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## 6. Knowledge based IT platform for Heritage Buildings

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*Due to the huge and complex pool of data about heritage buildings, the sustainable management of heritage buildings calls for an appropriate support system. Data collected must be analysed and then an appropriate approach for conceptualization, structure and organization must be applied along with the use of an IT platform for their intelligent management.*

*The innovative IT platform for heritage buildings based on knowledge-based system can support a heritage buildings expert to aggregate data into meaningful information that supports any of the heritage buildings lifecycle activities: first expertise analysis, documentation, preventive conservation, restoration, social and economic aspects of heritage buildings, use and management. For example, a heritage buildings expert specialized in biodeterioration wants to evaluate the state of conservation of a heritage building and therefore asks the platform about abiotic and biotic factors, which determine physical and chemical deterioration of stone materials. The expert may also ask the platform how biotic factors affect durability of stone. Answers to these questions are expected to properly address preventive conservation and restoration strategies. Similarly, stakeholders preparing investments into heritage buildings have to consider different approaches and scenarios and the platform can provide important answers or directions.*

**Keywords:** *Heritage Building; Interoperability; Heritage Buildings Core Ontology; Knowledge based management system; Intelligent Management.*

### 6.1. Introduction

Typical heritage buildings' (HB) processes like reconstruction, restoration and use change, create huge amounts of data coming from different stakeholders. The intelligent management of HBs requires semantic consolidation of data. Literature (Akoka, Comyn-Wattiau, & Laoufi, 2017) shows that semantic data are best managed with a Knowledge Based System (KBS). Such KBS integrates heterogeneous information sources and domain ontologies to organize information and direct the search processes. Existing knowledge about HBs must be captured to serve the expert's demands. The knowledge capturing process is part of knowledge engineering research where the task of identifying categories, subcategories and their relations is often referred to as constructing an ontology. As defined in literature (Akoka, Comyn-Wattiau, & Laoufi, 2017), ontology represents knowledge as a set of concepts within a domain, and the relationships between those concepts that enable meaningful search without in-depth knowledge about a specific domain area. Although some ontologies coming from construction domain (e.g. construction defect ontology, e-COGNOS project, etc.) and

some that consider parts of HB exist (Boochs & Trémeau, 2014) (e.g. European project ARIADNE with its CIDOC CRM Reference Model (Doerr, 2003), region-related cultural heritage ontology, building-shape ontology, etc.), there is a lack of comprehensively constructed ontologies for HB. As a solution a comprehensive ontology-based data HB-IT Platform (Tibaut, Kaučič, Dvornik Perhavec, Tiano, & Martins, Ontologizing the heritage building domain. V: IOANNIDES, Marinos (ur.). Advances in digital cultural heritage : International Workshop, Funchal, Madeira, Portugal, June 28, 2017 : revised selected papers, 2018), (Tibaut, Kaučič, & Dvornik Perhavec, Ontology-based data collection for heritage buildings. V: IOANNIDES, Marinos (ur.). Digital cultural heritage : Final Conference of the Marie Skłodowska-Curie Initial Training Network for Digital Cultural Heritage, 2017) suitable for trans-disciplinary domain experts and stakeholders is proposed based on real-world HB requirements. The platform could enable proactive reduction of time for searching solutions, reduction of risks involved, reduction of unexpected surprises related to impact of costs, time, materials and human resources.

## 6.2. Interoperability for Heritage Buildings

Innovation in the intelligent management of HBs should demonstrate intelligent, dynamic and self-organizing capabilities for understanding and responding to the shifts that impact the networks they belong to. To have seamless access to the available global (across borders) multi-lingual distributed data is fundamental to achieve this goal. Reconfiguration and reprioritization of HBs management processes, information models, and even terminology is now seen as a requirement for survivability, which means that HB related software systems need to become more interoperable and supported by open data. Hence, software adaptor technologies are gaining momentum due to the potential to define and regulate the peer-to-peer data access among networks of heterogeneous enterprise systems. At present, solutions based on de facto standard for transformations within the framework of Model-Driven Interoperability (MDI) have been put in practice in several application domains, including some for HBs [6]. Nonetheless, even those still lack the dynamism required to streamline complex systems in multi-lingual and large amount of data.

Although seamless data exchange and understanding is a key factor for innovation in the management of the HBs sector, it is almost impossible for the HBs stakeholders to capture the relationships among all those factors and turn data into valuable, actionable information. This cannot be done by using on-hand database management tools or traditional data processing applications. The use of data mining technologies will enable the HBs stakeholders to get actionable insights in the data resulting in smarter decisions and better business outcomes. They will be able to look at past performance and understand that performance by mining the related data (i.e., production, environment) to look for the reasons behind past success or failure and take better decisions for future. In order to improve the ability of the HB European stakeholders to develop innovation across their operating chain, there is the need to make available fully interoperable multi-lingual HB data products and services. To achieve this, it is necessary to have a framework for the interoperability between the heterogeneous source of information (data, knowledge, models, languages), supported by a reference ontology management system for big data mining and analysis [7]. In the core of this framework, there are the methods for semantic interoperability in assorted contexts of usability, comprising ontology harmonization of blended application context. This will result in the mining of large volumes of heterogeneous data (including multi-linguistics) into semantically interoperable data assets, and knowledge libraries for holistic management of the big data HB environment in terms of in/outs, along their life cycle, i.e., adaptation, feedback, monitoring, update, prune, merge, etc. For the sector, this is ground breaking and novel.

Interconnection with standards for data models and knowledge representation is necessary to fully achieve this objective. Model, data and knowledge morphisms and respective transformations are required for the adaptation and then global knowledge usage depending on language and user

profile (very important in this project context, considering the large number of different potential users and applications profiles that will use the data).

In the specific case of the HB sector, interoperability and (seamless) integration of data is very important considering that most of the sources/consumers of such big data are dispersed and not adopting standardized modelling. This would represent a set of heterogeneous source/consumers of heterogeneous data, as most of them will have their own data model representations. They need a suitable framework to assist them to access the data in the same way, independently of the data model, semantic and language (as many sources of data is stored in native language). Nevertheless, most of the applications store the data in local native language, even under a specific reference model. To be interoperable and manageable in a seamless way on a global scale (e.g. big data in the “HBs Cloud”), such harmonization and are required for a common understanding of such data in an independent but holistic form [8].

This framework will provide the data-mining platform as a cloud service that will be accessible by all the HB community, with its architecture for innovation in the intelligent management of HBs depicted in Figure 6.1. Nevertheless, by collecting and managing the data mining results from many HB stakeholders with full respect to confidential data; it will generate a knowledge base that will be of maximum usefulness for the HB sector. The stakeholders’ applications will be able to transform data to knowledge and use this knowledge to improve efficiency, increase profitability and do business in a sustainable, environmentally friendly way. To support this, a tool will be specifically designed for the HB sector.

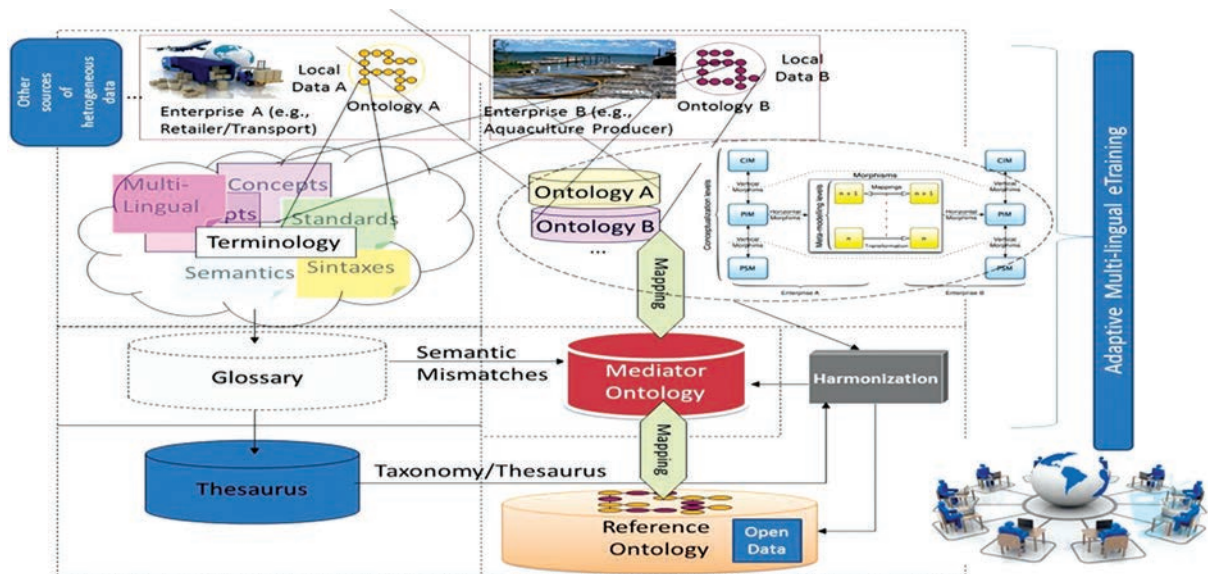


Figure 6.1. Interoperability Architecture for innovation in the intelligent management of HBs

Although software tools exist in the market no such tool is available for the HB sector. The proposed HB framework delivers a cloud-based HB framework (i.e. product, service, training,) supported by an intelligent business model for the analytics of HB data to enable much benefit to be derived in the HB sector. The introduction of an innovative multilingual knowledge base capacity suitable for the HB sector, which would enable large volumes of data to be accessible as semantic interoperable data and knowledge will improve significantly the sector and ultimately the EU’s competitiveness.

Anonymous data from the stakeholders can be seamlessly imported onto the framework that will incorporate an integrated cloud based data mining services to provide unique data mining insight. This enables the improvement of the knowledge of the system and makes it universal, i.e., the more companies using the framework, the more intelligent the framework becomes.

### 6.2.1. Requirements

Interoperability is the ability of two or more systems or components to exchange information and to use the information that has been exchanged. This includes two separate ideas:

1. The exchange of information, which is technical interoperability,
2. The ability of the recipient to use that information, which is semantic interoperability [9].

The attempt to solve this problem was in the past the “Rosetta’s stone” in which the meaning of the message is precisely the same in each language, but the notation is quite different.

More recently Zamenhof (1887) created the “Esperanto”, an easy-to-learn, politically neutral language that would transcend nationality and foster peace and international understanding among people of different languages.

Applications interoperability is not only a technical problem but it deals also with organisational issues. These aspects of interoperability are coherent with the definitions proposed by the European Interoperability Framework [10], which considers three aspects of interoperability:

- *Organisational Interoperability*: This aspect of interoperability is concerned with defining business goals, modelling business processes and bringing about the collaboration of administrations that wish to exchange information and may have different internal structures and processes. Moreover, organisational interoperability aims at addressing the requirements of the user community by making services available, easily identifiable, accessible and user-oriented.
- *Semantic Interoperability*: This aspect of interoperability is concerned with ensuring that the precise meaning of exchanged information is understandable by any other application that was not initially developed for this purpose. Semantic interoperability enables systems to combine received information with other information resources and to process it in a meaningful manner. Semantic interoperability is therefore a prerequisite for the front-end multilingual delivery of services to the user.
- *Technical Interoperability*: This aspect of interoperability covers the technical issues of linking computer systems and services. It includes key aspects such as open interfaces, interconnection services, data integration and middleware, data presentation and exchange, accessibility and security services.

The more we understand about the three types of interoperability, the less likely we are to underestimate the work required to make heritage building management intelligent and interoperable. These types of interoperability are interdependent, and all three are needed to deliver significant business benefits.

A Heritage Building and its location is a complex issue and in its management are involved different stakeholders: International Heritage Organizations; National Heritage Authorities, Institutions and Associations; Local and Regional planning authorities; Superintendence; Standard bodies, Pollution agencies, University & Research, Owners; Private, Public and; Religious; City Manager; Landscape architects; Risk and Security management; Economists; Fundraising company, Conservation scientist; Engineers; Architects of historical monuments; Archaeologists; Art Historians, Urbanists, Conservators, Construction and restoration Companies & consultants; Craftsman, Book sellers; Catering, Social media; Sponsor; Bank’s foundation and Private trusts, Users; Visitors; Tourists Guides; Volunteers, Neighbours.

Problems begin because every computer system stores data internally in a different way. This means that to communicate, data has to be translated from one format or internal language into another. The solution involves translating to a standard wire format (a lingua franca) that is understood by each party, but in computer interoperability, each and every message has to be translated from one format to another without error. The choice of interchange language is not sufficient to ensure Technical interoperability.

Each transaction needs to be defined in unambiguous detail as part of a complete, consistent, coherent, and computer-readable set of specifications for that transaction to ensure interoperability between the machines and minimize any possibility of error.

A related problem arises when the domain experts (such as architects, scientist, managers, etc.) are unable to fully understand these specifications due to the complexity of language or simply the time it takes to read them. As a consequence, these specifications may not be reviewed at the specification stage as thoroughly as is required.

Computer processing is essential when data has to be identified, matched, retrieved, or counted. For computer processing, the information needs to be structured, complete, unambiguous, and validated.

One way to simplify the problem is to distinguish between information that needs to be processed by computer and that needs to be read and understood by human users.

What are the semantic differences that should be addressed in constructing data sharing environments and developing cross-standard exchange mechanisms? [11]. Data sharing depends on reconciling different meanings (or semantics) and needs to consider the different standards that are now in circulation.

Interoperability is not only a technological issue, but a confluence of social and economic issues as well. This system should answer to queries based on established common requirements (Figure 6.2, Figure 6.3).

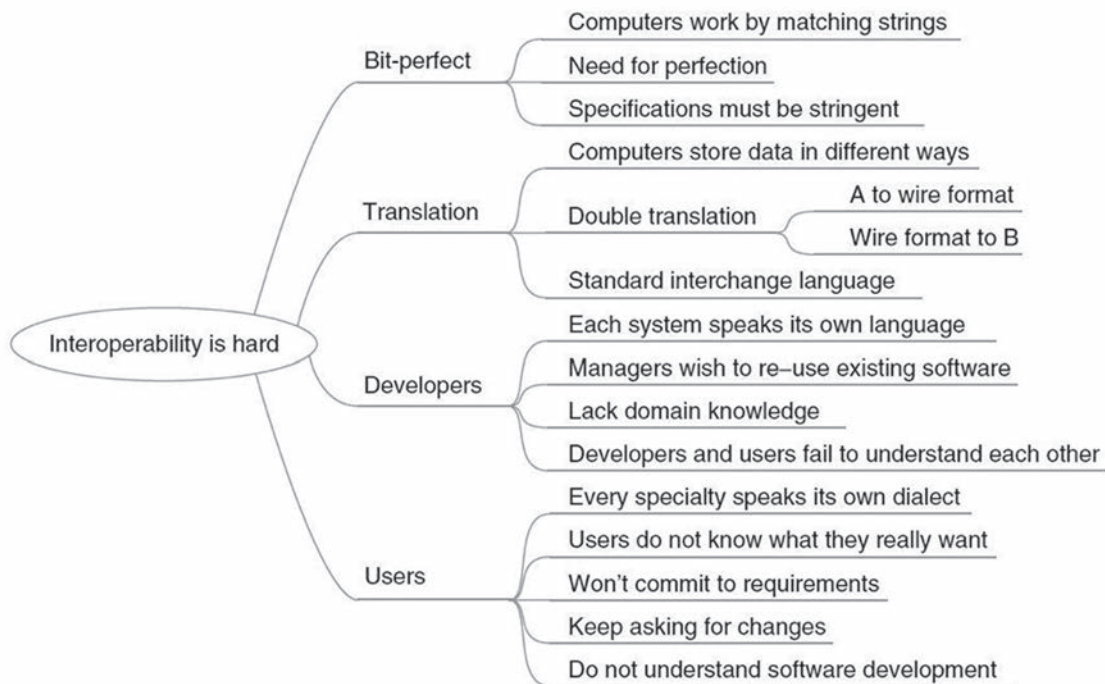
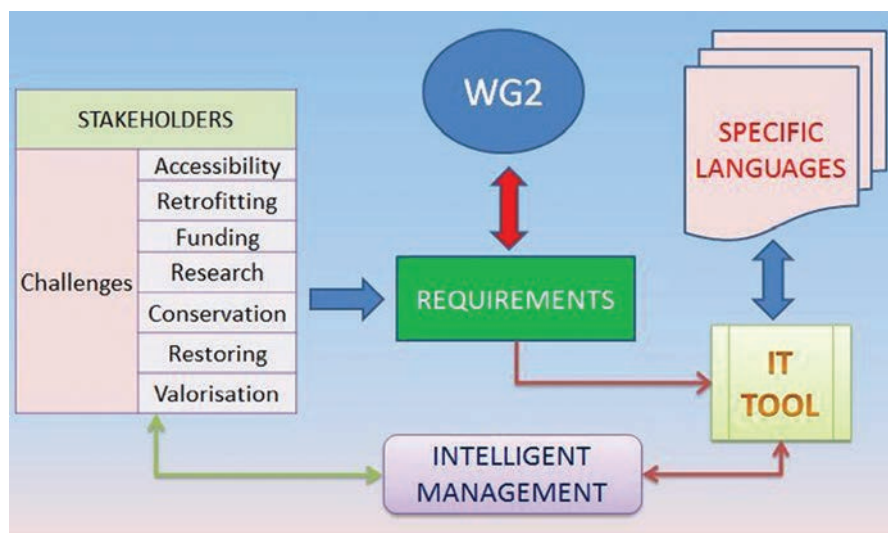


Figure 6.2. Interoperability constraints



(a)



(b)

Figure 6.3. Interoperability workflow

We need to appoint a set of common requirements that everyone agrees on in full consultation with all concerned interests. These do not have to be highly structured, although it needs to be easy to read and accompanied by supporting contextual data specific of what domain is concerned. The complexity of a Built Heritage unit can incorporate several addressable requirements in the field of Conservation, Maintenance and Valorization with all related specific technical languages.

We should consider the wider concept of cultural significance [12]. For this we have to take into consideration how and why cultural significance is assessed and how it can be used as an effective focus and driver for management strategies and processes.

Effective management of the built cultural heritage requires a clear understanding of what makes a place significant and how that significance might be vulnerable and to ensure that what is important about the place is protected and enhanced.

### 6.2.2. Parameters

The main parameters that influence interoperability in the HBs domain are:

#### *Objectives*

- Upgrade to modern needs
- Define the interests of each organisation towards the heritage building concerned
- Define data about the nature and subject derived from research, such as comparison with similar places or features
- Collect archive items (photos, documents, plans), will most frequently contain inherent information and context – for example, within a collection – to allow them to be documented appropriately
- Existence of information standards
- Urban planning

#### *Methods (Enablers T and NT)*

- Life Cycle oriented approach which includes preventative management
- Understanding the building before carrying out the upgrading works
- Assessment of existing performance of the building, materials, Monitoring, Testing, Calculations
- Assessment of construction of the building
- Assessment of services.
- Assessment and evaluation of expected risks to renovation; calculations
- Assessment of user's needs
- Assessment of building preservation status
- Planning maintenance management, alterations and intervention strategies, upgrading energy efficiency; Computer Modelling
- Impact Assessment of the chosen strategy
- Inspection Activities
- Diverse organisations to commit for working together and to embed their technical solutions in real-world working practice
- Technical development of tools for interoperability
- Existence of "information ecology". The ecology metaphor emphasises that information systems and data standards can only succeed where they also relate to the needs and experience of all parties involved. As in a biological community, no one organisation can predominate to the exclusion of others without an ensuing catastrophe.
- Existence of "Standards of standards"
- MIDAS XML is a set of World Wide Web Consortium compliant Extensible Markup Language (XML) schemas, based upon the MIDAS data standard
- CIDOC Conceptual Reference Model (ISO 21127)
- The Data Validator Tool (DVT) is an application developed to validate the content of MIDAS XML files; this tool will check the content (i.e., presence or absence) of the elements in MIDAS XML data against defined standards
- Structure of residential quarters, public spaces, the scale of the building and its architectural features (color, windows, doors, balconies, and other details)
- Landscaping and surroundings

#### *Indicators*

- Energy Consumption, Environmental impact of the construction and of the Demolition phases
- Evidential value, Historical value Aesthetic value, Communal value, Environmental value; Character and significance; Sensitivity of the buildings



- Energy efficiency, dynamic behaviour, latent heat, permeability, moisture barriers, hydro thermal behaviour, pores and capillarity, decay description
- Type of Construction, special elements, Thermal bridging
- Heating, Ventilation, Electronic control systems, Energy sources
- Fire, Security, Construction risks, Hazardous materials, Technical conflicts between traditional construction and required changes, Material compatibility
- User requirements, Function of the building
- Restoration of original performance, Conservation, Alteration, Maintenance, enhancement, removal of damaged alterations, Upgrading building elements
- Energy, Heating, Ventilation, Adding Insulation, Draught proofing, Repairs, Electronic control systems, Energy sources
- Users and Functions of the building
- Data accuracy and consistency
- Data availability and accessibility
- Degree of portability and scalability
- Sustainability indicators (environmental indicators such as energy consumption, presence of on-site renewable energy)
- Grids and numerical scales and other features identification

### *Barriers*

- Leading professional body doesn't have a strong focus on the building fabric
- FM qualification structure doesn't explicitly refer to historic buildings
- Lack of conservation awareness across other professions involved with FM - e.g. building control, structural engineers
- Lack of property data
- Lack of Formal Guidance from Contractors, Trade literature, Certification Schemes, Building Regulations
- Work to be done: best way to measure the energy performance of older buildings (now are not measured)
- Good practice in retrofitting are not communicated well
- Impact of retrofitting and the resulting environmental changes on older materials and finishes are not assessed
- Information about properties is often not collected in one place
- Computer-based solutions are frequently home-made and based on the IT knowledge of one person
- Poor communication skills - facilities managers may not be good at sharing information.
- Hard to find examples of full open BIM implementation for historic buildings (HBIM)
- Lack of understanding that there is a difference between full open BIM and 3D surveys
- Lack of a common language among different experts
- Lack of standard and optimal electric/electronic products/systems for heritage buildings in some areas (as renewable energy generation, mainly photovoltaic)
- The existence of recommended practices when doing engineering in HBs, with the aim of adding facilities related with comfort, security or lighting for maintenance or adaptation to tourist visits

### *Errors*

- The probability of misunderstanding any part of the requirement depends on difficulty of language and domain and technical knowledge of participants (people with high levels of both technical and domain knowledge are rare)
- The length of requirement. In a long requirement, exactly the same idea may be presented in different ways in two places, but each may be understood differently; if large blocks of infor-

mation are replicated in different sections, with small but important differences, these differences may be missed

- The number of options permitted; optionality greatly increases the chance of error
- The number of times different implementations to be made; each implementation involves mapping or translating the specification into the local implementation language.

Misunderstanding inevitably leads to error. Errors increase costs and reduce quality, create delays, and hit profits and reputation. Successful specifications avoid errors by limiting scope, being easy to understand, relatively short and simple, with few if any options. Many problems could be avoided by adequate thought and preparation by both users and suppliers. If time is running out, it is all too easy to be vague in a specification or offer the implementer a choice of options depending on the local context.

### 6.3. Conceptualization of the Heritage Building domain

The conceptualization process was realized through the following steps:

- research of the archived plans belonging to HBs
- identification of HBs basic structural elements
- development of an ontology for HBs.

Based on research of archived documentation about HBs the conceptualization process started with the extraction of the most common concepts contained in archived documentation.

Mostly mentioned methodologies for building ontology are Uschold's and Gruninger's Skeletal methodology, Gruninger & Fox's TOVE methodology, METHONTOLOGY [19], Noy & McGuinness's Seven-Step method, and a 5-step recipe by Gavrilova et al.

METHONTOLOGY rests on three flows: management phase, development phase and maintain phase all in 6 steps: 1) specifying the purpose of the ontology, the level of formality and the scope of the ontology; 2) collecting all the knowledge; 3) conceptualization phase, first building a glossary of terms with all possibly useful knowledge for the treated domain, grouping these terms according to concepts and verbs and gather them in tables, formulas and rules; 4) checking if there are any existing ontologies that can and should be used; 5) implementation phase producing ontology defined in a formal language that can be evaluated according to some references; 6) documentation of the ontology developed so far.

In the ontologization process all six steps of the METHONTOLOGY approach were applied.

#### 6.3.1. Heritage Building core ontology

A goal in the development of knowledge model was the design of an OWL (Web Ontology Language) ontology using an open source ontology editor and framework for building intelligent systems Protégé.

While creating the ontology we researched appropriateness of inclusion of existing common terminology and ontologies:

- buildingSMART Data Dictionary, a standardized data dictionary for AEC domain [13] and existing ontologies
- Ontology FOAF Vocabulary Specification, FOAF language [14], defined as a dictionary of named properties and classes using W3C's RDF technology; FOAF is a project for linking people and information using the Web
- Ontology ISA Programme Location Core Vocabulary [15]. The ISA Programme Location Core Vocabulary provides a minimum set of classes and properties for describing any place in terms of its name, address or geometry
- ISA Programme Person Core Vocabulary [16]. The Person Core Vocabulary provides a minimum set of classes and properties for describing a natural person, i.e. the individual as opposed to

- any role they may play in society or the relationships they must other people, organisations and property; all of which contribute significantly to the broader concept of identity
- Time Ontology in OWL [17]. The ontology provides a vocabulary for expressing facts about topological relations among instants and intervals, together with information about durations, and about temporal position including date-time information
  - The ISO 21127:2014 - reference ontology for the interchange of cultural heritage information (CHO) [18] is currently the furthest developed ontology for the integration of cultural heritage information and is intended to promote a shared understanding of cultural heritage information by providing a common and extensible semantic framework to which any cultural heritage information can be mapped.

The result was a general knowledge model (ontology) that can be applied to historical buildings.

Transformation of information contained in the documentation into ontology started with the creation of initial class hierarchy where classes represent most relevant concepts in the archived documentation. The current set of concepts is shown on the Figure 6.4.



Figure 6.4. HB Core Ontology - concepts

Visualisation of historical buildings ontology shows semantic hierarchy between various concepts in the ontology. The main concepts subgroups are the location, time, geometry, management, FOAF and CHO related concepts.

First, the documents were compared according to their table of contents to align the conceptually similar chapters (i.e. description of the construction object) and their related chapters were aligned first. In the next step, most relevant (and frequent) terms were identified as candidates for common concepts in the planned ontology. These concepts were defined in a class hierarchy and the various classes and concepts were linked via object properties and data points were set for various members using the data property functionality (Figure 6.5.).



Figure 6.5. HB Core Ontology - object properties

Analysis of the historical buildings ontology in this development stage shows following ontology statistics:

- 87 concepts (classes)
- 43 object properties and
- 18 data properties.

Software tool Protégé was used for development of ontologies. Ontology contains information about location, ownership, thickness of the main load bearing walls, material of main walls, levels of floors and thickness of walls in each floor and the characteristics of buildings material. SPARQL language was used to query the ontology.

Reconstruction project for a heritage building called Baroness' House (in Maribor, Slovenia) was used for validation of the conceptualization approach.

The following SPARQL query example displays existing knowledge related to the Baroness' House:

```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX owl: <http://www.w3.org/2002/07/owl#>
PREFIX hbco: <http://kgpi.fgpa.um.si/ke4aeco/hbco#>
SELECT DISTINCT *
WHERE { hbco:Baroness_House ?p ?o.
MINUS { hbco:Baroness_House rdf:type ?o. }
}
```

With the result, we can consistently support the reconstruction project of the historical building. An architect can use the HB-IT Platform to obtain information about buildings, which decreases the number of physical inspections on-site.

Figure 6.6 shows how the HBCO can be populated with data about a heritage building. The use case is made with data derived from the Château de Germolles. Similarly, other data about other heritage buildings can be inserted.

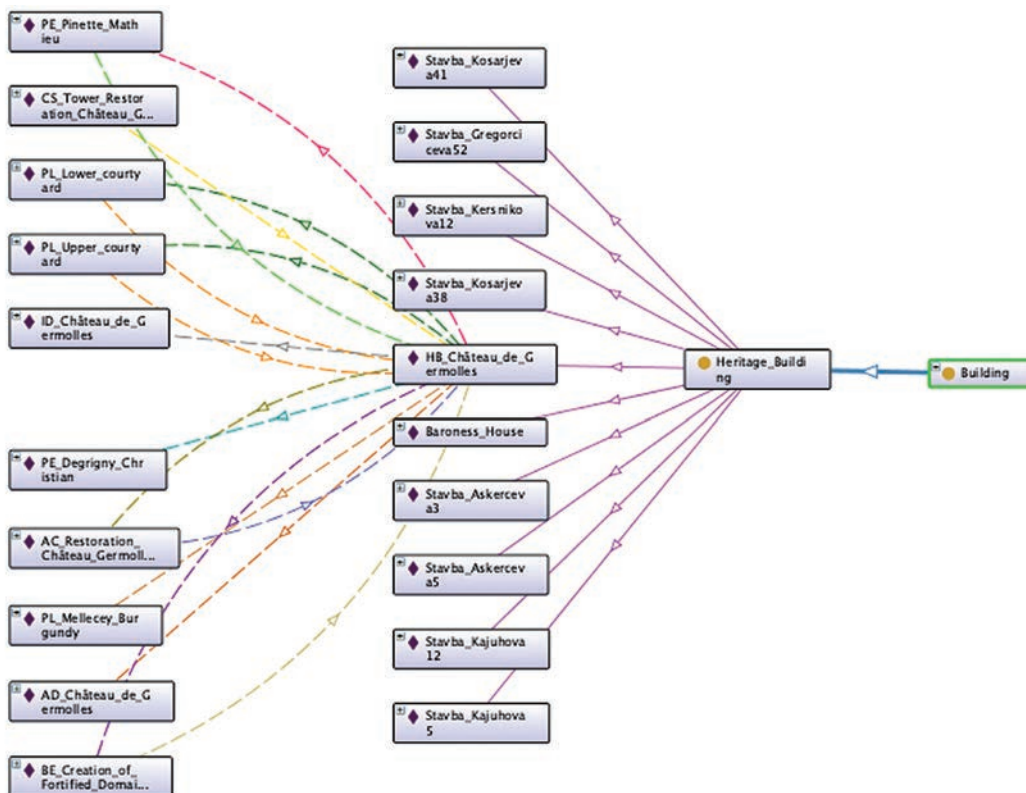


Figure 6.6. Ontology use case for Château de Germolles

#### 6.4. IT Platform for Heritage Buildings

New and innovative semantic applications (i.e. Semantic MediaWiki) can utilize knowledge-bases with the advanced searching and querying mechanisms provided by SPARQL. One such SPARQL example is to query knowledge-base for historical buildings where specific type and dimension of brick was used for walls. Since masonry brick is found on nearly every continental historic building, the query results can be used during a restoration project to learn from another previously completed restoration projects.

In addition to that, semantic applications can also employ reasoning mechanisms to infer logical consequences from asserted facts in knowledge-base. Semantic reasoning is an advancement to what was previously referred to as case-based reasoning approach. For semantic reasoning a knowledge base composed of ontology (or many interlinked ontologies) and semantic rules is needed.

In consequence, proper knowledge engineering in construction projects related to HB results in KBS acting as a consultation system, which supports more effective management of HB projects.

### 6.4.1. Concepts

Conceptually, the HB-IT Platform consists of two parts, a process “HB data capturing” and an architecture “Knowledge based system” which are interconnected with the ontology (Figure 6.7).

Main objective of iterative “HB data capturing” process is to produce “final” ontology representing HBs and HB related processes and activities. “HB documentation” exist in various formats and levels of digitalization, e.g. paper documents, voice recordings, video materials, images, database records, etc. forming data collections. HBs as main objects of interest are not necessarily entirely treated in sense of documentation and still represent valuable source of new information that can be organized

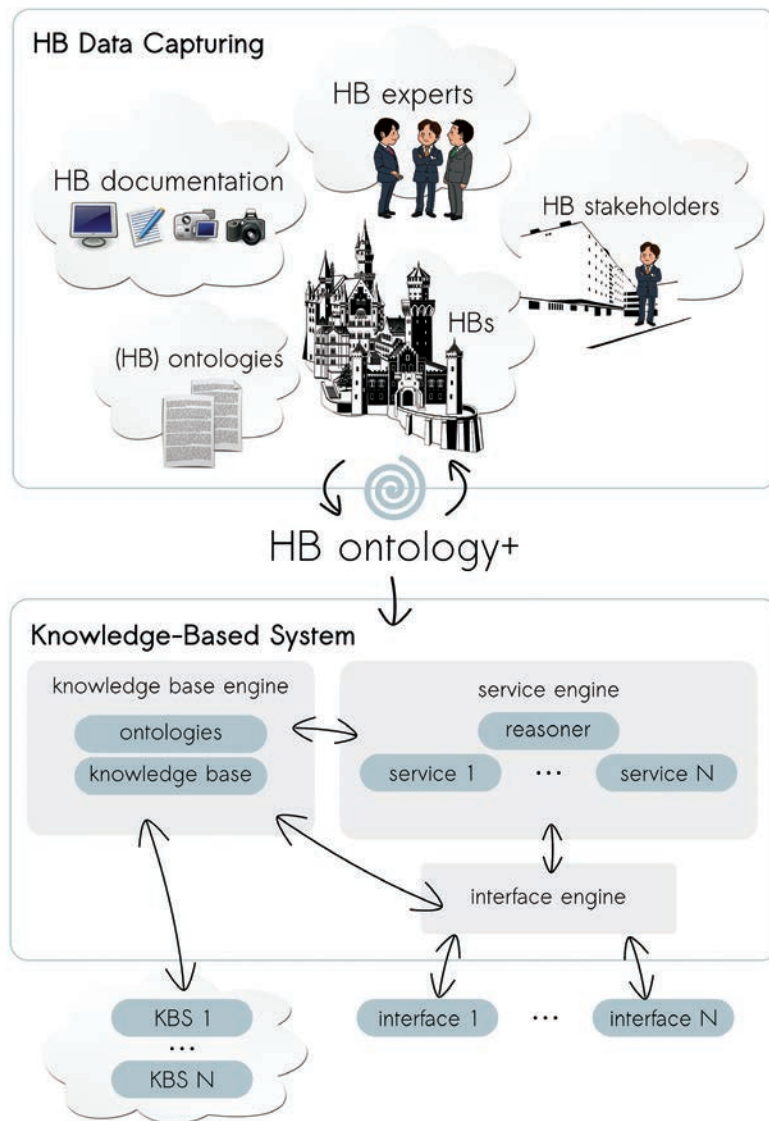


Figure 6.7. Conceptual framework of the Heritage Building IT Platform

and documented. The HB documentation is usually prepared and/or used by various HB experts (e.g. from fields of reconstruction, renovation, conservations, bio-deterioration, etc.) and stakeholders. In general, stakeholders have some influence or relation toward HB and vice-versa (individuals, groups and organizations, e.g. owners of heritage buildings or lands, private funders, finance institutions, legislation institutions, data providers, HB service providers, and other various HB related stakeholders).

In the process of producing “final” ontology, not all the work needs to be done from the scratch. Usually ontology experts search for related ontologies and include them into final result “HB ontology+”. Some ontologies can be directly connected to HB, some indirectly (e.g. ontology about building materials, which is useful for all types of buildings and therefore also HBs), and some serve as supporting or core ontologies for representation of core elements (e.g. time, location, person, etc.). In addition, some ontologies are appropriate entirely, some only partly, some need some changes or improvements, or some are inappropriate. All participating ontologies contribute to the “final” ontology.

When a version of “final” ontology is produced in current process iteration, that ontology is usually revised by experts and interested stakeholders. Based on the review feedback a new iteration of the process might start. For example, experts may identify missing chunk of information, some HB related service provider will provide that information (e.g. by analysing HB and preparing documentation) and new information and knowledge will result in new “final” ontology. Several methodologies for preparation of ontologies exist to produce best possible ontologies with minimal iterations. The same process is also used when new requests or demands about some HB process or activity are identified. Continuously improving ontology according to new tacit and explicit knowledge corresponds to well-known knowledge spiral.

Regardless of the process’s iteration number, “final” HB ontology is the most appropriate ontology that is then used in architectural part on Figure 6.6. Architectural part provides system intended for use by end-users. It consists of three main parts: knowledge base engine, service engine and interface engine.

Knowledge base engine consists of knowledge base, which is triple store (subject-predicate-object) containing all gathered knowledge objects about HBs according to the schema induced by one or several ontologies from the HB data capturing process. In addition, it consists of core functionality for accessing and manipulating triple-store data.

Different interfaces can exist for different end-users and areas of usage. All requests for retrieval or manipulation of HB information are channelled through interface engine. Interface engine can directly use knowledge base engine for retrieval and manipulation of data or can use service engine for more complex usage. Similar to different interfaces, service engine also can consist of different services for different usage. Core part of service engine is also reasoner for advanced usage of knowledge based HB data (e.g. using rules, fuzzy conditions, etc.).

Lastly, according to the “final” ontology and actual implementation of knowledge base engine, not all existing HB knowledge data may exist in this knowledge base system. Related knowledge data may exist in one or several other KBs, and therefore knowledge base engine is able to communicate and exchange knowledge with these KBs.

## 6.5. Conclusions

In the chapter requirements and parameters for interoperability for heritage buildings were presented. A solution for intelligent management for HBs named HB-IT Platform was proposed. The platform uses knowledge engineering approach resulting in an innovative Heritage Building Core Ontology (HBCO). As part of the Knowledge Based System (KBS) in the platform, the ontology sustains “why and how” queries in the lifecycle of HBs, i.e. exchange of knowledge on-/off- HB site. The ontology is a prerequisite for automation of semantic reasoning thru semantic links. Results from the chapter have proved that ontology development is an ongoing spiral and iterative, back-and-forth process, which must allow enough time for participation of different stakeholders’ views.

Usage of such platforms enables simple, quick and smart access to information about the HB project through user's custom semantic queries.

Use of the platform leads to an intelligent management of HB knowledge and facilitates its sharing and reuse among all personnel involved in HB projects.

## References

- [1] J. Akoka, I. Comyn-Wattiau, N. Laoufi, „Research on Big Data – A systematic mapping study,“ *Comput. Stand. Interfaces*, Izv. 54, p. 105–115, 2017.
- [2] F. Boochs, A. Trémeau, „Towards A Knowledge Model Bridging Technologies And Applications In Cultural Heritage Documentation,“ *ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci.*, Izvo. %1 od %2II-5, pp. 81-88, 2014.
- [3] M. Doerr, „The CIDOC Conceptual Reference Module: An Ontological Approach to Semantic Interoperability of Metadata,“ *AI Magazine*, Izv. Vol 24 No 3: Fall 2003, 2003.
- [4] A. Tibaut, B. Kaučič, D. Dvornik Perhavec, P. Tiano, J. P. Martins, „Ontologizing the heritage building domain. V: IOANNIDES, Marinos (ed.). *Advances in digital cultural heritage : International Workshop, Funchal, Madeira, Portugal, June 28, 2017: revised selected papers*,“ *Lecture notes in computer science*, pp. 141-161, 2018.
- [5] A. Tibaut, B. Kaučič, D. Dvornik Perhavec, „Ontology-based data collection for heritage buildings. V: IOANNIDES, Marinos (ed.). *Digital cultural heritage : Final Conference of the Marie Skłodowska-Curie Initial Training Network for Digital Cultural Heritage*,“ *Lecture notes in computer science*, Izv. 2018, pp. 63-78, 23-25 May 2017.
- [6] G. Zacharewicz, S. Diallo, Y. Ducq, C. Agostinho, R. Jardim-Goncalves, H. Bazoun, Z. Wang, G. Doumeings, „Model-based approaches for interoperability of next generation enterprise information systems: state of the art and future challenges,“ *Information Systems and e-Business Management*, 2016.
- [7] M. Zdravković, F. Luis-Ferreira, R. Jardim-Goncalves, M. Trajanović, „On the formal definition of the systems' interoperability capability: an anthropomorphic approach,“ *Enterprise Information Systems*, 2017.
- [8] C. Agostinho, Y. Ducq, G. Zacharewicz, J. Sarraipa, F. Lampathaki, R. Poler, R. Jardim-Goncalves, „Towards a sustainable interoperability in networked enterprise information systems: Trends of knowledge and model-driven technology,“ *Computers in Industry*, 2015.
- [9] L. E. Whitman, H. Panetto, „The missing link: Culture and language barriers to interoperability,“ *Annual Reviews in Control*, Izvo. %1 od %2Volume 30, Issue 2, pp. 233-241, 2006.
- [10] „EIF, European Interoperability Framework for pan-European eGovernment Services, Interoperable Delivery of European eGovernment Services to public Administrations, Businesses and Citizens (IDABC),“ 2017.
- [11] I. Horrocks, P. F. Patel-Schneider, D. L. M c Guinness, C. A. Welty, „OWL: a Description Logic Based Ontology,“ *Cambridge University Press*, pp. 1-23, 2007.
- [12] D. Worthing, S. Bond, „Managing Built Heritage: The Role of Cultural Significance,“ May 2016.
- [13] „buildingSMART,“ 2014. [Elektronski]. Available: <http://www.buildingsmart.de/bim-know-how/standards>. [accessed on 26 08 2014].
- [14] D. Brickley, L. Miller, „FOAF Vocabulary Specification,“ 2014. [Elektronski]. Available: <http://xmlns.com/foaf/spec>.
- [15] „ISA Programme Location Core Vocabulary,“ 2015. [Elektronski]. Available: <http://www.w3.org/ns/locn#>.
- [16] „Person Core Vocabulary,“ 2012. [Elektronski]. Available: <http://www.w3.org/ns/person#>.
- [17] „Time Ontology in OWL,“ [Elektronski]. Available: <http://www.w3.org/TR/owl-time>. [accessed on 2016].
- [18] M. T. Biagetti, „An ontological model for the integration of cultural heritage information: CIDOC-CRM,“ *JLIS.it*, Izvo. %1 od %2 v. 7, n. 3, pp. 43-77, 2016.
- [19] Fernández-López, M., Gómez-Pérez, A., Juristo, N.: *METHONTOLOGY: From Ontological Art Towards Ontological Engineering*. AAI-97 Spring Symposium Series, SS-97-06, 33–40 (1997). doi: 10.1109/AXMEDIS.2007.19