ | ☐ | | | | 5 |
| ☑ | ☐ | bgt_status | bgt-status | Text | ☑ | ☐ | | | | 8 |
| ☑ | ☐ | plus_status | plus-status | Text | ☑ | ☐ | | | | 10 |
| ☑ | ☐ | bgt_type | bgt-type | Text | ☑ | ☐ | | | | 6 |
| ☑ | ☐ | plus_type | plus-type | Text | ☑ | ☐ | | | | 14 |
| ☑ | ☐ | naam | naam | Text | ☑ | ☐ | | | | 28 |
| ☑ | ☑ | Shape_Length | Shape_Length | Double | ☑ | ☐ | Numeric | | | |
| ☑ | ☑ | Shape_Area | Shape_Area | Double | ☑ | ☐ | Numeric | | | |

Figure 103. Functional area "fields" view in ArcGIS Pro.

Table 22. Attributes of "plant cover" spatial object.

| ***PLANT COVER-BEGROEIDTERREINDEEL attributes*** | | |
|---|---|---|
| *gml_ID* | *gml_ID* | |
| *creationDate* | *creationDate* | *String* |
| *LV-publicatiedatum* | *publication date* | *String* |
| *relatieveHoogteligging* | *relative Altitude* | *String* |
| *inOnderzoek* | *in research* | *Integer* |
| *eindRegistratie* | *Final registration* | *Boolean* |
| *tijdstipRegistratie* | *time of registration* | *Boolean* |
| *namespace* | *namespace* | *String* |
| *lokaalID* | *localID* | *String* |
| *bronhouder* | *source holder* | *String* |
| *bgt-status* | *bgt status* | *String* |
| *plus-status* | *plus status* | *String* |
| *class* | *class* | *String* |
| *begroeidTerreindeelOpTalud* | *overgrown Terrain On Talud* | *Short* |
| *kruinlijnBegroeidTerreindeel* | *crown line Overgrown Terrain Area* | *String* |
| *TerminationDate* | *TerminationDate* | *Date* |
| *plus_fysiekVoorkomen* | *plus physical Appearance* | *String* |

Table 23. Attributes of "traffic area" spatial object.

| ***Terrain attributes*** | | |
|---|---|---|
| *gml_ID* | *gml_ID* | *String* |
| *creationDate* | *creationDate* | *String* |
| *LV_publicatiedatum* | *LV_publication date* | *String* |
| *relatieveHoogteligging* | *relativealtitude* | *Integer* |
| *inOnderzoek* | *in research* | *Boolean* |
| *tijdstipRegistratie* | *timeRegistration* | *String* |
| *namespace* | *namespace* | *String* |
| *lokaalID* | *localID* | *String* |

| *Terrain attributes* | | |
|---|---|---|
| *bronhouder* | *source holder* | *String* |
| *bgt_status* | *bgt_status* | *String* |
| *plus_status* | *plus_status* | *String* |
| *function* | *function* | *String* |
| *surfaceMaterial* | *surfaceMaterial* | *String* |
| *kruinlijnWegdeel* | *crown lineRoad section* | *String* |
| *wegdeelOpTalud* | *road sectionOnSlope* | *Boolean* |
| *plus_fysiekVoorkomenWegdeel* | *plus physical Prevent Road section* | *String* |
| *plus_functieWegdeel* | *plus_functionRoad section* | *String* |
| *eindRegistratie* | *finalRegistration* | *String* |
| *terminationDate* | *terminationDate* | *String* |

Table 24. Function typology of "traffic area" spatial object.

| *Function attribute raws* | |
|---|---|
| *OV-baan* | *Public transport lane* |
| *Fietspad* | *Bike path* |
| *Inrit* | *Entrance* |
| *Parkeervlak* | *Parking space* |
| *Rijbaan autoweg* | *Roadway* |
| *Rijbaan lokale weg* | *Lane local road* |
| *Rijbaan regionale weg* | *Carraigeway regional road* |
| *Transitie* | *Transition* |
| *Voetgangersgebied* | *Pedestrail area* |
| *Voetpad* | *Footpath* |
| *Voetpad on trap* | *Footpath on stairs* |

Table 25. Attributes of "terrain" spatial object.

| *Bgt Terrain attributes* | | |
|---|---|---|
| *gml_ID* | *gml_ID* | *String* |
| *creationDate* | *creationDate* | *String* |
| *LV_publicatiedatum* | *LV_publication date* | *String* |
| *relatieveHoogteligging* | *relativealtitude* | *Integer* |
| *inOnderzoek* | *in research* | *Boolean* |
| *eindRegistratie* | *finalRegistration* | *String* |
| *tijdstipRegistratie* | *timeRegistration* | *String* |
| *namespace* | *namespace* | *String* |
| *lokaalID* | *localID* | *String* |
| *bronhouder* | *source holder* | *String* |
| *bgt_status* | *bgt_status* | *String* |
| *plus_status* | *plus_status* | *String* |
| *bgt_fysiekVoorkomen* | *bgt physical Appearance* | *Boolean* |
| *onbegroeidTerreindeelOpTalud* | *bare Terrain part On slope* | *String* |
| *plus_fysiekVoorkomen* | *plus physical Appearance* | *String* |
| *kruinlijnOnbegroeidTerreindeel* | *crown line Bare Terrain Area* | *String* |
| *terminationDate* | *terminationDate* | *String* |

### 7.1.1.2 GIS project of the village of Sloten

After the attribute harmonisation of Sloten data, a GIS project has been created in ESRI ArcGIS Pro (Version 2.9). Then, the entities have been included in a unique geodatabase[140]. The project is in the RF EPSG:28992, Amersfoort/RD New. The harmonised layers considered are traffic area, functional area, buildings, plant cover, terrain, single destination, water and function designation. Information stored into the different object have not been translated for the scope of this thesis. Only data raw of typology or function have been translated, and entities have been classified with different symbology. Figure 104 below shows a screenshot of the GIS project of Sloten.

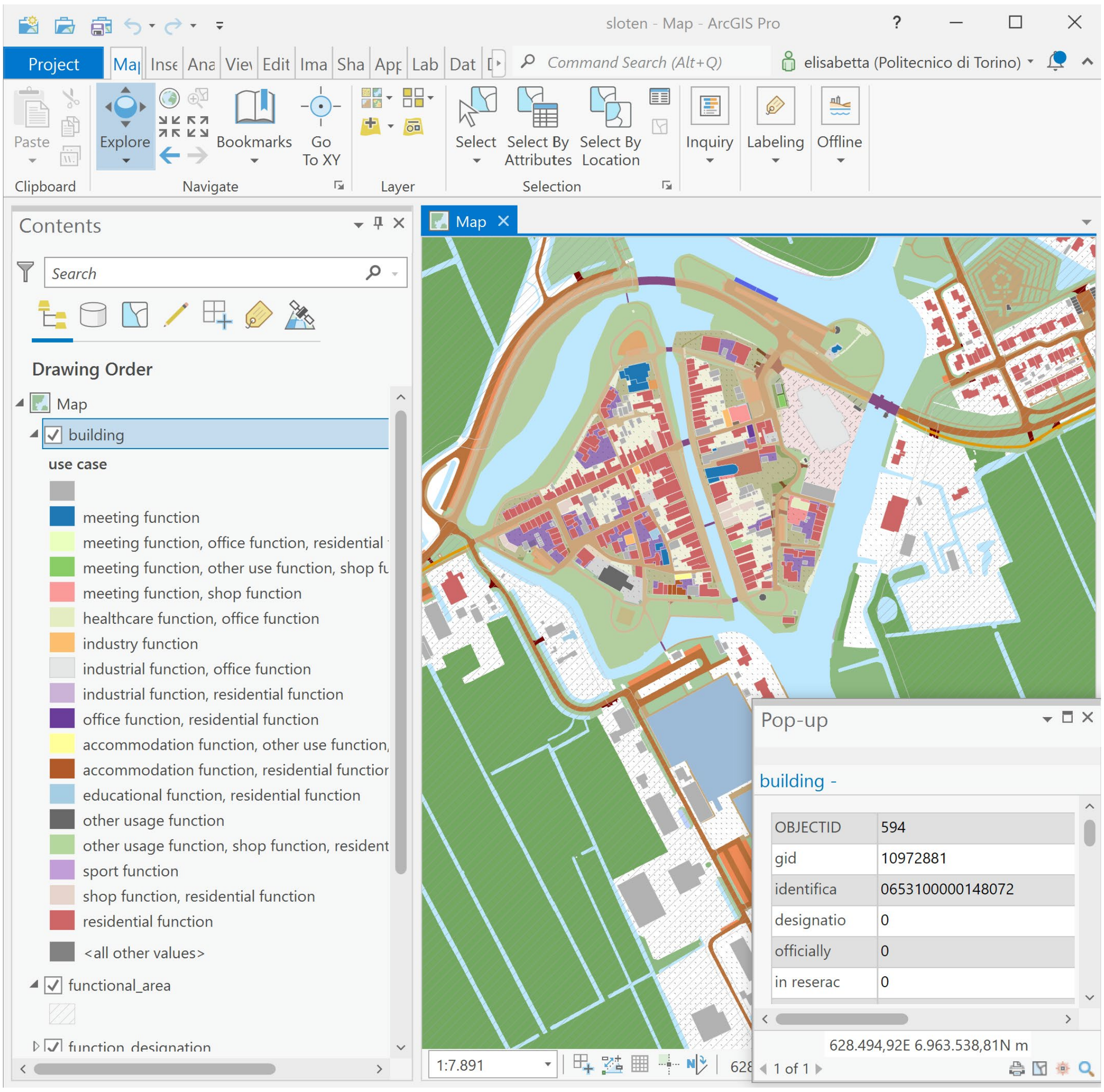



Figure 104. GIS project of the Sloten village, ArcGIS Pro screenshot of the GDB. Attributes of the building church entity (in blue) queried.

[140] https://pro.arcgis.com/en/pro-app/latest/help/data/geodatabases/manage-file-gdb/file-geodatabases.htm

### 7.1.2 Data harmonisation of Pomieri hamlet (II)

#### 7.1.2.1 Case study II – Pomieri hamlet, spatial data mapping and interpretation

Datasets harmonisation of Pomieri

Datasets reported in § 6.4.2 have been considered for the GIS project and the spatial visualisation of the hamlet of Pomieri and its territorial context. The harmonisation process was straightforward for case study II because not many spatial datasets are available in different formats for the Italian case study. Moreover, the primary source, the Piedmont Geoportal, already harmonised and stored data following the INSPIRE Directive for its metadata, and different datasets with various scales of representation have been selected. Names of attributes have been merged, translated and harmonised following the PPR and BDTRE specifications. Only terms of raws have been translated; the contents of the attribute tables remain in the original language.

The work performed focused more on GIS analysis to create thematic multiscale maps, focusing on different aspects such as landscape characteristics, risk areas, cadastral parcels, territorial boundaries, transports and mountain paths. Case study II is consequential of case study I because it embodies the multiscale documentation approach aim of the present thesis.

The GIS project of the Pomieri hamlet is subdivided into two different levels of detail. The first one represents the territorial framework and its spatial object (PPR, INSPIRE data at scale 1:100000 and 1:10000 and rasters such as the DTM, 10m have been imported and harmonised). The second scale of representation regards the "city objects" and represents the municipality of Prali and the hamlet of Pomieri. In this case, datasets from BDTRE (scale 1:10000), 3D metric survey data.

#### 7.1.2.2 GIS project of the hamlet of Pomieri and data harmonisation

As done for case study I, during the data integration and translation, the GIS project of Pomieri has been designed in ESRI ArcGIS Pro as GDB. The RF is WGS84- 32N - ETRF2000.

Below are reported the two scales of representation in which the GIS project is divided:

- Territorial landscape scale and framework map (*1:200000 and 1:100000);*
- City object scale: Prali and Pomieri buildings and related objects *(1:10000 and 1:2000).*

Thematic maps are reported in *Appendix B*.

***// territorial landscape scale and framework map***

Table 26 below shows datasets harmonised and translated included in the GIS of Pomieri and representing the landscape map and the framework territorial map.

Table 26. Framework map vectors. Sources and translation are reported. The last column, "output layers", reports harmonised and classified entities in GIS.

| ***Source*** | ***Scale*** | ***Data attributes raws*** | | ***English translation*** | ***Link*** | ***Output layer*** |
|---|---|---|---|---|---|---|
| Administrative areas - Regional area and Provinces<br><br>*The perimeter of the regional and provincial areas, obtained by merging the municipal areas of the ISTAT 2011 source*<br><br>*INSPIRE Administrative units* | 1:10000 | OID | Object-id | Object-id | *https://www.datigeo-piem-download.it/direct/Geoportale/RegionePiemonte/Limiti amministrativi/AMBITI_AMMINISTRATIVI_REGIONE.zip* | ***Administrative areas - Regions*** |
| | | UUID | Identificativo Univoco Universale | Universal Unique Identifier | | |
| | | data_acq | Data di acquisizione del poligono | Date of acquisition of the polygon | | |
| | | data_agg | Data di aggiornamento del poligono | Polygon update date | | |
| | | data_fine | Data di fine validità del poligono | End validity date of the polygon | | |
| | | Ente_for | Ente Fornitore | Supplier Entity | | |
| | | Ente_prod | Ente produttore | Producing body | | |
| | | Modo_prod | Modalità di produzione | Method of production | | |
| | | Sc_acq | Scala di acquisizione | Acquisition scale | | |
| | | region_ist | Codice ISTAT della Regione | ISTAT code of the Region | | |
| | | Regione_nom | Nome della Regione (maiuscolo) | Region name (uppercase) | | |
| | | cod_prov | Codice ISTAT della Provincia | ISTAT code of the Province | *https://www.datigeo-piem-download.it/direct/Geoportale/RegionePiemonte/Limiti amministrativi/AMBITI_AMMINISTRATIVI_PROVINCE.zip* | ***Administrative areas - Provinces*** |
| | | cod_cm | Codice ISTAT della Città Metropolitana | ISTAT Code of the Metropolitan City | | |
| | | nome | Nome della Provincia/ Città Metropolitana | Name of the Province / Metropolitan City | | |
| Administrative areas – Municipalities<br><br>*Delimitation of the municipal areas of Piedmont, starting from the ISTAT 2011 source*<br><br>*INSPIRE Administrative units* | 1:10000 | uuid | Identificativo Univoco Universale | Universal Unique Identifier | *https://www.datigeo-piem-download.it/direct/Geoportale/RegionePiemonte/Limiti amministrativi/AMBITI_AMMINISTRATIVI_COMUNI.zip* | ***Valleys, Valleys around Gemanasca, Val Germanasca municipalities*** |
| | | data_acq | Data di acquisizione del poligono | Date of acquisition of the polygon | | |
| | | data_agg | Data di aggiornamento del poligono | Polygon update date | | |
| | | data_fin | Data di fine validità del poligono | End validity date of the polygon | | |
| | | ente_for | Ente Fornitore | Supplier Entity | | |
| | | ente_prod | Ente produttore | Producing body | | |
| | | modo_prod | Modalità di produzione | Method of production | | |
| | | sc_acq | Scala di acquisizione | Acquisition scale | | |
| | | comune_ist | Codice ISTAT del Comune | ISTAT Code of the Municipality | | |
| | | comune_nom | Nome del Comune | Municipality name | | |
| | | zona_alt | Zona d'altitudine | Altitude area | | |
| | | d_zona_alt | Denominazioni zona d'altitudine | Denomination of altitudine area | | |
| | | provin_nom | Nome della Provincia | Name of the Province | | |
| | | provin_ist | Codice ISTAT Provincia | ISTAT code of the Province | | |

| ***Source*** | ***Scale*** | ***Data attributes raws*** | ***English translation*** | ***Link*** | ***Output layer*** |
|---|---|---|---|---|---|
| Built areas - *Perimeter of the built areas, Piedmont region, obtained from Vegetation map (IPLA 1986)* | 1: 100000 | Edific_ID | ID built areas | *https://www.datigeo-piem-download.it/direct/Geoportale/RegionePiemonte/Aree edificate/Aree_edificate_storico.zip* | ***Built areas*** |
| Hydrography - *Natural watercourses, divided into primary and secondary (IGM classification)* | 1: 100000 | Codice | Code | *https://www.datigeo-piem-download.it/direct/Geoportale/RegionePiemonte/Idrografia/Idro100-fiumi.zip* | ***Hydrography*** |
| | | Classe | Class | | |
| | | Fonte | Source | | |
| | | Tlr | Tlr | | |
| | | Dentro | Inside | | |
| | | Rev | Rev | | |
| | | Ordine | Order | | |
| | | Nome | Name | | |
| | | Denom | Denomination | | |
| | | Recet | Recet | | |
| | | Batt | Batt | | |
| | | Località | Location | | |
| | | Tipo | Type | | |
| | | Class | Class | | |
| | | Cat | Category | | |
| Ridges, *Piedmont Geoportal "Crinali"* | 1:25000 | FID | ID | *http://www.datigeo-piem-download.it/direct/Geoportale/RegionePiemonte/PPR/crinali_montani_principali_e_secondari.zip* | ***Ridges*** |
| | | Classe | Class | | |
| | | Decodifica | Decoding | | |
| Landscape Areas, *PPR Ambito - Tav. P3 Ambiti e unità di paesaggio, 1:250k* | 1:50000 | Ambito | Area | *https://www.datigeo-piem-download.it/direct/Geoportale/RegionePiemonte/PPR/ambiti_paesaggio_2012.zip* | ***Landscape Area 41*** |
| | | Nome | Name | | |
| Landscape unities, *PPR Ambito - Tav. P3 Ambiti e unità di paesaggio, 1:250k* | 1:50000 | FID | ID | *https://www.datigeo-piem-download.it/direct/Geoportale/RegionePiemonte/PPR/ambiti_paesaggio_2012.zip* | ***Landscape unities*** |
| | | Ambito | Area | | |
| | | Unità | Unity | | |
| | | TIP_N_COD / Tipologia normativa UP Codice | Typology code | | |
| | | TIP_N_DES / Tipologia normativa UP Descrizione | Typology description | | |
| | | Nome | Name | | |

| ***Source*** | ***Scale*** | ***Data attributes raws*** | | ***English translation*** | ***Link*** | ***Output layer*** |
|---|---|---|---|---|---|---|
| Administrative location – *BDTRE Piedmont Region "Sede Amministratva"* | 1:5000 | uuid | Identificativo Univoco Universale | Universal Unique Identifier | *https://www.geoportale.piemonte.it/geonetwork/srv/api/records/r_piemon:baff5a4d-4707-4746-a40d-7f7fcd163bb9* | ***Administrative location*** |
| | | data_acq | Data di acquisizione del poligono | Date of acquisition of the polygon | | |
| | | data_agg | Data di aggiornamento del poligono | Polygon update date | | |
| | | data_fin | Data di fine validità del poligono | End validity date of the polygon | | |
| | | ente_for | Ente Fornitore | Supplier Entity | | |
| | | ente_prod | Ente produttore | Producing body | | |
| | | modo_prod | Modalità di produzione | Method of production | | |
| | | sc_acq | Scala di acquisizione | Acquisition scale | | |
| | | Sede_amm_ent | Sede amministrativa | location | | |
| | | Sede_amm_ty | Tipo sede amministrativa | Type of location | | |
| | | Fme_basena | National databse | National database | | |
| | | Fme_datase | dataset | dataset | | |
| | | Fme_feature | feature | feature | | |
| Peaks - *PPR Tav. 4 vette* | 1:50000 | Nome | | Name | *https://webgis.arpa.piemonte.it/ags/rest/services/pianificazione/PPR_Tavola_P4/MapServer/63* | ***Peaks*** |
| | | Comune | | Municipality | | |
| Paths PPR - *PPR Tav. 4 Percorsi panoramici* | 1:50000 | Descrizione | | Description | *https://www.datigeo-piem-download.it/direct/Geoportale/RegionePiemonte/PPR/percorsi_panoramici_up p.zip* | ***Paths*** |
| | | Unità | | Unity | | |
| | | Comune | | Municipality | | |
| | | Categorie | | Category | | |
| | | Tipologia | | Type | | |
| DTM Sud-West & Cen-West *DTM - CTRN data* | 1:10000 (pitch 10m resolution/cell size) | - | - | - | *http://www.regione.piemonte.it/sit/* | ***DTM Piedomnt and DTM Piedmont Shadow*** |

The entitiy "municipality" has been edited merging geometries of municipalities of the different Valley to obtain new spatial objects identifing valleys: Val Germanasca (Massello, Perrero, Pomaretto, Salza di Pinerolo, ***Prali***), Val Pellice (Angrogna, Villar Pellice, Bricherasio, Bobbio Pellice, Torre Pellice, Luserna San Giovanni, Bibiana, Lusernetta, Rorà), Pinerolese (Cumiana, Pinerolo, Cantalupa, San Pietro Val Lemina, Frossasco, Roletto, San Secondo di Pinerolo, Prarostino) and Val Chisone (Usseaux, Pragelato, Roure, Fenestrelle, Perosa Argentina, Pinasca, Inverso Pinasca, Villar Perosa, Pramollo, San Germnano Chisone, Porte). The objects have been merged into a new geometry, "Valleys", and the attribute "municipality_name" has been changed in "valley_toponym". Moreover, entities "Valleys around" (with visualisation purpose of the thematic map) and "Val Germanasca Municipalities" have been exported from "municipality."

The DTMs have been cut on the boundaries of Val Germanasca and merged in a unique layer. The PPR Table 3 layers have been added, and some of them have been inscribed on the Val Germanasca boundaries. Mountain "paths" entities have been harmonised and merged from the PPR datasets.

***// City object scale: Prali and Pomieri buildings and related objects***

Table 27 shows datasets harmonised and translated, representing the city landscape map.

Table 27. City objects map. Sources and translation are reported. The last column, "output layers", reports harmonised and classified entities in GIS.

| ***Source*** | ***Scale*** | ***Data attributes raws*** | ***English translation*** | ***Link*** | ***Output layer*** |
|---|---|---|---|---|---|
| Roofs *from 3D metric survey vectorisation* | 1:200, 1:500 | elevation | | - | ***Roofs 3D*** |
| Footprint on the ground *from 3D metric survey vectorisation* | | altitude | | | ***Footprints*** |
| DSM *from the 3D metric survey* | | - | | | ***Hillshade DSM*** |
| ORTOPHOTO *from the 3D metric survey* | | - | | | ***Orthophoto*** |

<table>
<tr><th>Source</th><th>Scale</th><th colspan="2">Data attributes raws</th><th>English translation</th><th>Link</th><th>Output layer</th></tr>
<tr><td rowspan="14">BDTRE layers 2019<br><br>- water Surface (sp_acq_ver)<br>- woods (bosco)<br>- Natural shape of the soil (f_nter)<br>- Green Area (ar_vrd)<br>- Contour lines (cv_liv_class)<br>- Particular vegetation (for_pc)<br>-River area (ab_cda_vert)<br>- Excavation or landfill area (sc_dis)<br>- Agricultural Crop (cl_agr)<br>- pasture or uncultivated (ps_inc)<br>- Settlement unit (pe_uins)<br>- equipped area (aatt)<br>- water element (el_idr_vert)<br>- secondary Roads (ar-vms)<br>- Vehicle circulation area (ac_vei)<br>- Cable car (el_fne)<br>- Significant Area (loc_sg)<br>- secondary Road selement (el_vms)<br>- municipality Boundaries (lim_com)</td><td rowspan="14">1:10000</td><td>uuid</td><td>Identificativo Univoco Universale</td><td>Universal Unique Identifier</td><td rowspan="14">https://www.geoportale.piemonte.it/geonetwork/srv/ita/catalog.search#/metadata/r_piemon:da9b12ba-866a-4f0f-8704-5b7b753e4f15</td><td rowspan="14">- Water Surface<br>- Woods<br>- Natural Shape Of The Soil<br>- Green Area<br>- Contour Lines<br>- Particular Vegetation<br>- River Area<br>- Excavation Or Landfill Area<br>- Agricultural Crop<br>- Pasture/Uncultivated<br>- Settlement Unit<br>- Equipped Area<br>- Water Element<br>- Secondary Roads<br>- Vehicle Circulation Area<br>- Cable Car<br>- Significant Area<br>- Secondary Road Element<br>- Municipality Boundaries</td></tr>
<tr><td>data_acq</td><td>Data di acquisizione del poligono</td><td>Date of acquisition of the polygon</td></tr>
<tr><td>data_agg</td><td>Data di aggiornamento del poligono</td><td>Polygon update date</td></tr>
<tr><td>data_fin</td><td>Data di fine validità del poligono</td><td>End validity date of the polygon</td></tr>
<tr><td>ente_for</td><td>Ente Fornitore</td><td>Supplier Entity</td></tr>
<tr><td>ente_prod</td><td>Ente produttore</td><td>Producing body</td></tr>
<tr><td>modo_prod</td><td>Modalità di produzione</td><td>Method of production</td></tr>
<tr><td>sc_acq</td><td>Scala di acquisizione</td><td>Acquisition scale</td></tr>
<tr><td>_ent</td><td>Sede amministrativa</td><td>location</td></tr>
<tr><td>_ty</td><td>Tipo sede amministrativa</td><td>Type</td></tr>
<tr><td>Fme_basena</td><td>National databse</td><td>database</td></tr>
<tr><td>Fme_datase</td><td>dataset</td><td>dataset</td></tr>
<tr><td>Fme_feature</td><td>feature</td><td>feature</td></tr>
<tr><td colspan="3">Other specific attributes (such as toponym, condition, ..)</td></tr>
</table>

<table>
<tr><th>Source</th><th>Scale</th><th>Data attributes raws</th><th>English translation</th><th>Link</th><th>Output layer</th></tr>
<tr><td>Rabbini Cadaster vectorised form raster data – municipality of Prali</td><td>1:6000</td><td>DN</td><td>Number</td><td>https://archiviodistatotorino.beniculturali.it/dbadd/fd_tree.php?id=503927</td><td>Cadaster Rabbini of Prali</td></tr>
<tr><td rowspan="3">Paths CAI – Club Alpino Italiano</td><td rowspan="3">-</td><td colspan="2">Name</td><td rowspan="3">https://www.caipiemonte.it/commissioni/sosecp/catasto-sentieri/</td><td rowspan="3">Paths CAI</td></tr>
<tr><td colspan="2">Altitude</td></tr>
<tr><td colspan="2">Layer</td></tr>
</table>

Mountain paths entities have been harmonised and merged from CAI (Club Alpino Italiano) source[141]. The Rabbini cadaster has been georeferenced and then vectorised in a GIS environment (Figure 105). All the data of the BDTRE 2021 - GeoTopographic Database (vector dataset) have been analysed, harmonised and translated following the Specification of contents[142].


Figure 105. Rabbini Cadaster, Prali and Pomieri.

[141] https://www.caipiemonte.it/commissioni/sosecp/catasto-sentieri/
[142] https://www.geoportale.piemonte.it/cms/images/bdtre_doc/Specifica2.0.pdf

Figure 106, Figure 107 and Figure 109 show examples of GIS projects with different levels of detail (large and small scale of representation) of the Val Germanasca and the municipality of Prali.

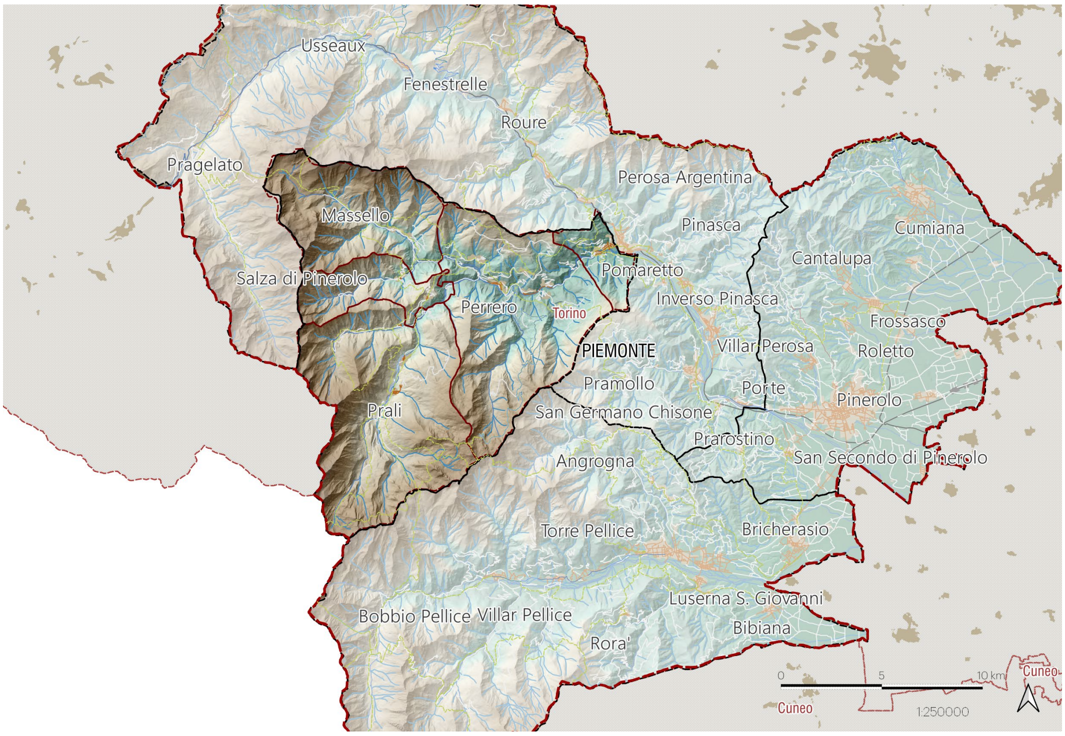



Figure 106. Framework landscape map of Val Germanasca.

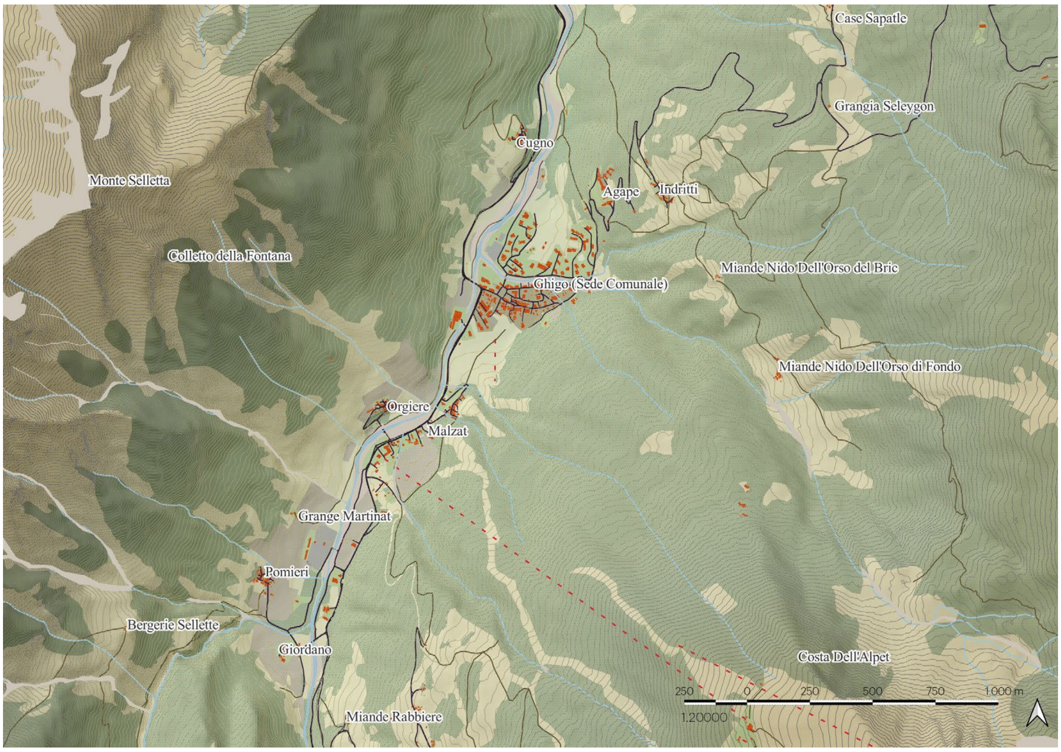



Figure 107. City territorial map of Prali municipality.


Figure 108. Rabbini cadaster vectorised.


Figure 109. Pomieri hamlet map.

## 7.2 The shared application ontology and the WebGIS

This section focuses on the possibility to make the developed ontology and the GIS project of case studies available and accessible online through a user-friendly application. Moreover, as mentioned above, one of the research aims is to link spatial data with their semantic concepts. The first paragraph (§ 7.2.1) describes how the ontology has been published online with all the entities and properties included in the documentation with unique and stable URI. After this step, the GIS projects developed for the two case studies have been published online through a WebGIS app (§ 7.2.2). This phase was fundamental to directly redirect the semantics entities by querying spatial objects in the WebGIS app. Finally, the two web sources, the MHC ontology documentation and the WebApps have been connected by means of Linked Data (§ 7.2.3).

### 7.2.1 The MHC ontology documentation publication

Among the different procedures to publish an ontology on the web, the tutorial of Garijo (2013) was selected. The document describes the approach for publishing an ontology online. In § 5.3.1, it was reported how the ontology file in OWL was made available online. A second step of the workflow is the ontology documentation publication, a human-readable text published online in HTML. Hence, the 5-star Linked Data scale by Vatant (2012) points *b, c* and *d* have been reached. Moreover, Berrueta et al. (2008), in *Best Practice Recipes for Publishing RDF Vocabularies*[143] (of W3C Working Group), reports the importance of having a common URI for each class. The *Naming* section states that: "the URI that identifies your vocabulary is referred to here as the vocabulary namespace URI or just vocabulary URI". In addition to the Garjio (2013) tutorial, the webpage "*Generating HTML documentation of an OWL ontology*[144]*"* provides a list of tools to publish online. The Live WL Documentation Environment[145] (LODE) has been selected among them. *"*It is a service that automatically extracts classes, object properties, data properties, named individuals, annotation properties, general axioms and namespace declarations from an OWL and OWL2 ontology, and renders them as ordered lists, together with their textual definitions, in a human-readable HTML page designed for browsing and navigation using embedded links*"* (Peroni et al., 2012, 2013). The OWL2 file of the MHC ontology stored on the GitHub page (*elicolu*[146]) has been uploaded[147]. Hence, LODE redirects to the web page:

- *https://w3id.org/LoDe/owlapi/https://raw.githubusercontent.com/elicolu/mh-centre_v1/gh-pages-branch/mh-centre_v1.owl*

[143] https://www.w3.org/TR/swbp-vocab-pub/
[144] https://www.w3.org/2011/prov/wiki/Generating_HTML_documentation_of_OWL
[145] https://essepuntato.it/lode/
[146] https://github.com/elicolu
[147] https://raw.githubusercontent.com/elicolu/mh-centre_v1/gh-pages-branch/mh-centre_v1.owl

Thus, it is necessary to change the URI of ontology in PURL, *http://purl.org/net/mh-centre_v1*, in *https://raw.githubusercontent.com/elicolu/mh-centre_v1/gh-pages-branch/mh-centre_v1.owl*

Once done that, it is easy to directly access the LODE documentation of MHC ontology (Figure 110, Figure 111, Figure 112) using the ontology W3id (Permanent Identifiers for the Web) URL. Here are the links:

*MHC ontology documentation URL*

- ***https://w3id.org/LoDe/owlapi/http://purl.org/net/mh-centre_v1*** (server link)
- ***http://150.146.207.114/lode/extract?owlapi=true&url=http://purl.org/net/mh-centre_v1*** (ontology documentation link)

**IRI:**
http://purl.org/net/mh-centre_v1
**Version IRI:**
http://purl.org/net/mh-centre_v1
**Date:**
07/04/2021 - 16/06/2021 - 24/08/2021 - 13/09/2021 - 27/10/2021 - 25/11/2021 - 07/12/2021
**Current version:**
**Contributors:**
Elisabetta Colucci - Supervised by: Margarita Kokla, Andrea Maria Lingua, Antonia Spanò
**Other visualisation:**
Ontology source

### Abstract

Geospatial ontology to support the documentation of Minor Historical Centres (MHC)

PhD thesis in Urban and Regional Development (URD) - Politecnico di Torino - 34th cycle

The research presented in this work encompasses two main research fields: geomatics and geographical information. The main research topic of this thesis focuses on the possibility to standardise spatial information in the domain of minor historical centres (MHC) and the related architectural, built and landscape heritage. Nevertheless, the notions of the urban centre, historical city, and ancient urban area are not consolidated overall, took different meanings, and evolved over the centuries. Historical centres (HC) are intended as a historical part of cities, villages and hamlets (urban, rural, minor or abandoned) with cultural, social and economic values. They need to be preserved, documented and safeguarded due to their intrinsic evolution of functions, values, morphologies, and geometries. Therefore, the study, the communication and the protection of this heritage are supported by many processes and require specific data to be collected, stored, and post-processed. In addition, these activities involve many disciplines, actors, and stakeholders, leading to sharing common knowledge and using a unique language.

The core of this research methodology focuses on the study of ontologies for spatial data: geospatial ontologies. Ontologies can be considered as conceptual structures able to formalise the explicit knowledge of a domain. They are of particular usefulness to create a unique and standard thesaurus and to ensure semantic interoperability. In the ontology engineering process, classes are semantically expressed with their relations and connected by relationships. In geographic sciences, this formalisation of concepts allows digital information control between different operating systems by communicating with geographic tools. This thesis is targeted to fill various gaps in the nowadays scenario of geospatial information (GI). There is no defined ontology containing helpful information to manage, share and collect data on historical and minor rural centres. Moreover, an interoperable structure is lacking to semantic formalises cultural built, urban, architectural heritage. The research developed a spatial ontology integrating existing knowledge (ontologies, vocabularies and standards) representing geographical objects of built and territorial heritage.

Figure 110. MHC ontology documentation published online, Abstract.

### Table of Content



### Introduction

MHC ontology rules Before starting adding concepts and relations in Protègè, some rules have been set for MHC ontology, taking into account the scope of my ontology:

□ classes are expressed with "singular" terms, □ IS-A relations are hierarchies (inheritance concept super-classes/sub-classes), □ new meronymy, "part-of" relations are codified adding one number e the letters (the initials of the two tables related) before the world "has-part" or "is-part-of" (e.g., 01_CH_has-part), □ words, properties and definitions are expressed in Great Britain English (e.g., historical centres – not historical centers), □ classes can have more than one superclass because Protègè (and OWL) supports multiple-inheritance, □ entities have different "roles": they could be ABSTRACT (without instances) or CONCRETE (with data/information), □ semantic descriptions of concepts have been added as "rdfs:comment" with their source (e.g., Getty ATT, HC books, CIDOC-CRM and so on), □ the concepts historic and historical are intended as the same adjective "historical", with the meaning "concerning history or belonging to the past".

Keywords: Geospatial ontology, Minor Historical Centres (MHC), Spatial and Temporal Documentation, Geospatial Information (GI), Geographic Information System and Science (GIS), Semantics Formalisation, WebGIS, Linked data, Multiscale representation, Level of Details, Cultural Architectural Built and Landscape Heritage.

### Classes

abandoned building   abandoned historical centre   abstract building   alpine core   alpine environment   alpine settlement   archaeological remain   architectural element
architectural heritage   avalanche   axex   b1 built work   b2 morphological building section   b3 filled morphological building section   b4 empty morphological building section   barn   biomass
boundary surface   brick   bridge construction element   building   building part   building plot   built environment   built heritage   canopy   central city   church   church   city furniture
city object   cityscape   citywall   construction area   country   cultural and natural values and attributes   cultural centre   cultural heritage   cultural reference   curve   door
E14_Condition Assessment   E18_Physical Thing   E19_Physical Object   E1_CRM Entity   E21_Person   E24_Physical Human-Made Thing   E26_Physical Feature   E28_Conceptual Object
E29_Design or Procedure   E2_Temporal Entity   E35_Title   E3_Condition State   E41_Appellation   E42_Identifier   E4_Period   E52_Time-Span   E53_Place   E55_Type   E5_Event
E71_Man-Made Thing   E73_Information Object   E77_Persistent Item   E7_Activity   E89_Propositional Object   E90_Symbolic Object   earthquake   economic process   energy
environment   facade outer wall   facility   factory   family   Feature   fortification line   fountain   function   gable   garden   geometry   Geometry Collection   geomorphology   geotermal
group of buildings   hamlet   heritage   high alpine area   historic naturalistic landscape value   historical building   historical centre   historical city   historical city core   historical monument
historical naturalistic heritage   historical quarter   historical town   historical urban centre   historical urban landscape   holiday resort/leisure centre   house   hydric   hydrology
ifc building element   infrastructure   inhabitant   intangible cultural heritage   intangible element   land use   land use pattern   landmark site   landscape   landscape area
landscape cultural heritage   landscape unity   landslide   line   line string   linear ring   maintenance   man made   man made context   masonry   memory   military structure   mine
minor historical centre   monument   mountain hamlet   mule track   Multi Curve   Multi Line String   Multi Point   Multi Polygon   Multi Surface   municipality   museum   natural

Figure 111. MHC ontology documentation published online, Contents and classes.

minor historical centre[c] back to ToC or Class ToC

**IRI:** http://www.semanticweb.org/elisabetta/ontologies/2021/3/Sloten_casestudy#minor_historical_centre

The concept of minor historical centres is introduced by Alberto Predieri, in his report for the "VI Convegno A.N.C.S.A."- Bergamo, 1971.

Minor historical centres  those included in developing cities (or even stationary ones), originally, they were the core of important political-cultural and economic functions, now lapsed, but with great historical-artistic-environmental value and with cultural and touristic interest. According to the Venice Charter of 1964 and Disegno di Legge n. 1942 in Italy, minor historical centers those municipalities that have a population of less than 5,000 inhabitants.

**has super-classes**
historical centre[c]
**is in range of**
51 c o has part[op], 79 h m h c has part[op], 80 v m h c has part[op]
**has members**
pomieri[ni], prali[ni]

monument[c] back to ToC or Class ToC

**IRI:** http://purl.org/net/mh-centre_v1#monument

**has super-classes**
cultural heritage[c]
**is in domain of**
55 m h has part[op]

concept: Architecture - Group: Culture > Visual arts

UNESCO THESAURUS

mountain hamlet[c] back to ToC or Class ToC

**IRI:** http://purl.org/net/mh-centre_v1#mountain_hamlet

**has super-classes**
hamlet[c]

Figure 112. MHC ontology documentation published online, Minor Historical Centre class.

### 7.2.2 The WebGIS publication: WebApps of Sloten and Pomieri

This part presents the WebGIS publication and the ESRI WebApps creation and design of GIS projects of Sloten and Pomieri case studies. The ESRI commercial platform has been selected to develop a user-friendly spatial app (WebMaps[148] and WebApp Builder[149]). Although many OS software has been adopted in this thesis, the choice of ESRI is due to many factors. Firstly, my and my research group personal skills and competencies are not in the OS Web Geoservers app development domain. Secondly, sharing a WebMap employing ArcGIS Pro allows saving time because WebGIS management is not one of the primary purposes of this thesis. Next, a key fact is the reliability of the ESRI platform and of its storage cloud that doesn't need maintenance and local servers. The WebApp allows customising the interface quickly and directly creating queries on the data. Finally, in this way, the data became usable and open. In the future, it could also be possible to download them from the WebGIS.

The following paragraphs show how the maps have been published and the different functionalities and scales of representation of the two case studies. The geodatabases of case studies have been created in ArcGIS Pro. Maps were published as "WebApp" in ArcGIS Server with a licence of ESRI provided by Politecnico of Turin (account name: Elisabetta.Colucci_poli[150]).

[148] https://doc.arcgis.com/it/arcgis-online/reference/what-is-web-map.htm
[149] https://www.esri.com/en-us/arcgis/products/arcgis-web-appbuilder/overview
[150] https://poli.maps.arcgis.com/home/content.html?view=table&sortOrder=desc&sortField=modified&folder=elisabetta.colucci_poli#content

## The WebApp for the village of Sloten (I)

WebGIS of Sloten

After developing the GIS projects of Sloten and importing each entity in a proper GDB, the map has been shared in the ArcGIS online platform. In the ArcGIS WebApp, it is possible to set some already implemented queries to visualise all the related information.

Figure 113 shows the WebApp interface designed for the Sloten case study. Different "widgets" have been added to the customised map, such as measurement tool, "about" boots (with details of case study and methodology), legend, attribute layers, base maps, attribute tables and on on. Moreover, it is possible to add new datasets on the map from other sources. Finally, the app allows querying each geometry, gathering harmonised information on data. The WebApp is available at the link:

- ***https://poli.maps.arcgis.com/apps/webappviewer/index.html?id=79efdbe52bde451aa76e71556d2682dc***


Figure 113. WebApp of Sloten case study I.

## WebApp of Pomieri hamlet (II)

WebGIS of Sloten

A similar procedure to the case study I has been followed for the map of Pomieri. In this case, for the GDB publication, different levels of detail have been considered (as above mentioned). Various scales of visibility have been set for the layers (rasters and vectors). The labelling from 0 to 1: 5000 was selected for city objects and 1.20.000 to 1.500.000 for landscape and territory objects. Thus, after the classification and customisation of spatial objects, it is possible to visualise both landscape and city objects by zooming in and out the multiscale map. Then, the map has been shared in the ArcGIS server, as done for case study I, and published as ESRI WebApp. Figure 14 and Figure 15 show the WebApp interface designed for the Sloten case study available at the link:

- ***https://poli.maps.arcgis.com/apps/webappviewer/index.html?id=edc2f340942f45689d58c3a627d83271***

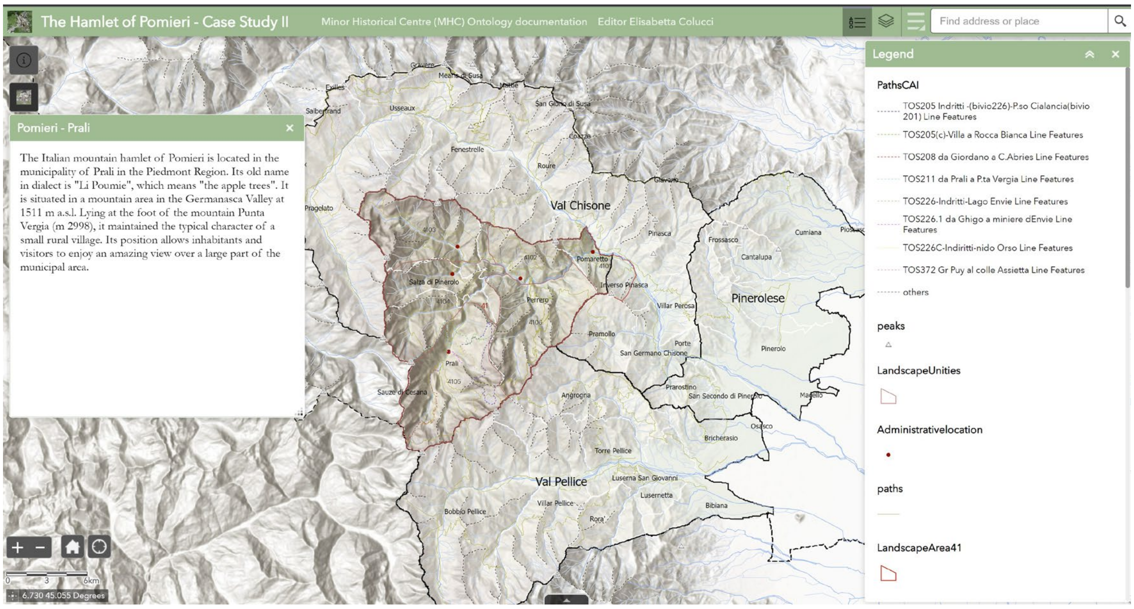



Figure 114. WebApp of Pomieri, case study II, territorial scale.

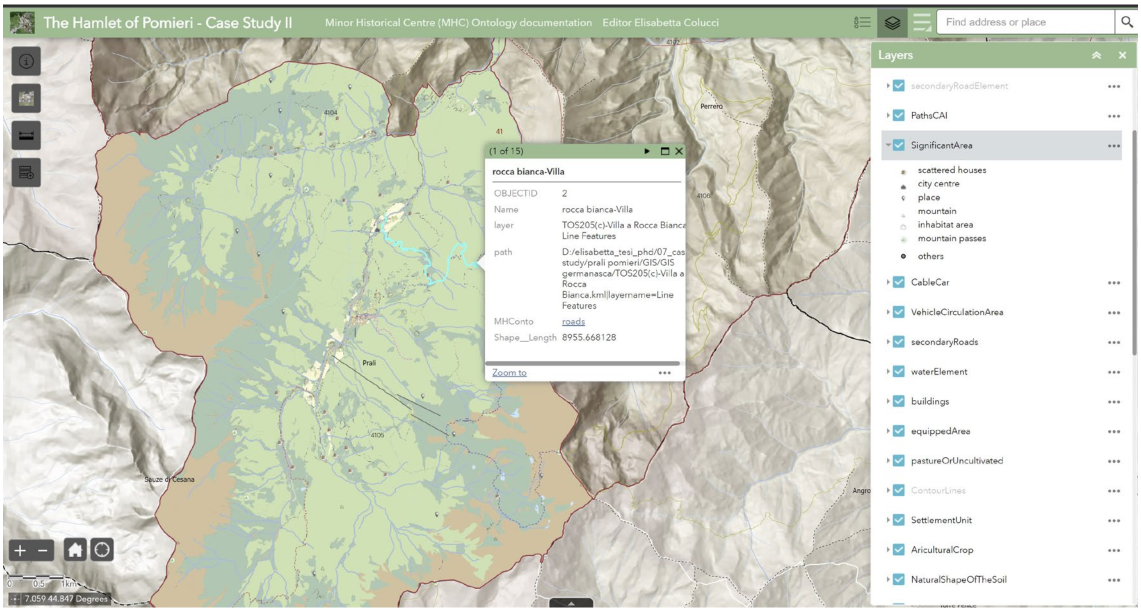



Figure 115. WebApp of Pomieri, case study II, municipality scale.

Some "pop-ups" have been customised for this case study, adding, for example, images related to different entities (Figure 116).

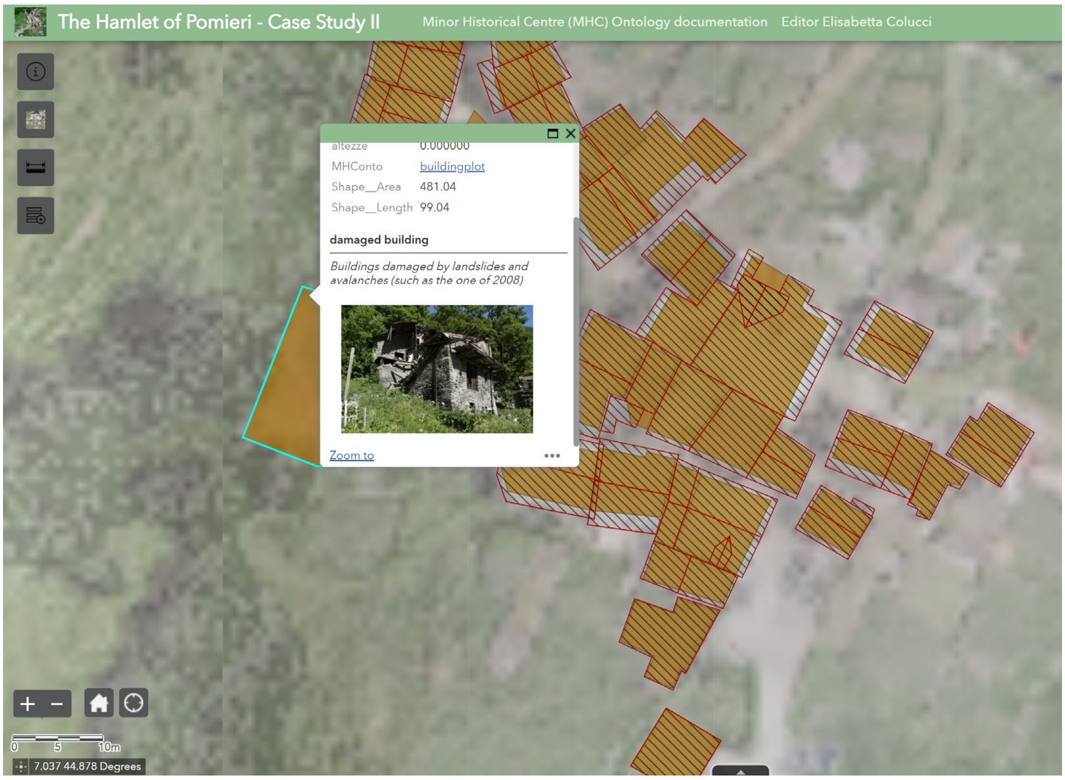



Figure 116. Pop-up designed for the "footprint" entity showing an image of the damaged building of Pomieri.

### 7.2.3 Linked Data connection and data querying

The present section describes the outcome of this thesis, the connection through Linked Data technologies of the GIS objects with their semantic classes published in the open MHC ontology. This approach demonstrates the usability of the developed tool. It validates the entire methodology, showing how it can spatially and semantically describe and document the HC domain by combining AI techniques and GI methods.

Linked Data are designed to share "machine-readable interLinked Data on the Web"[151], and they are defined by the W3C standard. The Semantic Web sets the basis for accessing, querying, and using data with different technologies (RDF, OWL, SPARQL, …). Furthermore, the Web of data create also relationships among datasets. "This collection of interrelated datasets refers to Linked Data" [152].

Some studies have been carried out in the semantic web and GI research framework to connect datasets with their semantics. Rompaey (2006) tried to solve connecting geospatial ontologies with topographic databases. Schade & Cox (2010) focused on Linked Data in SDI and GML representation. Moreover, the book "Linking data to ontologies" (Poggi et al., 2008) reported many examples of attempts of connection between the data and the ontology (and thus the assignment of semantics to the data). And also, other projects produced datasets in which objects information included their semantics (such as the Dutch BAG data

[151] https://www.ontotext.com/knowledgehub/fundamentals/Linked Data-linked-open-data/
[152] https://www.ontotext.com/knowledgehub/fundamentals/Linked Data-linked-open-data/

models[153] and the LinkedGeoData project[154]). Despite this, none of these methods provide a ***standard integrated domain application ontology*** for MHC linked to ***harmonised and integrated datasets***. Thus, in this PhD thesis, the data have been linked to the ontology by adding the stable and unique URI of different entities (such as City object, building, MHC, …) in the attribute table of spatial objects considered in the WebGIS of case studies. This URI has been implemented into the attribute table in ArcGISPro (in the Desktop App or the WebApp of ArcGIS server) by means adding a field and using the tool “calculate field”. The new field has the name “MHConto” and datatype “text”. It has been implemented as a *hyperlink* using the function:

<a href="file://filepath" target="_top">hyperlinkname</a>

For example, for the entity “LandscapeArea41”, the function to add the link to the ontology class “LandscapeArea” is:

'<a href="http://150.146.207.114/lode/extract?owlapi=true&url=http://purl.org/net/mh-centre_v1#d4e4750" target="_top">landscapeArea</a>'

Figure 117 reports an example of the URI implementation of semantic class into the attribute table of entities of the two case studies. Table 28 below reports some examples of GDB entities with the corresponding semantic class and its URI published in the W3 ontology documentation.

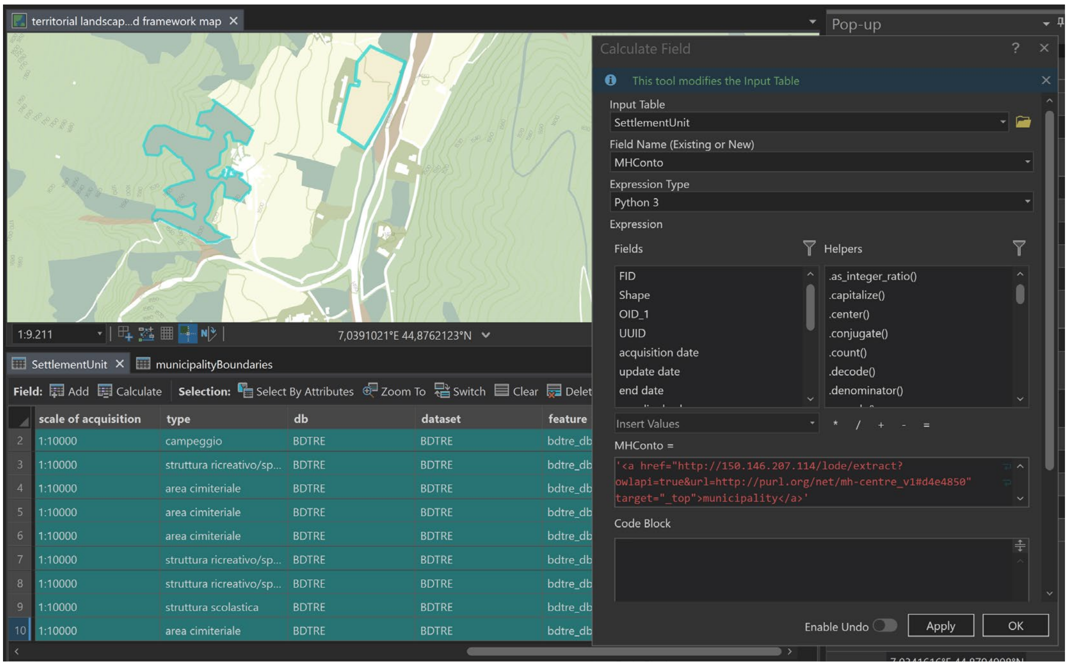



Figure 117. The new "MHConto" field as a hyperlink for the entity "SettlementUnit". It refers to the semantic ontological class Municipality (case study II, Pomieri hamlet).

[153] https://bag.basisregistraties.overheid.nl/datamodel
[154] http://linkedgeodata.org/

Table 28. Examples of GDB entities and related semantic classes of the MHC ontology.

| **Case studies (I-II) entities** | **Corresponding semantic class** | **URI** |
|---|---|---|
| Landscape areas (Piedmont Geoportal PPR) - II | *Landscape Area* | *http://150.146.207.114/LoDe/extract?owlapi=true&url=http://purl.org/net/mh-centre_v1#**d4e4748*** |
| Municipalities boundaries - II | *City_object* | *http://150.146.207.114/LoDe/extract?owlapi=true&url=http://purl.org/net/mh-centre_v1#**d4e6103*** |
| Buildings – I-II | *Building* | *http://150.146.207.114/LoDe/extract?owlapi=true&url=http://purl.org/net/mh-centre_v1#**d4e6225*** |
| Roof (3D metric survey) – I-II | *Roof Surface* | *http://150.146.207.114/LoDe/extract?owlapi=true&url=http://purl.org/net/mh-centre_v1#**d4e6147*** |
| Roads/transports – I-II | *Transportation object* | *http://150.146.207.114/LoDe/extract?owlapi=true&url=http://purl.org/net/mh-centre_v1#**d4e6272*** |
| Plant cover | Vegetation object | *http://150.146.207.114/LoDe/extract?owlapi=true&url=http://purl.org/net/mh-centre_v1#**d4e6305*** |
| Hydrography/water – I-II | *Water object* | *http://150.146.207.114/LoDe/extract?owlapi=true&url=http://purl.org/net/mh-centre_v1#**d4e6329*** |
| Functional Area - I | *Function* | *http://150.146.207.114/LoDe/extract?owlapi=true&url=http://purl.org/net/mh-centre_v1#**d4e4606*** |
| Rabbini cadaster - II | *Parcel/Ground* | *http://150.146.207.114/lode/extract?owlapi=true&url=http://purl.org/net/mh-centre_v1#**d4e5161*** |

Figure 118 shows the Sloten WebApp and the related semantics in the ontology documentation.


Figure 118. Sloten WebApp and Sloten semantic information in the ontology.

Finally, a possible query of the entity “roof3D” in the WebApp of Pomieri and the retrieved semantic information is presented in Figure 119.

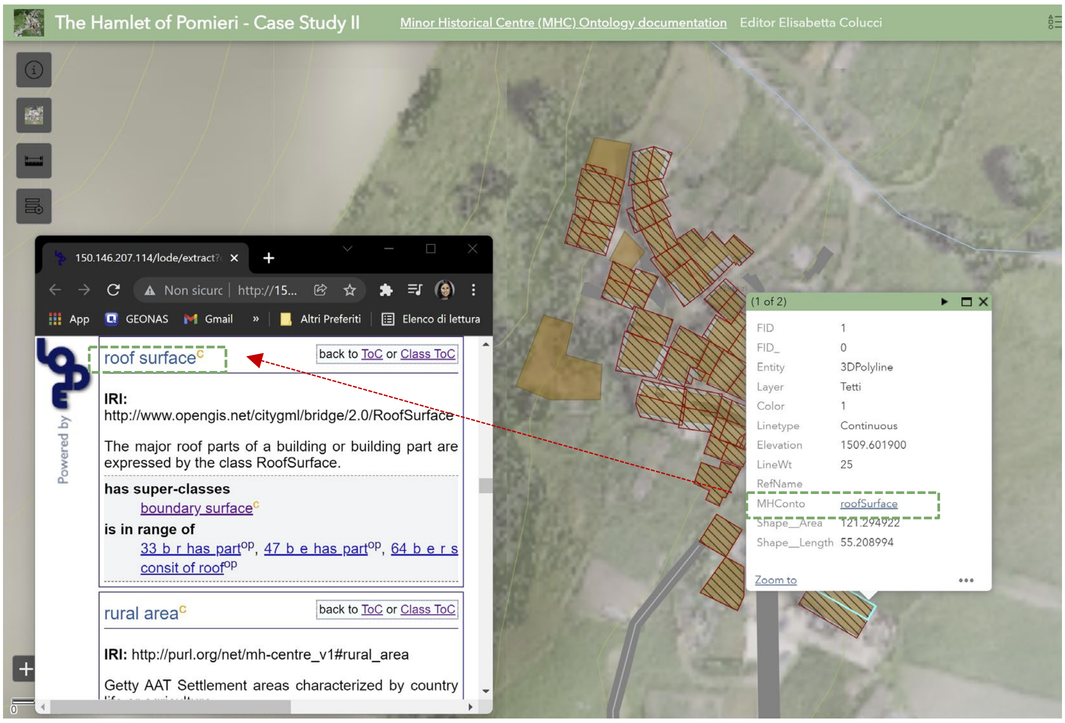



Figure 119. Query applied on "roof3D" entity in the WebApp of Pomieri.

# Discussion of results and future visions

*Part III* focuses on discussions of obtained results and critical considerations of practical implications. Some conclusions and future perspectives are reported to reuse the methods and the knowledge carried out in this thesis. Due to the integration of standardised ontologies, conceptualisations and vocabularies and their mereological and other relations, the MHC ontology and different ontology can be interconnected mutually.

# PART III

# 8

Chapter 8

# Discussion & Critical considerations

## 8.1 Goals reached by the methodology

This brief chapter aims to underline the goals achieved by the present research. Moreover, it wants to highlight why and how the study is ambitious and innovative. The methodology is replicable, reusable, and extendable for further studies and domains. As explained in the first chapters, this thesis is located in the geomatics domain, particularly in the area of GI. As geomatics techniques and methods support the research in different disciplines, this approach wants to help various stakeholders (citizens, researchers, policymakers, etc.) to store and get information on the same domain: the small, historical, and abandoned centres.

This chapter presents a list of critical considerations and reflections (all connected to each other) on the work done for this PhD thesis. Goals, technologies, and innovations developed also underline possible new solutions and future outcomes (explained in the next chapter, Conclusions and Future perspectives).

### 8.1.1 Development of a geospatial ontology in the domain of MHC

Before this study, the domains of cultural and built heritage and historical centres in ontology engineering had been considered and developed only in part. The CIDOC-CRM ontology, the Getty AAT vocabularies, the ontology draft on historical centres (Acierno, 2019) and the study towards creating a semantics for small centres (Kokla et al., 2019) answered only in part to the definition of complete semantic knowledge in this domain. Moreover, none of these approaches presented a whole ontology structure published, open and reusable (downloadable in OWL or

RDF language). The project of Towntology (Berdier & Roussey, 2007) presented an application of spatial ontology, but in the domain of town, without considering the cultural heritage component. Hence, starting from these already developed studies and the standards and data models on city, heritage and built architecture, it was possible to create a new knowledge base.

This first *methodological approach of reusing* classifications, definitions, and thesaurus could appear not innovative and very streamlined, but it represents the core part of the approach: ontology integration and merge. It is essential and, at the same time, creative, as there was no approach capable of integrating different structures and standards for a shared domain and goal.

The *ontology enrichment and population* represent the added value of the research. This great deal of the dissertation involves using existing methods and technologies by merging and mixing them into an iterative process. The replicability of the workflow has been validated by adding to the ontology real case studies data (spatial and textual). The domain could be extended and applied to other *historical centres or villages* for new scopes. Finally, linking harmonised and mapped spatial data stored into a WebGIS to their semantics concepts and description shows the possibility to share information among different users employing user-friendly tools. For example, each object (spatial or not) could have specific semantics shared for other datasets.

### 8.1.2 The concepts of HC became shared and general

Another fundamental objective reached by this research regards the definition of a ***common language***. It consists of the semantic description and meanings of terms and designing a shared structure. To achieve this aim, the study considers both top-down and bottom-up approaches. Firstly it defined concepts and constraints and then added instances. Afterwards, the concepts of historical centres and all the related classes could become shared starting from general ideas (such as cultural heritage definitions). Due to the applicability of the ontology-based approach on the different case studies and in a vast domain, it is possible to unpack this knowledge in various sub-domains and levels. In this way, through many levels of granularity, numerous use cases could speak the same language. Thus, the concept of “minor historical centre” - although it has different facets depending on the context in which it is considered - “became shared and general”.

### 8.1.3 Consistency between different levels of the ontology: part-of and the whole

As mentioned in the previous point, to better clarify the relationship between the different areas and levels of the ontology (described in Chapter 5), it is possible to underline that every ontology could be subdivided into *sub-domains*. To perform it, it is mandatory to check every ontology inconsistency with the help of ontology reasoners and ontology developer tools (such as Protégé editor software). In this way, it is possible to avoid object duplication or missing class relationships. Every user or group of technicians could extract part-of semantic knowledge from an ontology and reuse it in various ways (database creation, vocabularies, Linked Data datasets, etc.). For example, suppose restorers represent the use case. In that case, they will select only such knowledge and objects to describe historical centres in terms of their years of construction, materials, rules and regulations for conservations, etc. So, the consistency between *part-of* of the ontology and the *whole* represents this possibility to extract particular classes and properties helpful for such application, maintaining the option of adding this new knowledge to the entire ontology structure.

### 8.1.4 Integration and updating

The possibility to *integrate and update the ontology* is another essential innovative task reached by the reported workflow. It is possible because of the *iterative process* of ontology development guide, carried out by Noy & McGuinness (2001). It is linked to the previous consideration inasmuch it is possible to extract part of the ontology and add new information. This process allows updating the ontology-based process by editing the meaning of concepts, adding new sources, enriching the properties with data from different users or purposes, and changing relations to create new inferences. The process allows the coherence of the newly developed part of the ontology with the whole conceptualisation. Moreover, because the published ontology is in a shared language, such as OWL2 or RDF, it is possible to maintain the versioning in time of the different files. For users, developers or maintainers, it is also beneficial to receive feedback and continuously improve the semantics.

### 8.1.5 Updated "with and from" existing standards

As regards ontology enrichment, another field to consider is the *standards update*. They constantly evolve, trying to define common universal data models to be sharable at national and international levels. The developed ontology, designed starting from these existing models, answered the necessity of updating the knowledge through interoperable data formats. For example, some standards, such as the CIDOC-CRM ontologies and extensions, have been analysed during ontology engineering. They have been compared and mapped to other conceptualisations (such as GeoSPARQL and CityGML) to avoid repetitions and inconsistencies. Deprecated classes have been cancelled, and ontologies not yet developed as triple have been created *ad-hoc* in Protégé and merged with the other versions. The published minor historical centre ontology could be in the future integrated and merged with new versions of the considered data models and standards (as well as a more recent version of CityGML in RDF).

### 8.1.6 Open and reusable structure of the ontology

As reported in Chapter 7, every ontology – for definition – must be published as *open and free* with the documentation of its rules, classes, properties, etc. Due to its properties of sharing and fruition, different data models or spatial datasets (such as spatial data from geoportals or SDIs) could be linked to the semantics of their contained object. However, as explained in the "case studies" and "data mapping" paragraphs (§ 6.2, 6.3, 6.4, 6.5, 7.1), the datasets harmonisation and mapping is not yet a rapid and straightforward task to carry out. In this sense, adopting an open structure with existing instances could facilitate the integration. Moreover, adding new values, raw and attributes containing links to the semantics of spatial object (Linked Data) help share standard maps and language. Many historic core and villages or cities actions, plans, or processes could benefit from storing and getting information by querying open data.

Another aspect that underlines the *reuse of this developed knowledge* regards the ontology population task. The present research only added a few instances from case studies to make the ontology structure open and adapt it to new domain areas.

### 8.1.7 Consistency between objects and properties

It is essential to consider the *consistency and coherence* among existing or new things during the data mapping. For example, if there are different datasets for the same area or case study, they need to be coherent in terms of semantics, data formats and geometries. The ontology design presented here paid much attention by expressing similar concepts with the same semantics or making explicit different sources for the same object. For this reason, the comparison of concepts is an essential task during ontology design. At the same time, if the users of the application domain ontology will reuse this knowledge, they have to be able to recognise classes of the ontology linked to the data. Thus, for instance, the class "building" with its semantics will correspond to the "built" object, "edificato" (in Italian), in the BDTRE, the regional geoportal of Piedmont. Spatial data attributes have also been compared and mapped together, analysing similar values to store existing or new information.

Geometries have to be in the same Reference System, and the entities must have a coherent definition of their boundaries and geometries with the level of representation nominated. The concept or data mapping could also be reached employing the manual translation of attributes and classes in English, the language selected for the minor historical centre ontology.

### 8.1.8 Publication of maps and thesaurus on the web and connection through Linked Data

One of the most critical issues reached by the PhD thesis is the *publication of the ontology documentation* and the *connection between spatial data and the ontology* (named here the semantics). The first goal reached is to harmonise different spatial datasets and their publication on the web through a WebGIS application. After many attempts to add geometries and spatial objects into the OWL ontology in Protégé by converting them from CityGMl, GML or JSON formats in OWL or RDF, the most effective solution has been found in linking the data the ontology documentation by the use of Linked Data, with stable URIs. The ontology validation and publishing task added the correct ontology semantic class to each GIS object. This method has a great innovative value because it represents an interdisciplinary approach that merges geospatial information competencies and instruments with computer science and semantic WebApproaches.

Finally, in my opinion, a grand worth of this outcome of the research is represented by the dissemination of the open-source instrument, friendly user, replicable and easily understandable and queryable by many actors to help and improve minor historical centres knowledge activities.

### 8.1.9 Innovation for future actions of design and urban planning for sustainable future living

As expressed many times in the document, the main aim of this domain ontology is the *spatial and temporal documentation of minor historical centres* by the definition of a proper semantic structure and a knowledge base. This objective has been reached by integrating all the different conceptualisation of the domain and with the formalisation. The ontology enrichment and the population with case studies instances demonstrated the applicability of part of the ontology for other sub-domain of the spatial documentation purposes (such as storing regulations information and planning for sustainable developments of hamlets). Although this first scope has been reached, the ontology could be improved to answer many other actual needs. For example, these digital systems and models could help enhance the dialogue of the innovation in design and urban planning of the historic core of cities and historical centres located around towns or rural areas. Nowadays, many studies for *sustainable urban planning, social design, restoration actions, urban morphology, valorisation of abandoned built heritage* need common standards and language to help speed up the dialogue among citizens, restores, geologists, architects, planners, policymakers, etc. Sharing the knowledge of a specific domain should also contribute to reaching sustainable goals (Di LoDovico et al., 2021) for new ways of livings in minor centres.

### 8.1.10 Definition of a new concept of slow living thanks to the "net"

In my personal view, a critical reflection was born from the reading of the book "Salire in Montagna" (Mercalli, 2020) and many other papers and contributions (such as Dini et al., 2022) regards the possibility of reinhabiting the abandoned historical centre for a new *"living concept"*. It will consist of a more *"slow" and "contemplative" way of living*. The work that began in this thesis concerning the documentation of these places could really help enhance new territorial sustainable policies and planning. The collection of many definitions and information on historical centres and their organisation in a standard and sharable structure (the MHC ontology) could help launch future plans for the rehabilitation of small centres (for example, in the mountains to escape climate change, as reported in the Introduction). The idea is to "slow down", promoting the creation of new networks in hinterlands, enhancing part-time teleworking (as already proposed by some initiatives[155,156]).

This proposal could not be immediate and requires many actions and information. In this regard, the ontology could store the necessary knowledge to help to enhance the "net" (of communication, telematics works, transports, wireless, commerce, etc.), share best practices of restoration, planning and assist in simplifying the communication among actors for building permits processes and so on.

Some initiatives of rehinabitation of inner areas and mountain hamlets are reported in § 2.5. In addition to these, in this critical part, I would like to mention the projects of rehinabitation of Ghesc village and Paraloup Hamlet. Ghesc represents one of the ancient small historical centres of the Piedmont Region revitalised after 100 years. It is a laboratory village, hosting students every summer for cultural and artistic activities[157]. Paraloup, a cultural centre, is one of the most innovative examples of renovation of an entire hamlet with sustainable and local techniques and materials[158]. The hamlet of Elva, in the Maira Valley (piedmont Region), surveyed by the geomatics group of Politecnico di Torino is working to reinhabit that area and recover the road damaged by a landslide in 2014 (Pontoglio et al., 2019). And even more in the small, one example of repopulation and reconstruction of an alpine village is Borgata Coletta[159]. My friends Stefano Perri e Paola Treves are two young architects that decided to dedicate time, energy and passion to the recovery of the hamlet of Coletta with "slow" and traditional architectural techniques.

In this framework, some charters and manifestos have been defined. The first example is reported in Mercalli (2020): the *Vazon Charter*. It lists some rules to manage the return to built and live in mountain villages considering local culture, nature and sustainability. Following are summarised some crucial points.

- Restoring old buildings adopting new eco-sustainable technologies (thermal insulation, photovoltaic panels, solar thermal, etc.);
- Saving energy of communities (e.g., public lighting with timer sensors and energy self-production);
- Encouraging tourism by installing "dry" public toilets, benches, panoramic information points;
- Reactivating quality local agriculture and livestock farming;

[155] https://cloudcitadel.co/?fbclid=IwAR2d_RMBJ8kJCbGoZi7MGmQ7ZWDsrnZo3lvIeIs5YBq-o0MwoQLk-6MNOUo
[156] https://www.remotocommunity.it/?fbclid=IwAR1rnUeBdLFo9YxTdr_-iSNmLBnBE4zz2u5lkUrS3YsOy9Eyjl2q-QwuDYg
[157] https://www.youtube.com/watch?v=yO8elDp1Lgk
[158] https://paraloup.it/
[159] https://www.italiachecambia.org/2021/11/borgata-coletta-giovani-montagna/

- Preferring local stones and dry stone walls over asphalt and concrete for roads and reinforcement structures;
- Do not build new artefacts or buildings on agricultural land;
- Do not install invasive and continuous urban lighting;
- Do not asphalt and cement car parks and pedestrian paths;
- Do not widen roads for cars;
- Do not host significant urban events in the mountains;
- Do not build playgrounds, themed parks and any structure that is alien to the context of the mountain: the beauty of the mountain is enough.

The second one is the *Manifesto di Camaldoli*. It was promoted by the Società dei Territorialisti[160] after the conference "The new centrality of the mountain" in January 2019. Below are listed some key aspects.

- Affirming the idea of Italian mountains as a peculiar cultural heritage reach of values, resources and knowledge fundamental for the future of the country;
- Supporting "remaining", "returning", and "new" inhabitants that renovate the centrality of the mountain as a place of life and production;
- Establishing the centrality of the mountain on integrated, self-sustainable, agroecological, bioregional, inclusive, community local development;
- Producing concrete this development with national projects for the repopulation of the Alps;
- Encouraging new forms of community self-government, inspired by the historical autonomy of the mountains, capable of promoting a new civilisation that descends towards the plains, coasts, the Mediterranean, Europe, …

## 8.2 Limits to bridge and overcome

Finally, there are many "open" aspects and limits to bridge and overcome for every ongoing and innovative research. The first one regards the possibility of *improving the ontology-knowledge by adding semantics of concepts and relations in other languages* (not only in English). In this way, with the use of gazetteers for example, it could be easy to consider ontologies, data models and datasets from different countries and harmonise them. Another aspect is the *possibility to validate the ontology with other case studies* better, adding more information to document historical centres from many other points of view. Considering other datasets could also help to improve the interoperability of data formats.

[160] www.societadeiterritorialisti.it

# 9

Chapter 9

# Conclusions and Future perspectives

This research aimed to develop a spatial ontology in the domain of minor historical centres. The investigated aspects concern the definition and evolution of historical centres and their cultural, social and economic values. Moreover, an in-depth study on digital ontologies in the geospatial domain has been carried out, considering spatial information and architectural built and historical heritage standards.

The thesis described the ontology design process, from conceptualisation to enrichment and populations with information and knowledge derived from standards and application case studies. This study set the basis to develop a knowledge base in the built historical heritage domain focusing on MHC, particularly on villages and hamlets. The dissertation answered the main aim of designing a proper structure to store and share knowledge among different stakeholders and actors involved in historical centres and built architecture tasks. Moreover, the methodology and the ontology scope pointed to spatial and temporal describe the characteristics of these centres considering many aspects such as morphology, historical information, urban and landscape regulations and plans, risks information, etc. Finally, this work developed the first level of knowledge in the domain of abandoned MHC around cities, in rural places or hinterlands, allowing the reuse and the improvement of this structure with other information.

The ontology process is iterative, and an ontology domain (or application as in this case) could be enriched with new concepts and properties to describe other levels of granularity. Furthermore, the developed methodology is innovative because users can use a unique web tool through the webApps and the MHC ontology documentation. For this purpose, some *advantages* are listed below. They underline the added values embodied by this new methodology:

- *Saving time.* Through the WebApp, it is possible to query objects in the map and immediately get information without downloading different datasets. The user can easily open the documentation providing semantic knowledge on a specific domain.
- *Limited number of* software *used*. It is unnecessary to download and install GIS or ontology editor software (such as QGIS, ArcGIS or Protégé). There is a common online interface and OWL2 documentation published.
- *Required skills*. There is no requirement to be an expert user for consulting and querying the app, so even policymakers, municipalities actors, urban planners can have information and knowledge related to the MHC documentation domain.
- *Integration of standards and ontologies*. Stakeholders don't need to download all the ontologies in the HC domain individually; they can directly open other conceptualisations by querying the classes integrated into the MHC ontology.
- *Harmonisation of datasets.* The datasets are also harmonized according to different data models and standards.
- *Integration of regulations and plans*. Part of the rules, plans and regulations of case studies are integrated into the ontology structure. Moreover, it is possible to insert further information without downloading any documents because they are linked to spatial objects in the map and concepts in the ontology.

Possible activities and work to be carried out in the future are reported in the next section.

## 9.1 Future works and activities

There are many open aspects and limits to bridge and overcome for the usability, adoption, enrichment, and spreading of the geospatial ontology. Below, a list of some possibilities of this thesis progress is reported. All points are related and connected to each other, and they could be further developed together in community and multidisciplinary projects:

- Making the ontology multilingual, improving the ontology knowledge by adding semantics of concepts and relations in other languages (not only in English). In this sense, the adoption of gazetteers (Laurini, 2015) could make it easier to integrate ontologies, data models and datasets from different countries and harmonise them.

- Considering other datasets could improve the interoperability of data formats. For example, converting different datasets in the same standard format, such as cityGML, can guarantee the effective reuse and sharing of data. Another option can be using Cellfie, a plugin of Protégé, to transform data to the ontology, importing data from Excel workbooks.

- Improving the knowledge base and the ontology by integrating it with other existing conceptualisations and ontologies to represent architectural cultural heritage such as CIDOC CRMdig[161], ArCo and Cultural-ON.

- Validating the methodology and the ontology by adding instances from other case studies. This process of inserting more information will enhance the documentation of MHC purpose, giving a 360° view of the domain. Moreover, some automatic ontology validation and evaluation approaches and parameters (Gangemi et al., 2006; Vrandečić, 2009) can be applied to the MHC ontology.

- Developing and designing 3D maps for MHC. The use of 3D city models with different levels of detail combing spatial datasets with 3D metric survey data can enrich the information knowledge and improve the usability of the tool. For example, regarding case study II, the hamlet 3D buildings could be visualised in 3D in GIS visualisation. The 3D map can be created by digitalising the 3D metric products of the integrated survey. In this way, it is possible to query the model, gathering information on the objects directly (Colucci et al., 2018).

- Integrating GIS and BIM domains for creating a complete and multiscale city digital twin to enhance and promote urban resilience plans and projects. In this way, the IFC standard and the related parametric models' formats could be integrated into a 2D or 3D GIS or Urban BIM platform.

- Applying the geospatial ontology for 3D cadasters plans will help the different bodies to have a standard structure and language. This approach could also be related to possible BIM future cadasters (Osello, 2018).

[161] https://cidoc-crm.org/crmdig/fm_releases

- Making the information editable and integrable in the WebGIS App, with different user levels. In this way, architects, restorers and administration could add their specific information.

- Converting the harmonised GIS dataset in OWL2 or RDF and adding them into specific application ontologies queryable in SPARQL.

- Adding to the ontology semantic information concerning indoor cultural heritage such as museum collections artworks. Ontologies could help retrieve information on related CH, artworks sheets and catalogues (integrating, for example, the Europeana standard).

- Combining the geospatial ontologies with other AI methods and techniques such as machine learning (ML) and deep learning (DL) approaches. For example, ontology hierarchy and taxonomy could be helpful to train neural networks in built and cultural heritage domains (Malinverni et al., 2019).

- Implementing the WebApp (integrating 3D GIS, BIM and ontology documentation) in a unique interface. This aim can be reached by working with a multidisciplinary approach involving computer scientists or other domain experts.

Other possible works can be born from the described methodology. This study and its applications are an exemplary replicable method. The hope is to spread this developed knowledge across different experts to generate new research and practical projects by ***sharing knowledge*** and working together with an ***interdisciplinary approach***.

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# Appendix A

## Classes from standards, conceptualisations and books

This Appendix reports a list of classes (concepts or entities) studied and analysed for the ontology design of the methodology. Many of these have been adapted, changed, deprecated, or merged during the ontology engineering process to answer the domain's scope.

### Concepts from Standards for Built Heritage Knowledge

I. UNESCO Thesaurus[162]

Hierarchy of concepts were extracted from UNESCO Thesaurus, "a controlled and structured list of concepts used in subject analysis and retrieval of documents and publications in the fields of education, culture, natural sciences, social and human sciences, communication and information"[163]:

- *Urban areas*
  - ***Historic cities***
  - *Suburbs*
  - *Small towns*
- *Architecture*
  - *Buildings*
  - *Monuments*
  - *Historic monuments*
- *Cultural heritage*

United Nations Educational, Scientific and Cultural Organization

UNESCO Thesaurus

[162] http://vocabularies.unesco.org/browser/thesaurus/en/
[163] http://vocabularies.unesco.org/browser/thesaurus/en/page/concept13188

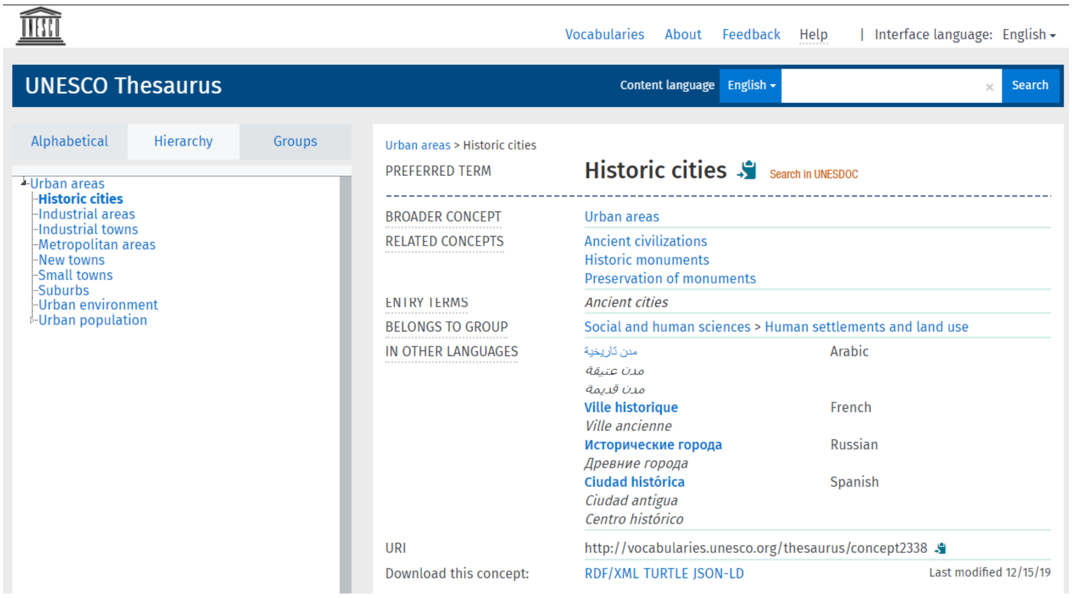



Figure 120. Historic cities term in the Unesco Thesaurus.

\\ UNESCO HUL, Historic Urban Landscape (2011)

These concepts derived from natural language text (Kokla et al., 2019).

“Historic Urban Landscape (HUL) is "the *urban area* understood as the result of a *historical layering of cultural and natural values and attributes*, extending beyond the notion of historical centre or ensemble". This new broader notion includes an enriched definition of historical urban structures including the: "*topography, geomorphology, hydrology* and *natural features*; its *built environment*, both *historic* and *contemporary*; its *infrastructures above and below ground*; its *open spaces* and *gardens*, its *land-use patterns* and *spatial organization*; *perceptions* and *visual relationships*; as well as all other elements of the urban structure. It also includes *social and cultural practices and values, economic processes* and the *intangible dimensions of heritage* as related to diversity and identity".

- ***Historic Urban Landscape***
- *Historical Layering of cultural and Natural Values*
- *Natural Features*
- *Topography*
- *Geomorphology*
- *Hydrology*
- *Built Environment*
    - *Historic*

- *Contemporary*
- *Infrastructures (above and below ground)*
- *Open Spaces*
  - *Gardens*
- *Land Use Patterns*
- *Spatial Organization*
- *Visual Relationships*
- *Social and Cultural Practices and Values*
- *Economic Processes*
- *Heritage*
- *Perceptions*

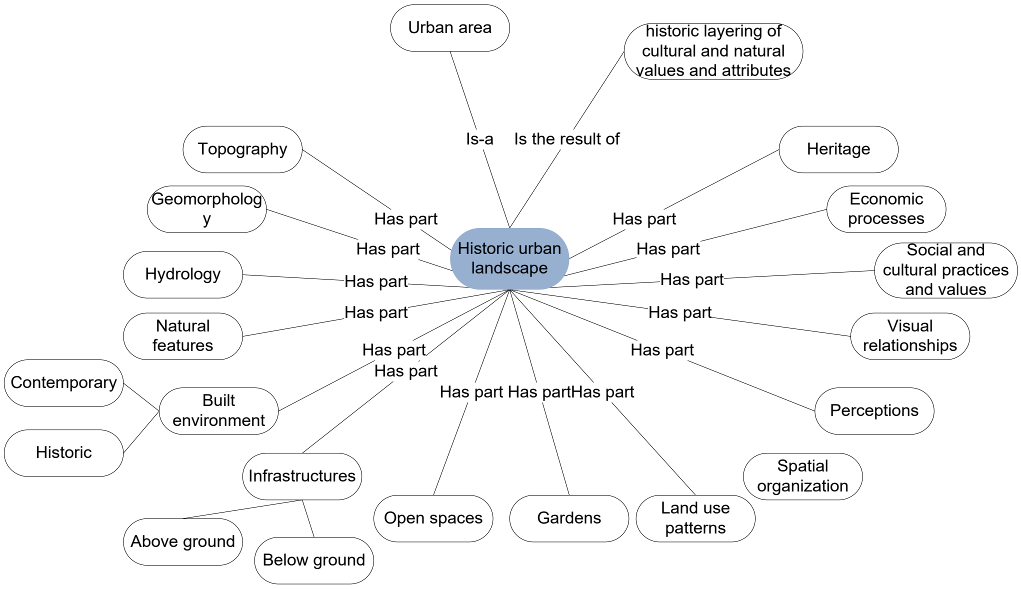



Figure 121. Structured representation of HUL concepts and relationships from (Kokla et al., 2019).

\\ UNESCO HUL Historic Urban Landscape (2019)

*UNESCO World Heritage Centre, 2019. "The UNESCO Recommendation on the Historic Urban Landscape. Report of the Second Consultation on its Implementation by the Member States"*

"From the available list from the survey, the most recognized category of urban area type is a ***cultural landscape***. However, the HUL approach is a tool and a methodology and not a category of heritage. In terms of quantity of designations, the highest number of designations are for the ***historic centre***. Based on different vocabularies, it was impossible to reach meaningful quantitative data on categorisation of ***urban areas***".

- *Historic Urban Landscape*
- *Cultural Landscape*
- ***Historic Centre***
- ***Urban Areas***

II. ICOMOS - Historic towns and urban areas (2011)[164]

Concepts have been extracted from natural language text and defined according to a structured representation (Kokla et al., 2019).

Historic towns and urban areas are “*spatial structures* that express the evolution of a society and of its cultural identity. Historic sites are an integral part of a *broader natural or man-made context* and the two must be considered inseparable. Historical towns and urban areas are made up *of tangible and intangible elements*. The tangible elements include, in addition to the *urban structure, architectural elements*, the *landscapes* within and around the town, *archaeological remains, panoramas, skylines, view-lines* and *landmark sites.* Intangible elements include *activities, symbolic and historical functions, cultural practices, traditions, memories*, and *cultural references* that constitute the substance of their historic value”.

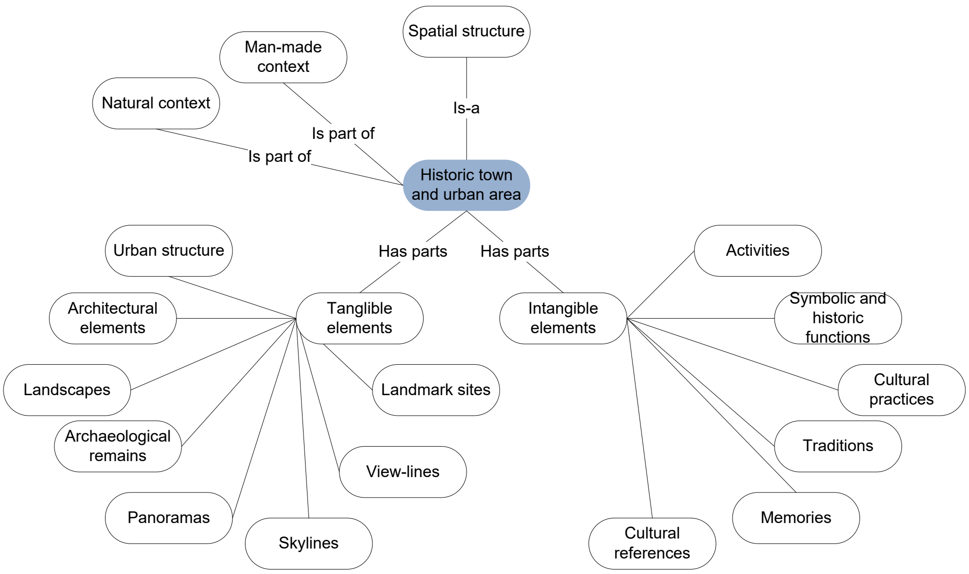



Figure 122. Structured representation of ICOMOS concepts and relationships from (Kokla et al., 2019).

[164] https://www.icomos.org/en/what-we-do/focus/179-articlesen-francais/ressources/charters-and-standards/159-charter-for-the-conservation-of-historic-towns-and-urban-areas

## III. NLUD - the National Land Use Database

From natural language text to structured representation (Kokla et al., 2019).

"*Building*: a *substantial and permanent construction* with a *roof* and *walls* for giving *shelter,* e.g. *house, office, shop, warehouse, factory, church, barn."*

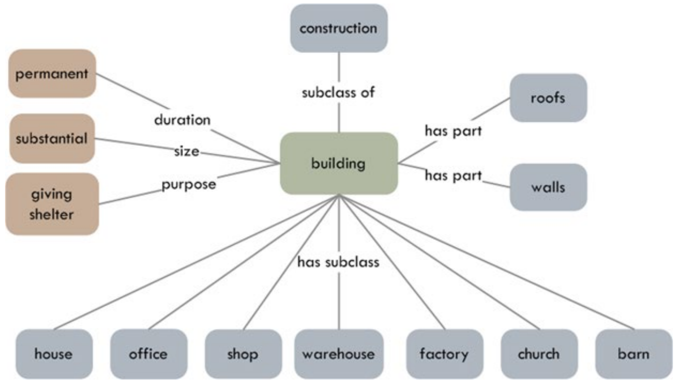



Figure 123. Structured representation of NLUD concepts and relationships from (Kokla et al., 2019).

## IV. CIDOC Conceptual Reference Model (CRM) ontology[165]

The main source from which concepts have been selected and extracted are the CIDOC-CRM documentation of the core ontologies and their extensions (Doerr et al., 2013, 2018; Doerr, Felicetti, et al., 2020; Ronzino et al., 2016). The primary source is "The Reference Model" (Doerr et al., 2020). Figure 124 shows an example of the selected entities from different ontologies of CIDOC-CRM.

| CIDOC CRM CORE | CRM-geo | CRM-archeo | CRM-ba | CIDOC-sci |
|---|---|---|---|---|
| CIDOC CRM | CRM geo Spatiotemporal model | CRMarchaeo Excavation Model | CRMba Model for Archaeological Buildings | CRM sci Scientific observation model |
| E1 CRM Entity | SP1 Phenomenal Spacetime Volume | A1 Excavation Process Unit | B1 Built Work | S1 Matter Removal |
| E4 Period | SP2 Phenomenal Place | A2 Stratigraphic Volume Unit | B2 Morphological Building Section | S2 Sample Taking |
| E5 Event | SP3 Reference Space | A3 Stratigraphic Interface | B3 Filled Morphological Building Section | S3 Measurement by Sampling |
| E18 Physical Thing | SP4 Spatial Coordinate Reference System | A4 Stratigraphic Genesis | B4 Empty Morphological Building Section | S4 Observation |
| E19 Physical Object | SP5 Geometric Place Expression | A5 Stratigraphic Modification | B5 Stratigraphic Building Unit | S5 Inference Making |
| E22 Man-Made Object | SP6 Declarative Place | A6 Group Declaration Event | **from: CIDOC CRM CORE** | S6 Data Evaluation |
| E24 Physical Man-Made Thing | SP7 Declarative Spacetime Volume | A7 Embedding | E5 Event | S7 Simulation or Prediction |
| E25 Man-Made Feature | SP10 DeclarativeTime-Span | A8 Stratigraphic Unit | E7 Activity | S8 Categorical Hypothesis Building |
| E26 Physical Feature | SP11 Temporal Reference System | A9 Archaeological Excavation | E12 Production | S9 Property Type |
| E27 Site | SP12 Spacetime Volume Expression | A10 Excavation Interface | E18 Physical Thing | S10 Material Substantial |
| E28 Conceptual Object | SP13 Phenomenal Time-Span | **from: CIDOC CRM CORE** | E24 Physical Man-Made Thing | S11 Amount of Matter |
| E29 Design or Procedure | SP14 Time Expression | E1 CRM Entity | E52 Time-Span | S12 Amount of Fluid |
| E41 Appellation | *SP15 Geometry* | E3 Condition State | E53 Place | S13 Sample |
| E52 Time-Span | **From: OGC GEO-SPARQL** | E6 Destruction | E55 Type | S14 Fluid Body |
| E53 Place | *SpatialObject* | E7 Activity | E92 Spacetime Volume | S15 Observable Entity |
| E59 Primitive Value | *Feature* | E13 Attribute Assignment | | S17 Physical Genesis |
| E61 Time Primitive | *Geometry* | E18 Physical Thing | | S18 Alteration |
| E70 Thing | **from: CIDOC CRM CORE** | E27 Site | | S19 Encounter Event |
| E71 Man-Made Thing | E1 CRM Entity | E53 Place | | S20 Rigid Physical Feature |
| E73 Information Object | E4 Period | E55 Type | | S21 Measurement |
| E7 Activity | E5 Event | E81 Transformation | | S22 Segment of Matter |
| | E18 Physical Thing | **from: CIDOC-sci** | | |
| | E26 Physical Feature | S1 Matter Removal | | **from: CIDOC CRM CORE** |
| | E29 Design or Procedure | S4 Observation | | |

Figure 124. Summary table of some selected entities from the CIDOC-CRM ontologies.

[165] http://www.cidoc-crm.org/

## V. GETTY VOCABULARIES, The Art & Architecture Thesaurus (AAT)[166].

A specific investigation of concepts related to historical centres, cities, cultural heritage, landscape and so on has been performed in the thesaurus of Getty (AAT). Figure 125 shows the hierarchy of "historic centres" in the vocabulary. The Getty concepts have been considered in the singular (e.g., "historical centres").

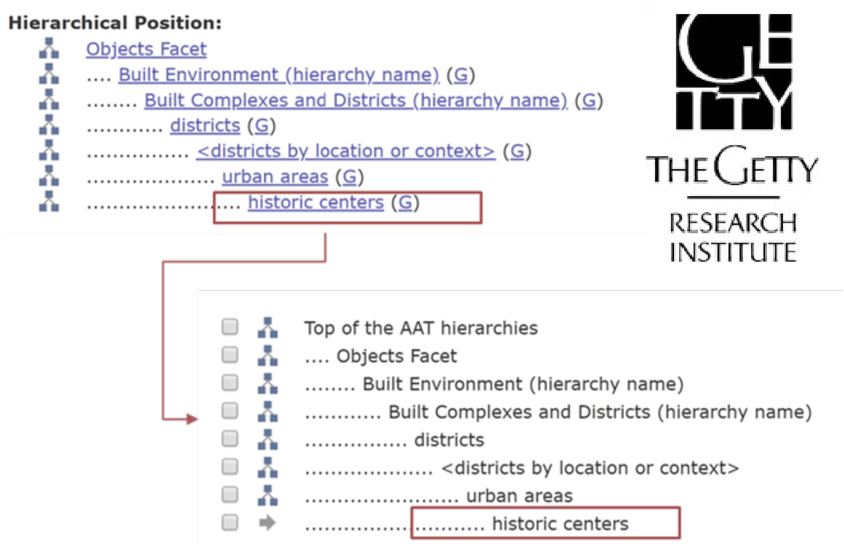



Figure 125. Historic centers concepts and hierarchy in the Getty AAT.

- Object Facet
- Built Environment
- Settlements and Landscapes
    - Landscapes
    - Cultural Landscapes
    - Historic Landscapes
- Built Complexes and Districts
    - Districts
    - Urban Areas
    - **Historic Centres**
- Single Built Works
    - Abandoned Building
    - Cultural Centers
    - Historic Buildings
- Open Spaces and Site Elements
- Associated Concepts Facet
    - Cultural Heritage
    - Intangible Cultural Heritage

[166] https://www.getty.edu/research/tools/vocabularies/aat/index.html

    - Tangible Cultural Heritage
    - Architectural Heritage
- Components
    - Architectural Elements
    - Structural Elements
    - Enclosing Structural Elements
    - Walls
    - Bearing Walls
    - Surface Elements
    - Openings
    - Barriers

**Concepts from Standards of *Geographic Information***

I. OGC GeoSPARQL - A Geographic Query Language for RDF Data[167]

*Open Geospatial Consortium, 2012. "OGC GeoSPARQL - A Geographic Query Language for RDF Data. Version 1.0., Matthew Perry and John Herring, OGC® Implementation Standard – available at http://www.opengis.net/doc/IS/geosparql/1.0)*

- *Geometry*
- *Feature*
- *Spatial Object*

II. CityGML (OGC standard)[168] and CityGML ontology in OWL [169]

- City Object
    - Opening
        - Door
        - Window
- Boundary Surface
    - Roof Surface
    - Wall Surface
    - Building Plot
    - Water Boudary Surface

[167]https://www.ogc.org/standards/geosparql/; Ontology link in RDF: http://schemas.opengis.net/geosparql/1.0/geosparql_vocab_all.rdf
[168] https://www.ogc.org/standards/citygml
[169] http://vgibox.eu/repository/index.php/CityGML_in_OWL; http://cui.unige.ch/isi/onto/citygml2.0.owl

- Site
  - Abstract Building
    - Building
    - Building Part
- Transportation Object
- Vegetation Object
  - Plant Cover
  - Solitary Vegetation Object
- Water Object
- Bridge Construction Element
- Land Use
- City Furniture

In figures below (Figure 126, Figure 127, Figure 128, Figure 129) concepts from different LoDs.

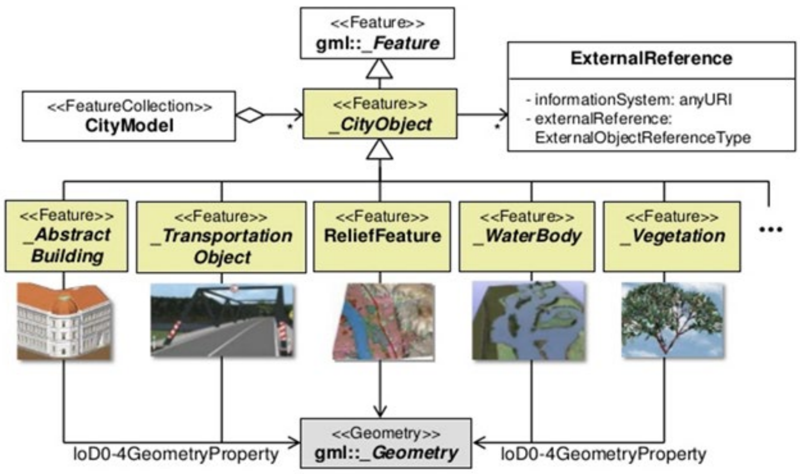



Figure 126. CityGML UML model, Level of Detail 0.

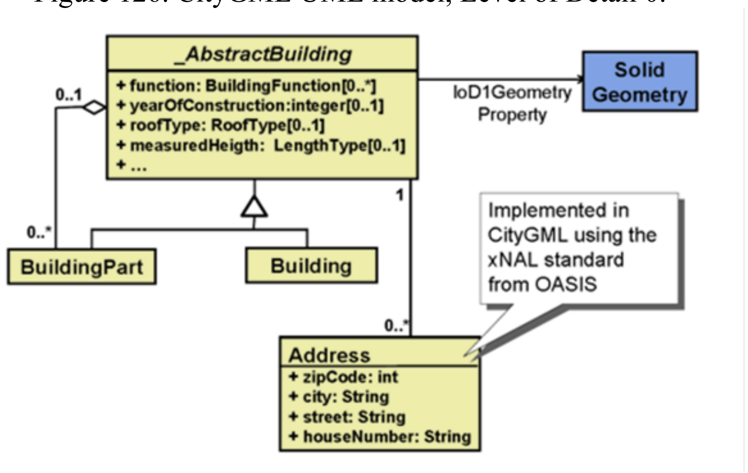



Figure 127. CityGML UML model, Level of Detail 1.

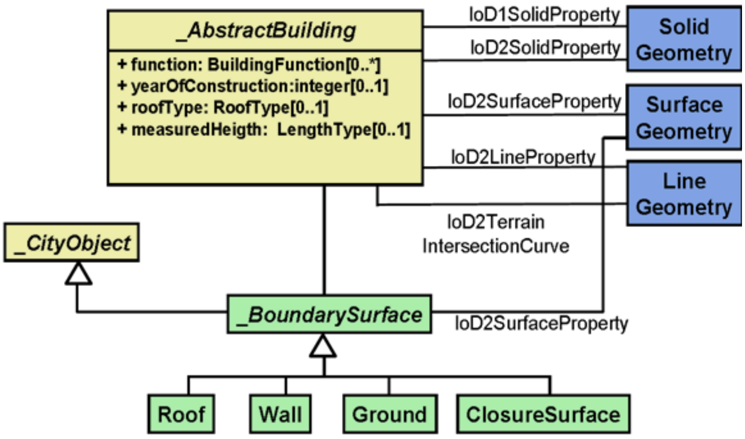



Figure 128. CityGML UML model, Level of Detail 2.

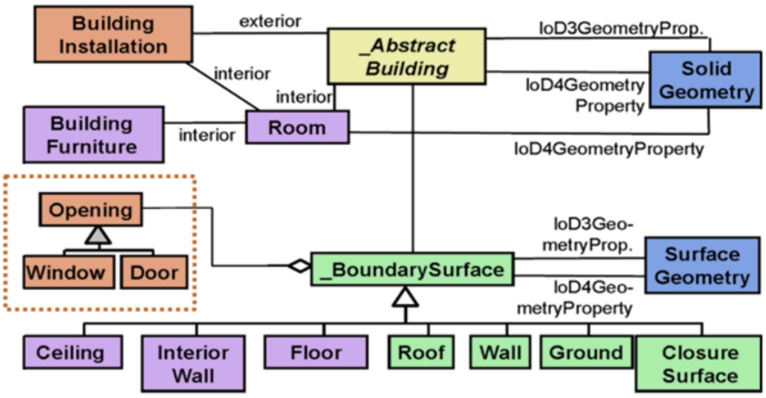



Figure 129. CityGML UML model, Level of Detail 3.

III. IFC Buildings – BIM (sources: Ifc documentation[170], IfcArchitectureDomain[171], IfcOWL ontology - FC4_ADD2[172])

- ifcObject
- ifcProduct
- ifcElement
- ***ifcBuildingElement:***
  - *IfcBean*
  - *IfcBuildingElementProxy*
  - *IfcChimney*
  - *IfcColumn*
  - *IfcCovering*
  - *IfcCurtainWall*
  - *IfcDoor*

[170] https://standards.buildingsmart.org/IFC/RELEASE/IFC4/ADD2_TC1/HTML/
[171] https://standards.buildingsmart.org/IFC/RELEASE/IFC4/ADD2_TC1/HTML/annex/annex-d/ifcarchitecturedomain/index.htm
[172] http://ifcowl.openbimstandards.org/IFC4_ADD2/index.html#http://www.buildingsmart-tech.org/ifcOWL/IFC4_ADD2#IfcBuildingElement

  - *IfcFooting*
  - *IfcMember*
  - *IfcPile*
  - *IfcPlate*
  - *IfcRailing*
  - *IfcRamp*
  - *IfcRampFlight*
  - *IfcRoof*
  - *IfcShadingDevic*
  - *IfcSlab*
  - *IfcStair*
  - *IfcStairFlight*
  - *IfcWal*
  - *IfcWindow*
- ifcElementComponent
  - ifcBuildingElementPart
- ifcGeographicElement
- ifcTransportElement
- IfcSpatialElement
  - ifcSpatialStructureElement
    - IfcBuilding
    - ifcSite
    - ifcSpace

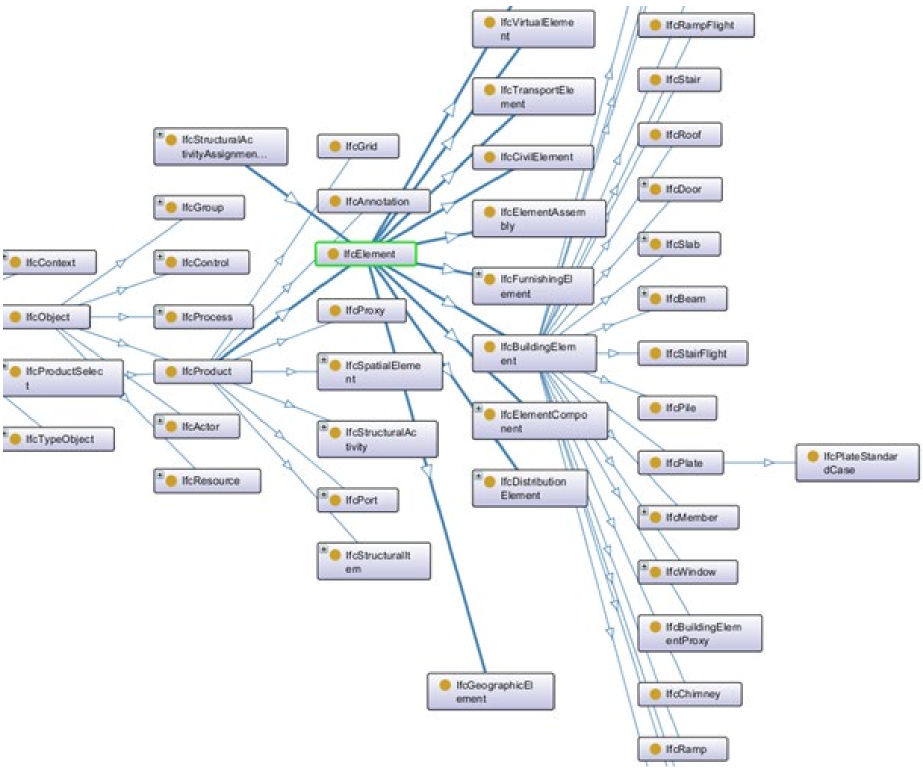
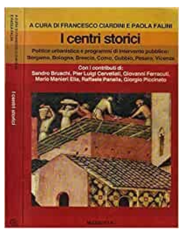


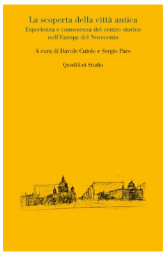
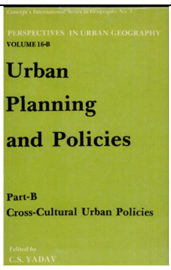

Figure 130.Graphic visualisation of Ifc BuildingElement classes in OntoGraf tool (Protégé).

## Concepts from the literature of *Historical Centres*

Table 29 reports the different book sources from which concepts on MHC notions have been exracted.

Table 29. Concepts extraction from books on "historical centres" definition and evolution.

| ***Sources*** | | ***Concepts*** | |
|---|---|---|---|
|   | *Fano, G. (1974). Centro storico e città in espansione.* | Urban Centres<br>New Urban Center<br>Old Urban Center<br>Recent Past<br>Architectural Ruin<br>Tradition<br>Culture<br>Historical Centres<br>Neighbourhoods<br>Cities<br>Architecture<br>Social & Political Relationships | Social, Economic & Political Life<br>Politic Transformations<br>Economic Transformations<br>Cultural Value<br>Historic Architecture<br>Landscape<br>Cultural Heritage<br>Valorisation<br>Restoration |
| Jounal Article | *Volpiano, M. (2017). Centri storici.* | Historical Centre<br>Urban Space<br>Monuments<br>Cultural Environmental Heritage<br>Social Value<br>Political Value<br>Economic Value<br>Legislative Value<br>Conservation<br>Valorisation<br>Protection | Safeguarding<br>Rehabilitation<br>Landscape<br>Cultural Heritage<br>Monumental Centres<br>Urban Dimension<br>Urban Historical Centres<br>Settlements<br>Cultural Units<br>Urban Culture<br>Environmental Cultural Heritage |
|   | *Cervellati, P. L., Scannavini, R., & De Angelis, C. (1977). La nuova cultura delle città.* | Historical centres<br>Pre-industrial cities<br>Settlements<br>City<br>Country-side/ Rural Areas<br>Fortified Cities | Urban History<br>Central Area<br>Urban Planning<br>Monuments<br>Cultural Value |
|   | *Cervellati, P. L., & Miliari, M. (1977). Il punto le interpretazioni la bibliografia su I centri storici.* | Historical Centres<br>City of the past<br>Ancient centres<br>Buildings<br>Environment | Architectural Heritage<br>Monuments<br>Quarters<br>Neighbourhoods<br>Villages |
|   | *Ciardini, F., & Falini, P. (1978). I centri storici.* | Historical Centres<br>Squares<br>Courts<br>Colonnades<br>Porches<br>Terraces<br>Staircases<br>City centre<br>City | Services<br>Economic Value<br>Conservation<br>Commercial Activities<br>Minor Historical Centres<br>Tourism<br>Coastal areas<br>Mountains areas<br>Urban renovation |

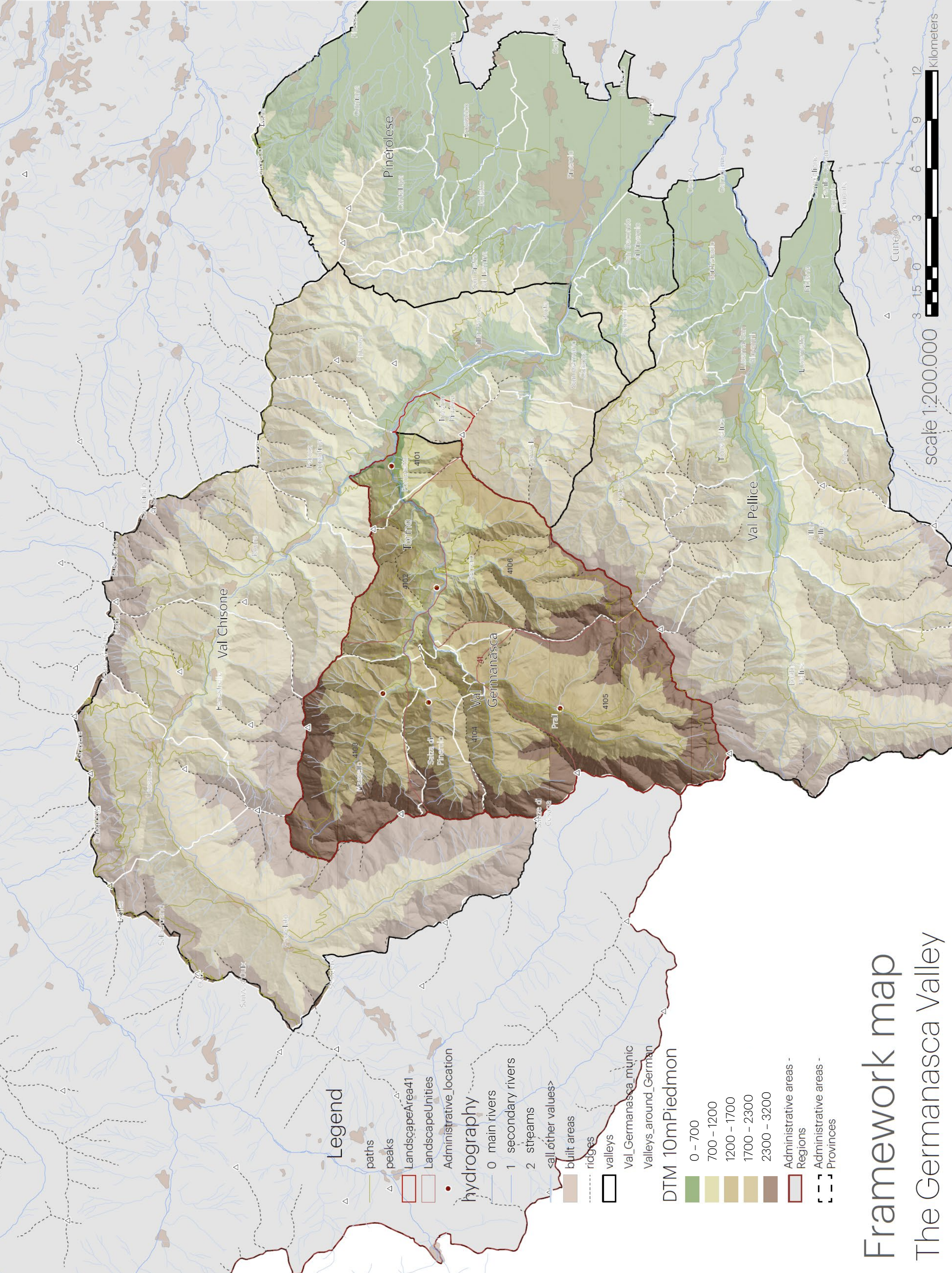
| ***Sources*** | | ***Concepts*** | |
|---|---|---|---|
|  | *Cutolo, D., & Pace, S. (2016). La scoperta della città antica.* | Historical Centres<br>Old City<br>City Centre<br>Core<br>Civic Centre<br>Urban Agglomeration<br>Old Town<br>Urban Historical Centre<br>Settlement | Cuture<br>Agglomeration<br>Conservation<br>Urban Planning<br>Urban Culture<br>Ancient Walls<br>Historical Evidence |
|  | *Yadav, C. S. (Ed.). (1986). Urban planning and policies.* | Historical Centre<br>Services<br>Primary urbanization<br>Privileged Position<br>Main Town Services<br>Central location<br>Town centre | Accessibility of services<br>Availability of services |
|  | *Rolli, G. L. (2005). Conoscenza, rappresentazione, recupero urbanistico dei Centri storici minori.* | Minor Historical Centre<br>Small Villages<br>Hamlets<br>Buildings<br>Buildings Units<br>Urban Furnitures<br>Boundaries Elements<br>Roads<br>Nodes<br>Site<br>Boundary Walls<br>Fortified Structures<br>Walls-houses | Natural/ManMade Boudaries<br>Access Point<br>Achaeological Site<br>Paths<br>Roads<br>Fortified Lines<br>Transport Networks<br>Architectural Discoveries<br>Peripheric Fabrics<br>Squares |
| PhD Thesis | *Cerasoli, M., & Biere Arenas, R. M. (2016). The sustainable future of the smaller historical centres.* | Historical Centre<br>Complexes of Properties<br>Urban area<br>Aesthetic value<br>Traditional Value<br>Cultural Asset<br>Economical Asset<br>Social Asset | Monuments<br>Buildings<br>Historical, Arstistic, Documentary interest<br>Historical Urban fabric<br>Paved Public<br>Public Pedestrian<br>Paved Areas<br>Public Green Spaces |

# Appendix B

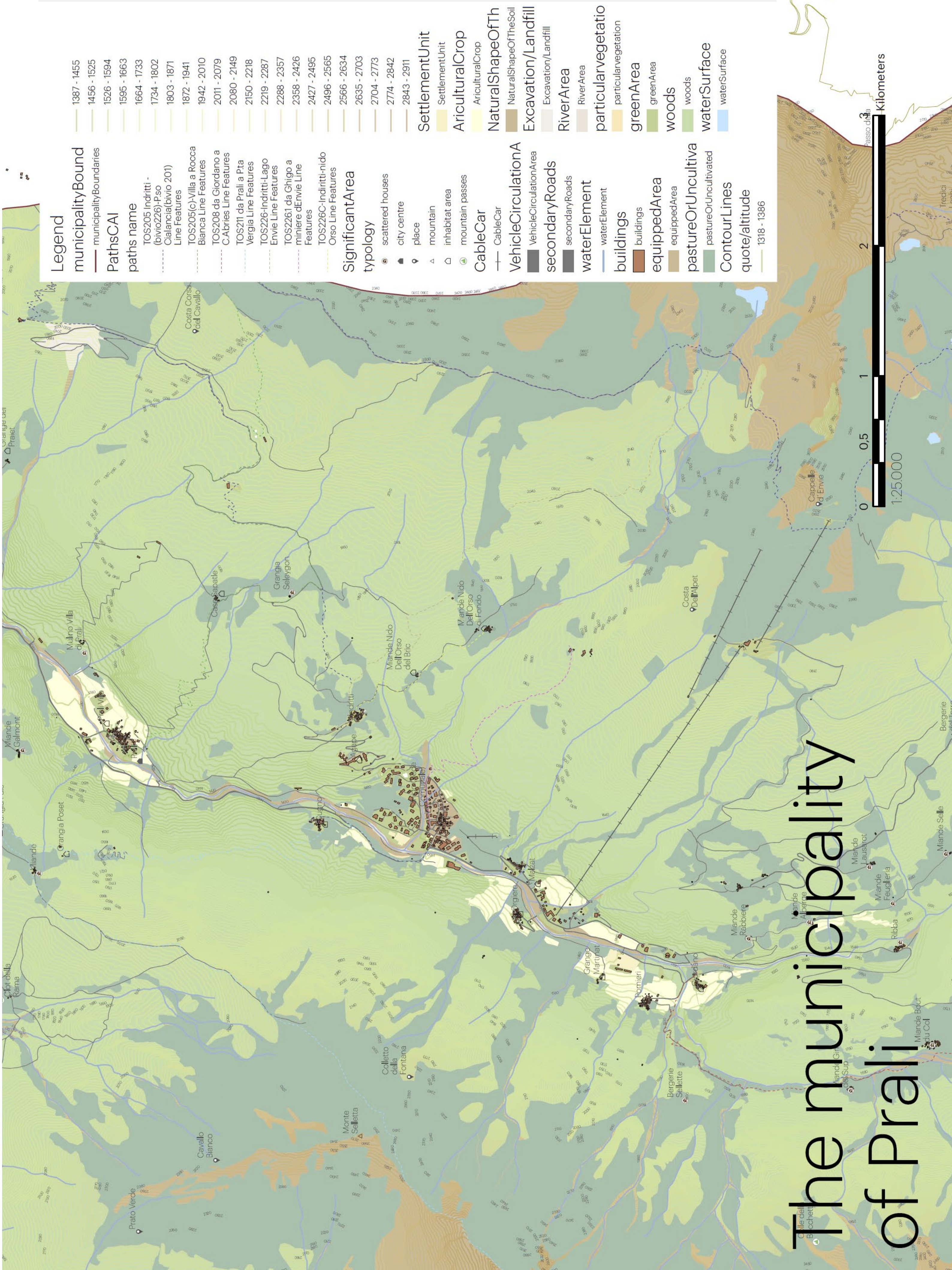
## Maps and datasets

# Case Study I, Sloten village – ***Urban scale***

## Case Study II – Framework map, Germanasca Valley – ***Territorial scale***

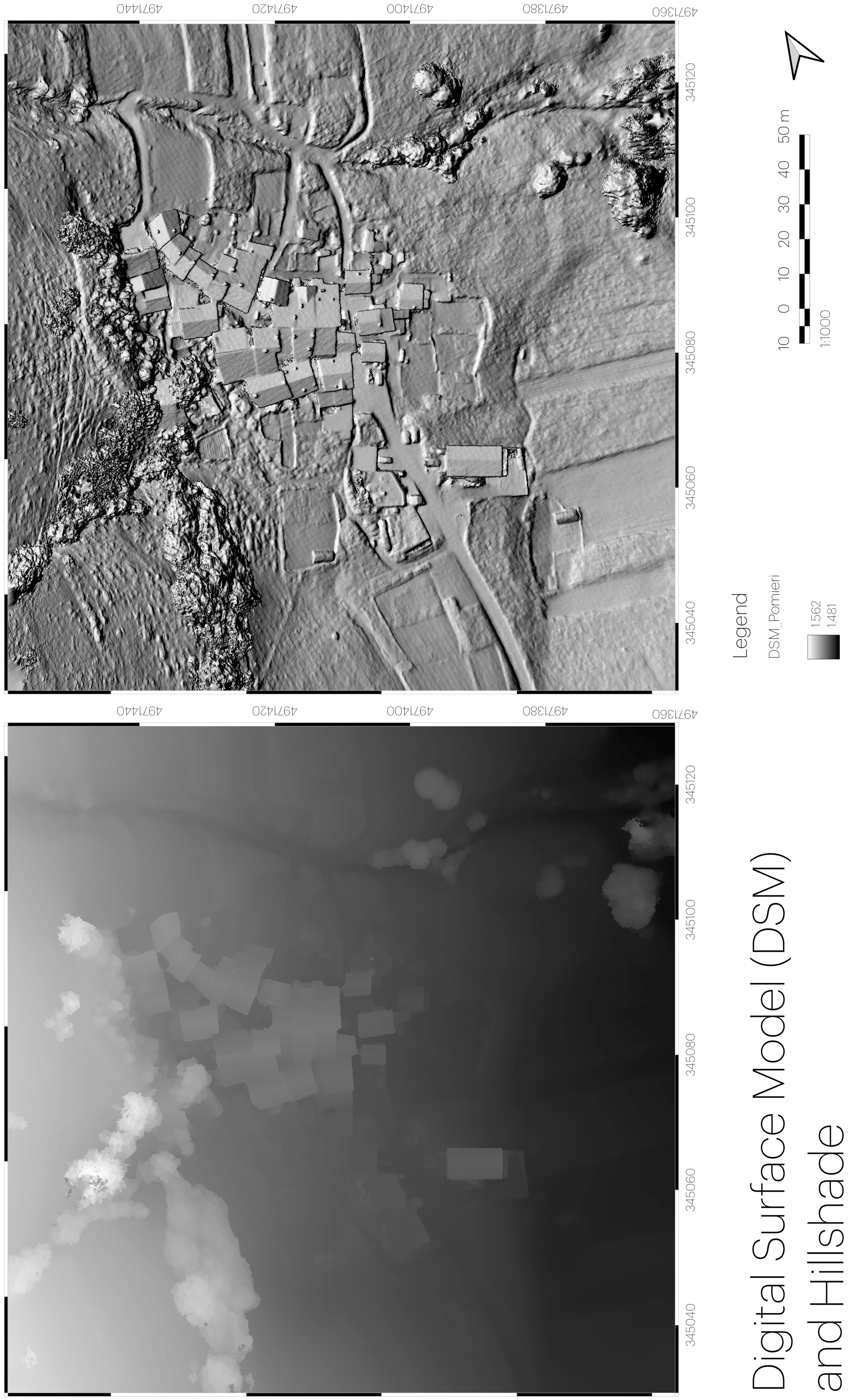


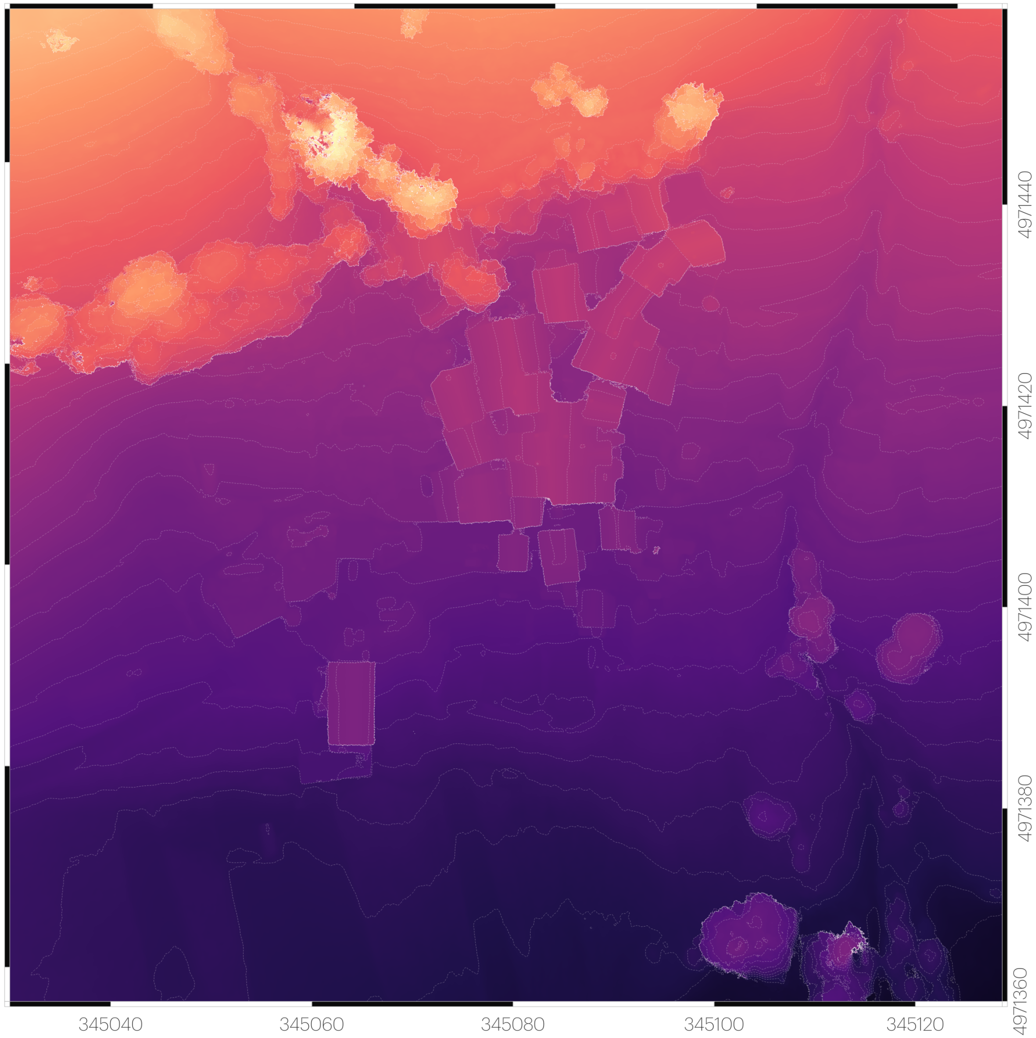
Case Study II – The municipality of Prali – ***Landscape scale***



Case Study II – Framework map, The hamlet of Pomieri – ***City scale***

Case Study II – 3D metric survey data, ***DSM & Orthophoto***







# DSM and Orthophoto

Legend

Contour lines

DSM

1.562
1.481

Legend

Orthophoto

10 0 10 20 30 40 50 m

1:1000