# Linked Data for Road Authorities

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## Abstract
Road authorities are facing the great challenge of improving the effectiveness and efficiency of their core processes. They need to improve information exchange and sharing between various application domains, such as planning, design, engineering, project management and asset management. The aim of the EU project known as 'V-Con' (short for 'Virtual Construction for Roads') is to develop an information system that can enhance the exchange and sharing of this information.

For this purpose, V-Con has chosen an information modelling approach based on distributed models with loose connections. Linked data technology was selected as the basis to support this approach. This paper presents the distributed modelling approach based on linked data technology that is being used in the V-Con project.

**Keywords:** Distributed modelling, linked data, BIM, GIS, road authorities

## 1 Introduction
Road authorities face the challenge of improving the effectiveness and efficiency of their core processes in the areas of project management, asset management and network management. Improving information management is crucial to this endeavour. Ideally, information that has been created at a particular location would be used and re-used many times by other actors in other locations, inside or outside an organisation. In practice, though, this is often difficult to achieve. Different systems, different file formats, different technologies, different semantics, and so on, hinder the smooth exchange of information and interoperability of systems throughout the life cycle of roads.

In the EU project known as 'V-Con', road information systems are being developed in which information from various sources is linked. Such information can include, for example:

- Requirements from a Systems Engineering system;
- Geographical data from a GIS system;
- Design information from a BIM system;
- Maintenance planning data from an Asset Management System.

In the first phase of the V-Con project, an inventory of relevant information standards (V-Con, 2013a) and an analysis of possible integration approaches (V-Con, 2013b) was carried out. An important conclusion of this analysis was that a distributed, or federated, model structure is needed for a multi-domain information environment such as road infrastructure. The idea of distributed models has gained popularity in the BIM community in recent years. Van Berlo et al. (2012) described a pragmatic approach using distributed models and linking information in native formats by using IFC as a reference, not as a central model. Nowadays, few researchers still believe in the feasibility of central models and tight mappings for the integration of building information. BIM vendors are also working on solutions based on distributed models (see, e.g., (Oogink, 2014), perhaps encouraged by IT experts who think that the interoperability problem may never be completely solved (Neuhold, 2014).

Another important conclusion from the analysis phase was that semantic technology and linked data technology could be very powerful technologies for V-Con. Semantic web and linked data have also gained popularity in the BIM community in recent years (Pauwels P. (., 2014) (Sicilia, Madrazo, & Pleguezelos, 2014). It seems that linked data technology is particularly suited to current ideas on distributed modelling and loose connections.

In the next phase of the V-Con project, a system specification is being developed. As part of this task, the potential of semantic web and data technology is further explored. This paper, which can be seen as a progress report of this work in the V-Con project, reports on the findings to date of the specification phase of the V-Con project. More specific, it aims to identify and elaborate the implications of using linked data technology in the V-Con project.

## 2 Project Context, Scope and Business Requirements

V-Con (V-Con consortium) is a EU research project that is being carried out under the 7th Framework Programme (FP7). The aim is to standardise and implement BIM technology in the road construction and management sector. The project partners are two road authorities, the Dutch Ministry of Waterways and Public Works, or Rijkswaterstaat (the Netherlands) and Trafikverket (Sweden), and two research institutes, TNO (the Netherlands) and CSTB (France). V-Con will run from 2012 to 2016.

V-Con is a so-called pre-commercial procurement (PCP) project. This means that after an analysis phase, software vendors are invited to tender for the implementation of a system, as specified by the V-Con consortium. The first call for tender proposals was launched in September 2014. The expectation is that software vendors and consortia will express their interest in and react to the proposed approach after the launch. The subsequent phases, until 2016, will see the final specifications and implementation of the system.

The scope of the V-Con project is primarily project management, as implemented by road authorities. This covers the interfaces with construction companies and interfaces with asset management at the road authority (see Fig. 1). It does not currently cover the linking or integration of different asset management systems with each other (the links between the asset management circles in Fig. 1), nor does it cover traffic management. However, it is expected that having proved its value for integrating project management information, the approach will also be applied to these areas in future.

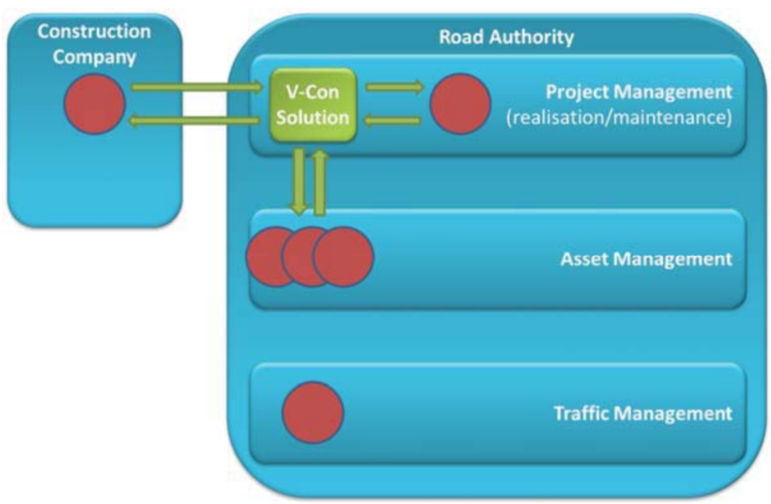


Figure 1. The scope of V-Con. The green square and arrows represent the solution and interfaces developed in V-Con. The red circles represent existing applications. The blue areas represent organisational domains.

The business requirements for V-Con were analysed by investigating use cases for systems engineering, repaving and the geometric design of roads (V-Con, 2014a). These use cases reveal a typical pattern for road construction processes, which is summarised as follows:

- A project is initiated by Asset Management, which wants to make a change to the road network; the need for the project is communicated to Project Management in terms of user requirements;
- Project Management translates the need for the project into system requirements and communicates this to a Construction Company;
- The Construction Company responds to this with a design proposal, and later with a realised system, and communicates this to Project Management;
- Project Management approves the design and later the realised system and communicates this to Asset Management.

This pattern is represented by the green arrows in Fig. 1. Furthermore, the use cases analysed for the V-Con business requirements revealed the main software applications that are involved in this process: systems engineering, BIM, GIS and asset management.

## 3 Technical Requirements

Further to the project context, scope and business requirements, as described above, the V-Con project has a number of important technical requirements. First, the application domains mentioned above must be supported, as well as supporting technologies such as BIM and GIS. In addition to this, a number of high-level requirements were identified in the analysis phase of the project (V-Con, 2013a), such as:

- Support of different levels of road information (from international to project level);
- Use of open standards;
- Support of object libraries;
- Future-proofing.

These technical requirements are further described below.

### 3.1 Application domains: BIM, GIS, Systems Engineering and Asset Management

The V-Con project aims to link the following application domains: Building Information Models (BIM), Geographical Information Systems (GIS), Systems Engineering (SE) and Asset Management (AM). Of these domains, BIM and GIS have international open standards, meaning that these areas will be used for the first elaborations and test cases.

### 3.2 Levels: international/national/company/project

A typical characteristic of road information is that information is defined at different levels. Information can be defined at the international, national, company or project levels. All of these levels may use different object definitions, standards, rules and constraints, terminologies and languages. One way to implement these different levels is through the use of object libraries (see section 3.4).

### 3.3 Open standards

An important starting point for V-Con is to maximise the use of open standards. There are a number of reasons for this. In the first instance, the use of any standard is motivated by the fact that standards help to reduce the number of interfaces that have to be developed. In addition, the use of *open* standards is motivated by the wish to remain independent of software vendors and to eliminate the risk of a vendor lock-in. Last but not least, public organisations such as road authorities are legally obliged to use open standards.

Two areas of open standards are particularly important for road project information: BIM and GIS. On the BIM side, the buildingSmart Initiative (bSI) has initiated an ‘Infrastructure Room’ (http://www.buildingsmart-tech.org/infrastructure) hosting the ‘OpenInfra initiative’ to define information structures, extending the current Industry Foundation Classes (IFC) schema supporting the design, building and maintenance of civil infrastructure objects. One of the first specifications is that of IFC Alignment (the basic geometry needed for roads, bridges, tunnels etc.).

On the GIS side, the Open Geospatial Organization (OGC) has initiated the development of ‘InfraGML’ in the Land and Infrastructure Standards Working Group (LandInfraSWG). InfraGML is related to CityGML and in sync with BuildingSmart by a Memorandum of Understanding (MoU) as a kind of fresh new LandXML (the earlier *de facto* Autodesk standard).

### 3.4 Object libraries

One relatively new development in road information is the development of standardised libraries of road objects, or even road concepts. CAD libraries of road objects have existed for many years, but these libraries are linked to specific CAD systems. The BuildingSMART Data Dictionary (bsDD) is being developed by BuildingSMART, with an emphasis on buildings.

Regarding infrastructure, there is an interesting development in the Netherlands known as 'Concept Library Netherlands' (CB-NL). The aim of CB-NL is to create a library of standardised definitions of building and infrastructure objects to be used in projects. CB-NL recently adopted a linked data approach, similar to that used by V-Con, and the two projects are trying to harmonise their efforts. Meanwhile, the Dutch Ministry of Waterways and Public Works is developing a company-specific library known as OTL. This illustrates the multi-level characteristic of road information, as described in section 3.2.

### 3.5 Future-proof

Finally, the V-Con project aims to provide a solution that is future-proof. The open standards policy described in section 3.3 can be regarded as one consequence of this aim. Another consequence is the adoption of a software approach that allows for flexibility, extensibility, re-use of software components, and so forth.

## 4 A Solution-focused Approach

### 4.1 Possible approaches

Which approach might cover all of the requirements described above? The V-Con project analysed and compared three approaches (V-Con, 2013b) (van Nederveen, Bektas, Luiten, & Böhms, 2013):

- An approach based on BuildingSMART standards, with an IFC-Road schema as the core model;
- An approach based on COINS, a Dutch BIM standard with strong built-in system engineering concepts;
- A so-called hybrid approach, with neither IFC nor COINS as the core model, but with a distributed model structure based on the linked data concept.

In addition, a possible fourth approach would have been one based on GIS standards such as (Infra)GML, which would bring similar pros and cons to the first approach.

Initially, the BuildingSMART approach and the COINS approach seemed to be straightforward and logical options. Both approaches had drawbacks, however: BuildingSMART support for infrastructure is still under development, and support for systems engineering and life-cycle management concepts is lacking. COINS offers more support in these areas, but knowledge of the approach is limited to the Dutch infrastructure community. The third approach presented an opportunity to combine the strengths of the first two approaches with solving a number of modelling problems related to both BuildingSMART and COINS. V-Con therefore decided to take the third approach: a hybrid approach based on distributed modelling and linked data technology. This approach is described in the following sections of the paper.

### 4.2 Proposed approach: distributed modelling

Researchers have been working on solutions to interoperability problems in construction for many years, using technologies such as product modelling and BIM. It has often been assumed that interoperability might be achieved by defining a central core model and interfaces from domain applications to and from this core model. In practice, interoperability has often proved difficult to achieve. Therefore, in recent years, increasing numbers of researchers have considered new approaches based on distributed, flexible and dynamic model structures (van Berlo, Beetz, Bos, Hendriks, & Tongeren, 2012) (Pauwels P. (., 2014).

For the V-Con project, a so-called *distributed modelling* approach was chosen. In such an approach, no attempt is made to develop a central model that integrates various data from all sources. In addition, no attempt is made to replace existing standards with a new, all-encompassing 'über-standard' that covers all of the necessary information. Instead, existing standards such as IFC and CityGML are taken for granted and the emphasis is on linking to these standards.

Moreover, the links are supposed to be loose. For example, road data can be stored in different places, thus creating redundancy. In such cases, the approach entails linking these data with an expression such as 'BIM_bridge_x is the same as GIS_bridge_y'. No attempt is made to merge the domains and eliminate redundancy; redundancy is thus accepted.

### 4.3 The Linked Data approach

'Linked Data' (W3C, 2015b) was used as the technological approach for V-Con for several reasons. Most importantly, it was expected that 'Linked Data' would provide the best prospects for meeting the general requirements, including flexibility, extensibility and future-proofing, as described in section 3.5 (the infrastructure-specific requirements will be met later, when the chosen approach has been elaborated).

The Linked Data concept is defined by the World Wide Web Consortium (W3C) and states that the data should be:

- Available on the web;
- In a structure that is machine-readable (e.g. not PDF);
- In a non-proprietary format (e.g. not Excel);
- In semantic technology formats (such as RDF/XML, Turtle and JSON-LD), re-using semantic web language semantics (RDF, RDFS, OWL);
- Linked to other data, achieving a kind of fully distributed web-based database.


Figure 2. Linked (Open) Data Requirements (Berners-Lee, 2006)

The interrelation or 'linking' of different ontologies/individual ('instance') data, where both are 'RDF datasets', can be done via constructs available in the Linked Data languages (OWL, RDFS and RDF). Examples of the constructs include:

- owl:equivalentClass
- owl:equivalentProperty
- rdfs:subClassOf
- rdfs:subPropertyOf
- owl:sameAs
- rdf:type

Examples have been developed in a separate TNO Linking Guide (Bohms, 2015). The general benefit of using the same universal language for linking and modelling is that we can re-use existing reasoner functionalities to infer new information and, depending on the actual scenario, obtain the links between existing data, transformed ('converted') data and/or semantically enriched data.

'Data' can be divided into factual datasets ('content') and conceptual data, referred to as 'ontologies', which denote concepts and their interrelationships by defining classes, datatype properties ('attributes'), relationships ('object properties'), data types and restrictions. The standards involved are well designed (they have a sound mathematical/logical basis) and have good modelling power. 'Traditional' web features are used where possible (such as the use of URIs as an identification mechanism).

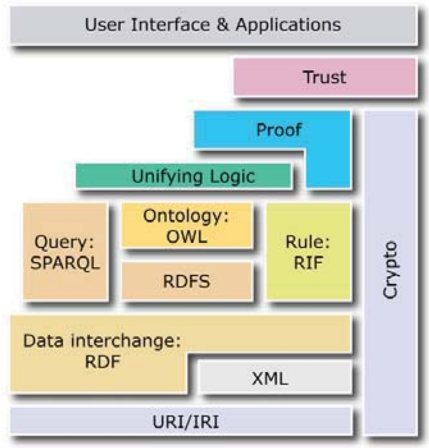


Figure 3. Semantic Web Stack of standards

Anyone can make their own datasets and ontologies with a unique 'name space' supporting multiple views/aspects/disciplines, etc., whereby all these data can be flexibly linked together and dynamically updated in 'Open World' fashion. Due to the standard and equivalent syntax forms, all these data can be imported/exported (uploaded/downloaded) or directly accessed via the standard SPARQL query language (W3C, 2013). Meta-level access (info containers with linked data and possible non-linked data attached) was recently standardised as the Linked Data Protocol (LDP) (W3C, 2015a). Increasing numbers of web services interfaces for transporting actual data on the web are becoming more readily available. Due to their logical underpinnings, inferences can be made and consistency can be checked automatically by a variety of reasoners.

Finally, a large number of commercial and open source software tools support the Linked Data approach, such as TopBraid Composer or Protégé for editing, Web Protégé for publishing and collaboration and Apache Marmotta for deployment.

## 4.4 Ontology structuring

When working on the ontology approach, it soon became apparent that clarity was needed with regard to terms, definitions and structuring mechanisms. The V-Con project used a number of principles and starting points. First, a distinction was made between datasets and data structures:

- A data structure (or ontology) is a class-level definition of the structure of a dataset. A data structure can cover the semantics of a real world object and properties, but also their explicit shape representations.
- A dataset is a collection of data at instance level, structured according to a data structure.

This distinction is comparable to the distinction between type and instance or class and instance in relational and object-oriented modelling respectively.

Second, we found that a layered structure would be needed in order to have a sound conceptual structure. The elements of this structure are (1) OWL (W3C, 2014b), the Web Ontology Language in which basic ontology concepts and constructs are defined; (2) the so-called CMO or Concept Modelling Ontology (Bonsma, Bonsma, Zayakova, van Delft, & Böhms, 2014), which contains a few extensions of OWL for decomposition structures and for units; and (3) domain-specific ontologies that are defined according to OWL and CMO. In addition to this, a Modelling Guide was developed that describes 'how to model' (V-Con, 2014c). (Moreover, there may be multiple ontologies in order to distinguish between information on international/national/company/project-specific levels; see section 3.2.)

Third, it was decided to distinguish between so-called common ontologies and context ontologies. This distinction applies to both the data structure level (class level) and the dataset level (instance level):

- Common ontologies describe data on class level that need to be exchanged or shared between different contexts or used for linking data from different contexts.
- Context ontologies describe data on class level that are typically derived from an existing data structure, such as BIM/IFC or GIS/CityGML.

In the following sections, two types of datasets in W3C Linked Data format are discussed for interfacing with a software application:

- Common Dataset;
- Context Dataset.

### 4.5 Elaboration: link between software application and common dataset

The first case describes an interface with a software application that understands a common ontology used in the V-Con solution. The software application (red circle) could, for example, be a non-graphical systems engineering application in which system requirements are managed. The interface links this application to a common dataset in a W3C linked data format (see Fig. 4).

The software application exports a dataset according to the agreed format and Ontology, such as RDF/XML and the Common Ontology. The V-Con Solution directly imports the data and creates a dataset in the V-Con Solution.

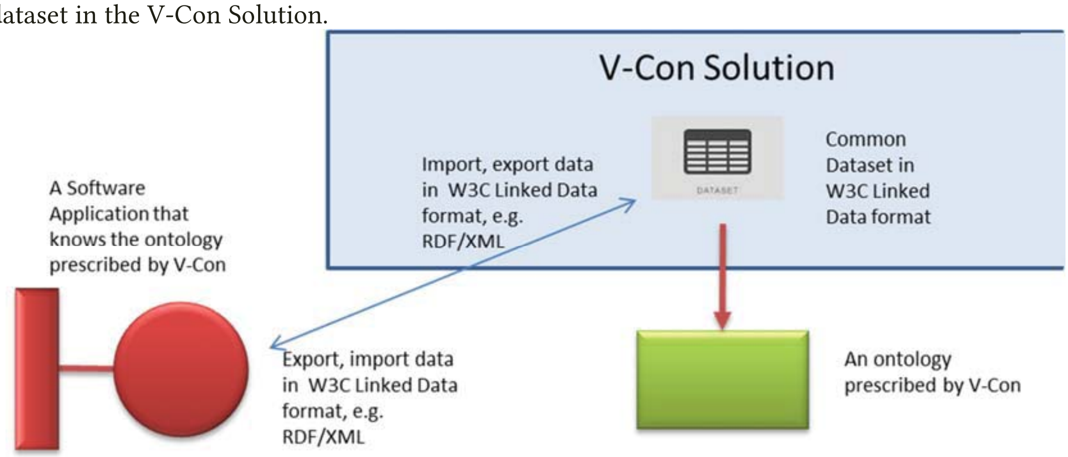


Figure 4. Example of interface between a software application and the V-Con Solution, using an Ontology described by V-Con and a W3C data format

### 4.6 Elaboration: link between software application and context dataset

The second case describes an interface between a BIM application and the V-Con Solution. In this example, a dataset is used with a data structure and a data format standardised in the domain of the BuildingSMART Initiative (BuildingSMART, 2012), which is known by the BIM application. This BIM application does not know the Ontologies used by the client (expressed in OWL2, Version 2 of the Web Ontology Language), nor does it know the W3C data format (see Fig. 5).

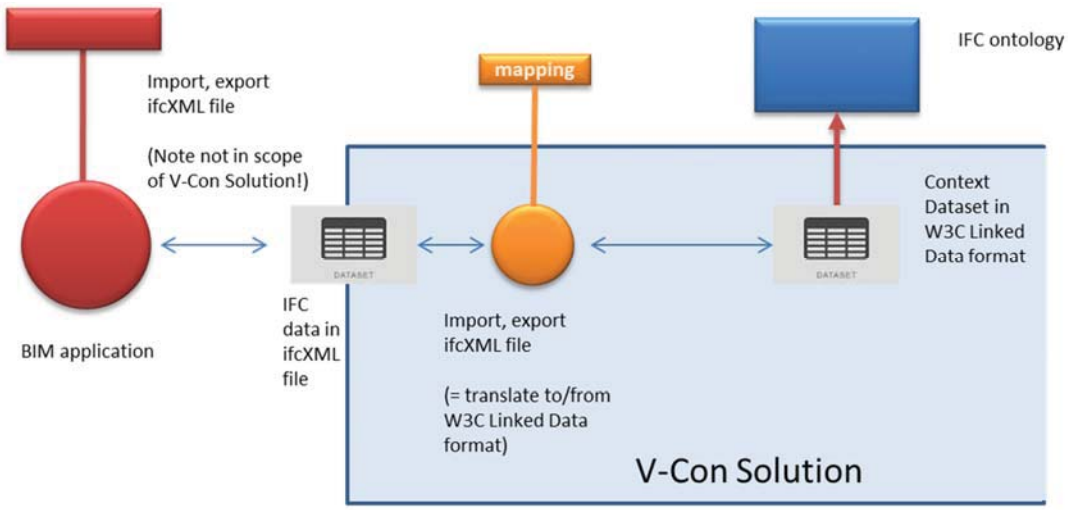


Figure 5. Example of the interface between a BIM application and the V-Con Solution, using a data structure and a data format standardised in the IFC domain

Fig. 5 shows the following (from left to right):

- The external BIM application interfaces with the V-Con Solution via an exported ifcXML file. This is an example of a file-based interface.
- The V-Con Solution imports this ifcXML file. This means that the dataset represented in the ifcXML file is translated to a Context Dataset in the V-Con Solution with a data structure defined in an IFC Ontology. To do this, the V-Con Solution has a Translator to translate datasets in ifcXML format to the W3C format used by the V-Con Solution.
- This translated BIM dataset is converted to the data structure of the Context Ontology using the mapping (orange rectangle in the figure).
- In the V-Con Solution, this Context Dataset can now be connected to the common dataset (the types of connections will be elaborated in section 4.8).
- The return route from right to left, i.e. exporting datasets to external datasets in a standardised open data structure, can also be followed.

As stated above, the interface described here contains both translations and conversions. Based on the literature, such as Pauwels & van Deursen (2012) for the AEC domain and W3C (2014a) for general application, V-Con has formulated working definitions for translation, conversion and other connection types (see section 4.8).

## 4.7 System overview

The hybrid approach with multiple domain standards is illustrated in Fig. 6.

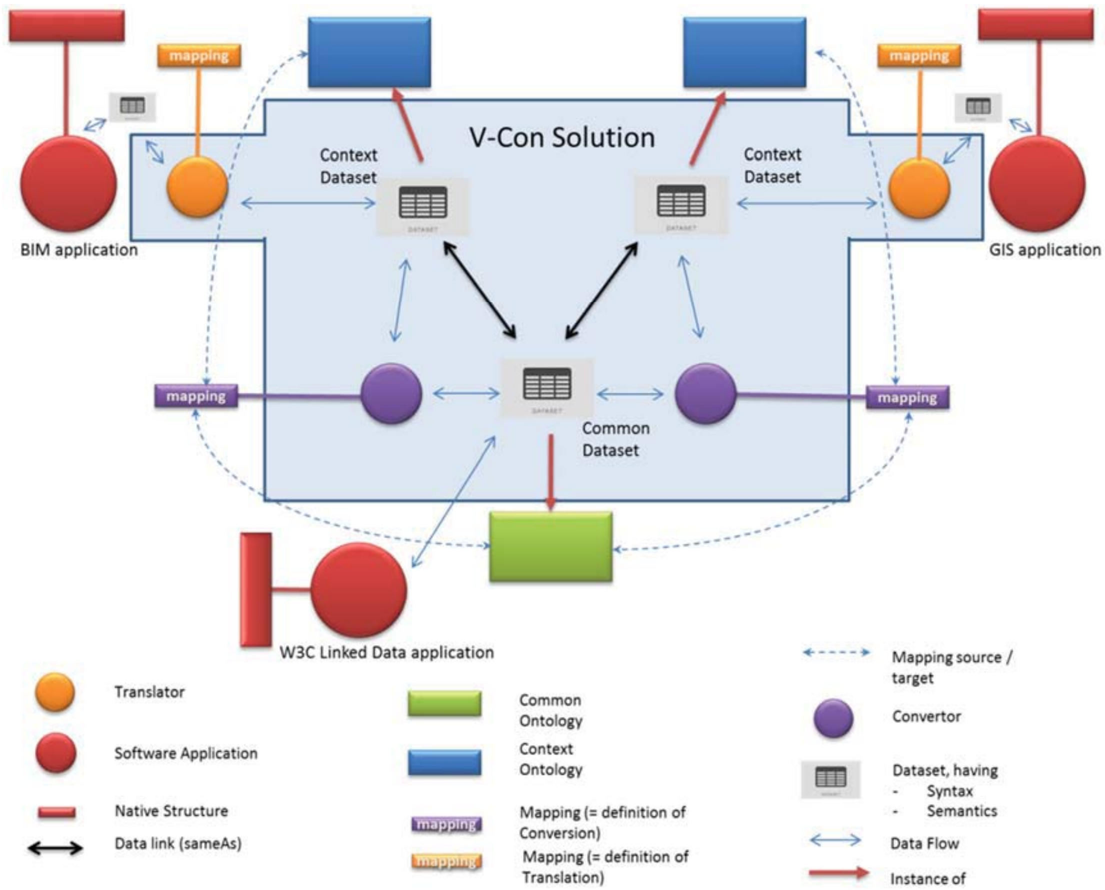


Figure 6. Overview of the envisaged V-Con solution and its environment

Fig. 6 shows that the V-Con Solution is able to deal with multiple datasets, each defined in its own domain standard by an Ontology in OWL2. One dataset is defined as the Common Dataset, a dataset that is structured according to a Common Ontology containing objects and properties that need to be exchanged or shared between different contexts or used for linking data from different contexts.

The Context Datasets are connected to each other via the Common Dataset. The Context Datasets are structured according to a Context Ontology typically derived from an existing data structure, such as IFC2x3 or CityGML2.0. Some of these data can be unique for the context, while some of them can overlap with other contexts and can be exchanged, shared and linked via a Common Dataset. Managing the links between objects that refer to the same real-life objects to ensure that complementary data can be found, as well as managing overlapping data in different datasets, are key functionalities of the V-Con Solution.

Connections between Common and Context Datasets are defined in *mappings*, which are specifications of how objects and properties according to one Ontology could be converted into objects and properties according to another Ontology (and vice versa). The V-Con Solution may interface directly with Software Applications that know the syntax of W3C Linked Data (see section 4.5). The V-Con Solution also interfaces with specific servers that are outside the V-Con Solution; this example features a BIM application (see section 4.6) and a GIS application.

### 4.8 Connection types

As can be concluded from the first modelling trials, data can be linked in many different ways. Moreover, there is often a lot of confusion when discussing different kinds of data connection types. In many cases, part of this confusion originates from confusing data structures and datasets. It was therefore decided to agree upon a number of definitions of connection types (V-Con, 2014b).

The following terms are used to describe the characteristics of connections between data structures or *Ontologies*:

- *Extension* (of Ontology): an Ontology in which classes and property types are further specialisations of classes and property types of the original Ontology.
- *Mapping* (between Ontologies): a specification of how objects and properties according to one Ontology could be converted into objects and properties according to another Ontology (and vice versa). For instance, one Ontology can indicate that two classes are 'equivalent', which implies that both classes refer to the same set of objects, and this information can be used to map data according to one Ontology to data according to the other Ontology.

The following terms are used to describe the characteristics of connections between *datasets*:

- *Translation* (of datasets): transformation of a dataset according to one format into a dataset according to another format, without changing its data structure (see TC2). For example, translating a STEP Physical Format (SPFF) file into an RDF/XML file, where the first is defined according to an EXPRESS schema and the second according to an equivalent OWL Ontology. Translation can also be applied to the class level (in the example, according to a mapping between EXPRESS and OWL).
- *Linking* (between objects and valued properties): connection, for example 'SameAs' links as defined by OWL, which implies that two objects refer to the same real-life object.
- *Conversion* (of datasets): transformation of a dataset according to one Ontology ('source') to a dataset according to another Ontology ('target'), as defined by a mapping of the 'source' Ontology to the 'target' Ontology. The data format stays the same when converting.
- *Enrichment*: in a conversion, a dataset can be enriched by additional objects or properties, as defined in the mapping definition.

The terms 'translation, linking, conversion and enrichment' as used in V-Con can be positioned in the life-cycle of linked data with the LOD2 Stack by Auer et al. (2012) as follows:

- V-Con Translation = LOD2 Extraction (making data LD compatible),
- V-Con Linking = LOD2 Interlinking (asserting links between data),
- V-Con Conversion = LOD2 Classification (according to target ontology/ontologies),
- V-Con Enrichment = LOD2 Enrichment (adding knowledge).


Figure 7. Stages of the Linked Data life-cycle supported by the LOD2 Stack (Auer, et al., 2012)

## 5. Implementation

The V-Con approach described above has not yet been implemented. Implementation will take place between 2014 and 2016 in a PCP process that should lead to a V-Con Solution. This is a stepwise process; instead of a 'one shot' procurement process, different phases are defined in which requirement specifications on different levels are published and different deliverables are requested from software vendors. The process also allows room for a review and consultation process between software vendors and the V-Con consortium. This approach was chosen because V-Con is considered a highly innovative project for which it is not possible to define good specifications without having to review the brief and to adopt new innovations with software developers.

Since the first call for proposals in 2014, the V-Con consortium has continued to work on the system specification. Important activities in this context include:

- The assessment of ontologies to be provided by the consortium for use in V-Con;
- Further development of IFC-Road, part of the BuildingSMART and OGC collaboration to support road modelling;
- The development of very small test cases ('mini-cases'), in which specifications for the V-Con Solution are illustrated with small and simple examples.

## 6. Conclusion

In this paper a progress update is given of the elaboration of the linked data approach in the V-Con project. The V-Con project aims at improved road information sharing and exchange. V-Con is currently developing a system specification for this purpose based on linked data technology.

The linked data approach seems to be very appropriate for V-Con, as it offers concepts and tools for the chosen distributed modelling approach for improved interoperability. In addition, linked data technology provides an opportunity to improve information models, for example by making better use of internet technology and by solving persistent modelling problems in areas such as decomposition and units.

On the other hand, there are uncertainties, both on the conceptual side and on the implementation side. For example, the linked data reasoning concept can be very powerful, but its full potential is unclear. In addition, the software companies that are taking part in the consultation process may come up with unexpected innovative ideas, concepts and technologies, which may lead to quite a different elaboration of current ideas on the V-Con solution.

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