# DISTRIBUTED MODELING FOR ROAD AUTHORITIES

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## ABSTRACT

A great challenge for road authorities is to improve the effectiveness and efficiency of their core processes by improving data exchange and sharing using new technologies such as building information modeling (BIM). BIM has already been successfully implemented in other sectors, such as architecture. But the civil infrastructure sector still lags behind.

This paper reports the core findings of the research undertaken in an FP7 project called V-Con, Virtual Construction for Roads. In this EU-funded project, BIM technologies are being implemented at road authorities. Typical interest areas of the road authorities are the programming phase, in which requirements management and systems engineering play a key role, as well as the use and maintenance phase, in which asset management is essential. These processes require special attention in information management for road authorities. Furthermore, road authorities are interested in standardized "as designed" road information. IFC would be a good standard for this, but there is no "IFC for roads" yet. But road authorities are also interested in information about the context of the road, as usually defined in GIS. So GIS should be linked to the envisaged system as well.

Finally, it was observed that there is a need in the infrastructure sector for so-called concept libraries, libraries with objects and concepts that can be located and managed on different levels (from project-specific to national and global). It was found that the support of such libraries requires changes in the way information modeling and exchange is commonly approached. The new approach is called "distributed modeling" and will be elaborated in this paper.

**Keywords:** distributed modeling, BIM-GIS, systems engineering, road authorities,

## 1. INTRODUCTION

### 1.1 Background and Research Gap

National road authorities are facing great challenges in the improvement of their services. They need to provide a more reliable infrastructure, higher quality, better cost-effectiveness, improved sustainability, shorter lead times between (political) decision and use of infrastructure, no hindrance of environment and traffic during construction and maintenance (V-Con Consortium 2012).

The right ICT-based integration over the life-cycle and supply-chain for infrastructures is seen as a key opportunity for a) better information management (that leads to shorter lead times), b) less failure costs, c) better handover to commercial parties for realization and maintenance (and vice versa), d) improved asset management, and e) more intelligent traffic management.

However, there is a lack of standardized information exchange and sharing over the civil infrastructure sector, comparing to the residential and commercial building sector. There is no comprehensive, generally accepted standard (or combination of standards) is directly available. Consequently, there is also a lack of software tools that support open information exchange/sharing in the sector during the various life-cycle stages and supply chain phases of artifacts and lack of interfaces with the tools that support new the new functionality, e.g. in realization, asset management and network management.

### 1.2 The Scope

The scope of the BIM and distributed modeling for road construction has two dimensions;

- Life cycle phasing
- The supply chain/decomposition

The life cycle phasing of BIM for road construction focuses on two phases: the programming phase and the use and maintenance phase. In these phases a few processes can be seen that are not commonly supported in BIM models: requirements management/systems engineering in the programming phase, and asset management in the use/maintenance phase. On the other hand, design and engineering processes are typically not taking place at road authorities (although in the past road authorities indeed did design and engineering work, but in the last decade this has significantly decreased).

Regarding supply chain/decomposition levels: road authorities generally work between the level of road network and geographical environment and the technical level of components and material of construction works. For information standards this means that both BIM and GIS standards are of primary importance.

### 1.3 ICT Scope

Traditionally ICT-development is done linearly: identify a problem, define a solution, develop software functionalities and data structures to enable support that specific solution. The result of this traditional approach is that each process/problem has its own unique information structure, often fixed in standards. Previous attempts to define one common reality all fail in the end, because the reality is too complex for that. When gathering information for asset management, The Dutch road authority (RWS) identified nine external sources of information, each with their own communities, processes, information standards and supporting software. The challenge for a scenario that combines the features above is that the scenario has to integrate the different existing 'worlds'.

There is a need to have a 'world' where the following features exist.

- There is no unique view on reality exists but different perspectives on reality are desirable,
- There is no one process that leads one data structure but multiple data structures that support multiple processes,
- Communication between processes and data standards need mapping and transformations by adding intelligence provided by semantic information structures
- There will not be just one unique data source, organizing all concepts and perspectives on concepts. Therefore there will be distributed collaborative ontologies/libraries, preferably based on semantic modeling to ease connectivity and alignment.

Current examples of standards modeling 'a world' relevant for civil infrastructures are BuildingSmart IFC, OGC CityGML, COINS CBIM, COBie and LandXML. However, in order to come up with 'the world' that incorporates the features stated above requires better understanding of their potentials and limitations within the given scope. This understanding requires assessment of the information exchange standards that configures 'the world'.

Configuring the 'world' will focus on semantics, rather than on technologies and languages that are needed to describe the semantics. It will concentrate on object information (i.e. objects, classes, properties, relationships), rather than on representation information (shape description, geometry). Furthermore, it can be stated that for this early stage of the project, the focus will be on data rather than on (software) functionality, and on specification rather than on implementation.

## 2. OVERVIEW OF THE EXISTING BIM-RELATED STANDARDS AND TECHNOLOGIES

The existing BIM-related standards and technologies have two categories; 1) vendor-specific (often developed, provided and managed by vendors) and 2) open standards. This overview focuses on the open standards that provide standardization on semantic level. Open standards can be mostly open-source and free. The reason of focusing on open standards is due to the reason that vendor-specific standards create vendor dependency and they often result in the following consequences:

- Vendors may push the users to buy their products, because these products are compliant with the vendor's other products, although these products may not provide the functionality for your needs;
- Vendors may raise license fees unexpectedly, especially when they have obtained a dominant market position;
- Vendors may go away (go bankrupt, change their product line), and this leaves the users with useless information.

An important additional argument for public sector clients such as road authorities is the level playing field argument: in tendering processes, candidates should all have the same chances, so no candidate should have an advantage because he has more experience with specific software (Folmer & Punter, 2011).

These consequences urge the importance of the open standards such as IFC, IFD, COINS etc. However, open standards have still their limitations in practice. Many large organizations have decided to standardize on one vendor such as Autodesk, for pragmatic reasons. But for this research, the arguments for open standards as stated above were found prevalent.

Below, we list the most commonly used open standards and organizations behind these standards. These and other standards and organizations are described in more detail in (Nederveen & Bektas, 2013).

### 2.1 BuildingSMART

Industry Foundation Classes (IFC) is currently the leading standard for building object data. IFC provides standard descriptions for buildings and building objects. IFC is widely known and used by building information experts and it is also well supported by software vendors who have developed IFC interfaces etc. IFC can be considered a professional standard: it is well defined and well documented. The IFC organization buildingSMART is a professionally working organization, although the number of actual developers of IFC parts is limited. Moreover, buildingSMART obtains little direct funding, so a significant part of the development efforts have actually taken place in R&D projects that are funded by other parties (companies, research funds, etc.).

An important issue for road authorities is that IFC does <u>not provide road objects</u>. IFC does provide methods and tools for development of standardized road objects, in the form of an "IFC for Roads", but this has yet to be developed. In addition to this, IFC does not provide much support for requirements management/systems engineering or for life cycle/asset management.

From an ICT point of view, it should be noted that the IFC technology is largely based on ISO STEP Technology (EXPRESS language, STEP Physical File format etc.). This technology has been developed in the pre-Internet era, more than twenty years ago. As a result, some characteristics of ISO STEP and IFC can be regarded as not "Internet-aware".

In addition to IFC, the BuildingSMART organization also manages a few other standardization developments. The most interesting one for this research is the BuildingSMART Data Dictionary or bsDD. The goal of the bsDD is to form a basis for library structures in conjunction with IFC. Its development originally started with the International Framework for Dictionaries, which has result in ISO standard 12006. Unfortunately, bsDD is not yet defined and documented very well. As a result, it is not yet suitable for usage in road projects. Also, the bsDD more or less assumes that object libraries are stored centrally, but we have observed a need in road infrastructure practice for decentralized, distributed library structures. This is discussed further in 2.5.

## 2.2 COINS

COINS (COINS Consortium 2010) is a Dutch standard for BIM. It has been developed by a large consortium of participants active in the infrastructure domain. COINS is complementary to standards issued by buildingSMART such as IFC, bsDD and IDM. COINS supports the exchange of Systems Engineering information and ensures that an object tree, GIS data, 2D drawings, 3D models, IFC models and object type library can be stored in association in a database. It also provides an interchange format called BIM container.

COINS is relevant for this research for several reasons. First of all, COINS provides support for road information. Furthermore, it supports methods for requirements management based on systems engineering. The main problem with COINS is that it is only known and used in the Netherlands.

## 2.3 GIS

The leading open standard of Geographic Information Systems (GIS) is the set of standards based on GML, managed by the Open GIS Consortium (OGC). These standards are relevant because they cover the GIS-side of the scope of this project.

The OGC standards are well defined and use modern, Internet-aware XML-technology. The main issue is of course that these standards use different ways for describing roads, buildings and especially their geometry than IFC and related standards.

## 2.4 W3C

The World Wide Web Consortium (W3C) manages well known Internet concepts such as the World Wide Web and languages such as XML, XST etc. Less known but very relevant for developers are the new advanced technologies based on Semantic Web concepts, in particular ontologies defined using the Web Ontology Language (OWL).

The advantage of these new technologies is that they are fully Internet-aware and conceptually well-defined, with for example clear distinctions between languages and models. The W3C organization is also of high quality: clear and transparent and on a very high professional level. The common technologies such as XML are very widely used, but this is not the case for more advanced technologies such as OWL.

## 2.5 Concept Libraries and Distributed Modeling

BIM environments are usually visualized as a circle of actors (disciplines, applications) positioned around a central Building Information Model. However, more and more people involved in BIM state that there is a need for a more decentralized approach. Not everyone believes in the ideal of a “central BIM” anymore.

In addition to that, a growing interest has emerged in the use of object libraries in the BIM context. Part libraries or object libraries for CAD are already commonly used in construction projects for many years. Most CAD/BIM systems provide such libraries and provide functionality to build such libraries yourself. The key principle is that the instance model (“the design”) not only contains explicit object data but also references to object libraries, where the library object properties are stored.

Recently a new initiative called CB-NL (Concept Libraries in the Netherlands) was launched (Adriaanse et al. 2012). This initiative, supported by many companies and organization in the construction industry, is a typical example of an expressed need for a domain-specific library of BIM-objects, with sufficient flexibility to address local or national requirements. This initiative and similar developments in other countries confirm a need for an approach for local use of library structures in a BIM environment that is not yet addressed by the bsDD by buildingSMART. Currently, researchers are exploring ideas on how such distributed concept libraries for construction could be developed, see for example (Beetz, 2013).

The identified needs for distributed modeling and decentralized concept libraries will be taken on board in the next section, in which an assessment is made and a solution direction is chosen for road construction information.

## 3. CONFIGURATIONS AND ASSESSMENT OF THE EXISTING STANDARDS FOR BIM FOR ROAD CONSTRUCTION

The scenario for BIM and distributed modeling refers to a direction towards configuring the information exchange standards within the scope of road construction and a midterm of development and implementation period. Within this scope and time horizon, existing standardization approaches are identified and assessed in order to create a breakthrough that synthesizes the relevant approaches of the existing approaches. The existing approaches are based on the configurations of the existing information exchange standards that can be used as a scenario for BIM and distributed modeling for road constructions. The first one based on the buildingSmart initiative (bSI), and the second one based on COINS. Below, the assessment of the standards in each approach based on the three main criteria is presented.

### 3.1 Selection criteria for assessing the information modeling standards

In order to develop a scenario for BIM and distributed modeling for road constructions, we need to assess the state of the art of the existing standardization approaches. For this assessment, we based on the Folmer (2012)'s three branched model, Quality Model of Semantic Standard (QMSS)[1]. The QMSS included quality of standard, process and quality in practice as listed below.

- The quality in practice: International Acceptance
- The quality of the product: Functionality, technological robustness
- The quality of the process: Strength of the standardization organization

The quality of product deals with the content (the specification). The process quality relates to the development and maintenance processes as carried out by the organization developing the standard. The quality in practice deals with the performance of the implementation of the standard and the environment in which the standard is applied (Folmer 2012). The QMSS model is adopted to be used for assessing the quality of the BIM-related exchange standards for road construction. In assessing the product quality of the standard, information is needed on the following issues;

- The functionality of the standard (whether the standard is interoperable)
- The usability of the standard (whether it can be implemented and used without any burden)
- Durability of the standard (whether the standards is future-proof)

In assessing the process quality, three types of information needed.

- Development & maintenance (whether these processes are professionally organized)
- Communication (to what extent the standard is presented and 'communicated' to the outside of the world)
- Organization (to what extent the organization develops the standard is capable)

In assessing the quality in practice, there is information required as follows;

- Acceptance (whether the standard is accepted in practice)
- Interoperability (whether the standard leads to interoperability in practice)

Below, the assessment of the existing configurations based on the Folmer's model within the context of BIM for road construction is presented.

### 3.2 buildingSMART Configuration

The buildingSMART configuration should have a core model for road modeling and is the IFC for Roads schema in EXPRESS. This schema is an extension of the IFC2x4 schema in EXPRESS but it is still to be developed. The model for a specific road is an instance of these schemas. The data files are represented in STEP Physical File format (SPFF) and comply with the schemas.

In the bSI configuration, a schema can be semantically extended by libraries, for example in a "bsDD for NL Roads". In this example the bsDD for NL Roads adds classes and properties to the schemas that have been

[1] The QMSS model has approx. 50 sub criteria to assess the quality of the information standards. This model was adopted through the series of workshops conducted with the road authorities and ICT experts in the V-Con project.

identified as needed by the Dutch road sector. This bsDD is formatted as a SPFF file and specified as an instance of IFD (which itself is specified in EXPRESS). With the current languages, a small part of IFC involving proxies and properties can then be instantiated to model additional data (as identified needed by the Dutch road sector) in the SPFF file for a specific road. The model of the road from A to B can point to the extra semantics defined by the Dutch road sector by referencing to library parts in the bSDD for NL Roads. The bSI configuration is assessed based on the criteria introduced in 3.1 and presented below.

- Quality in Practice: Market Acceptance

+ bSI has IFC and IFD components, and represents a broad acceptance among software vendors and contractors, focus on design phase.

- Quality of the Product: Strength and flexibility

+ 3D geometry representation is good enough for construction level;
+ Installed base of tools supporting underlying technologies
+ IFC Bridge development is available as starting point for IFC for Infra; playing field for static /dynamic
- There is no direct support for multiple distributed collaborative model layers; therefore not supporting national object type libraries supports a national standard
- The Systems Engineering and lifecycle management still needs to be supported.
- 3D geometry is not enough for early design phases of road design (highest level); (modeling the landscape; clothoides)
- IFC and IFD are based on old, non-web aware STEP technology (EXPRESS, SPFF, SDAI) hampering the interrelation and reuse of distributed collaborative libraries; Web-based is essential for accessing data and object type models managed by others
- EXPRESS is also hardly web-aware and XSD is not powerful enough for the semantics that we want to support.

- Quality of the Process: Organization

+ bSI well established organization maintaining the standard; compliancy important improvements have been made; bSI is getting more and more mature
+ OpenInfra is opportunity for V-Con
- Locally unique id approach limits flexibility; therefore every modeller is dependent of a (commercial) organization to develop models
  - End-users from infra sector (road authorities and contractors) are not well represented in bSI organization

As become apparent in the assessment above, the greatest asset of this configuration is that it is based on a striong and internationally known organization, buildingSMART and its standards which are known, accepted and used by researchers and practitioners all over the world. Also there is also a lot of support from various software vendors. The standards of the buildingSMART, particularly IFC, are the “default” open standards for BIM. The standards are relatively mature, well-organized and widely used. However, the support from the buildingSmart initiative on the infrastructure domain still is needed. This support should include the infrastructure objects (i.e. IFC bridges, roads etc.), the extension for the system engineering and life cycle management, the dynamic model layers (needed for the library structures and flexibility). And the underlying technologies of this configuration can be a barrier this support for BIM and distributed modeling for road construction at road authorities. This leads us to the second configuration, COINS.

### 3.3 COINS configuration

COINS contains a light weight object tree oriented information model with strong built-in systems engineering concepts (function, function fulfiller, requirement, performance, verification). COINS facilitates both static extensions by specific plug-in models (reference frames) as well as dynamic extensions by referencing object type libraries (OTL). The object type library format is part of the COINS standard (catalogue parts) and is founded on set theoretic principles.

COINS BIM does not specify a native geometric model (other than location and orientation) but uses an interface class (Explicit 3D Representation) to refer to foreign shape description models. In principle, any format is acceptable, e.g. IFC, GML, Collada, DWG, etc. Shape representation references can be differentiated to detail level, discipline or life cycle stage. Shape representations can be attached to both object instances (BIM) and to object types (OTL).

COINS standard is specified using the web ontology language (OWL) which fully exploits web technology to link models together (both BIM's and OTL's). Tooling (database management, version history, viewing, report generation, etc.) is developed as part of the Rijkswaterstaat SAA/BIM program[2]. COINS configuration mobilizes the built-in facilities (reference frameworks and object type libraries) to define an open-infra model. Explicit 3D representation must be specified in a (preferably open standard) format like IFC. As long as no such an infra-specific open format is available propriety standards like DWG could be used alternatively (taking in infra-specific CAD systems like Civil3D or MX). A coupling with the GIS standard GML is already exploited within the SAA project. Below, we present the assessment of the COINS configuration based on the criteria introduced in 3.1.

- Quality in Practice: Market Acceptance
  - \- Only known in Dutch infrastructure community (clients and contractors)
  - \- Not known by CAD-vendors; no CAD-interfaces provided by vendors
- Quality of the Product: Strength and flexibility
  - \+ Systems engineering functionality supported
  - \+ Flexible model structure, using distributed, collaborative modeling
  - \+ Multiple geometric representations possible (links to external geometric representations)
  - \+ Different levels of details and different life-cycle phases supported
  - \+ Good facilities for adaptation to specific project needs
- Quality of the Process: Organization
  - \- No international organization (fully Dutch)
  - \- Only Dutch clients, contractors, education institutes and software companies involved
  - ? Mature process and management of the standard (review and change procedures, etc.)

COINS scenario is based on the Dutch COINS standard. It has some clear advantages. From a functional/scope viewpoint, it is developed for infrastructure and it provides support for systems engineer/life cycle management. From a technological viewpoint, it uses advanced web-aware technologies such as OWL, which provides a good starting point for the support of flexible, distributed collaborative libraries. However, COINS is a specific/particular Dutch solution that uses modern technologies like W3C OWL, but more like a way to express its own specific meta-schema constructs. There is a need to update OWL in order to use the full its strengths. COINS configuration need static, internationally agreed elements to enable software vendors to develop and exploit road specific software and interfaces based on the standard.

### 3.4 The Necessity of an Integrated Configuration

The buildingSmart and COINS approach did inherit some potentials but also had their shortcomings to stand alone as a sufficient scenario for BIM and distributed modeling for road constructions. Both approaches however have potentials that can be fostered, combined and be parts of a new scenario combining different worlds and their information structuring standards.

The existing approaches showed that each domain has its own information modeling standard and have strength on their domain:

- OGC with CityGML in GIS technologies,
- buildingSmart with IFC in BIM,
- BIR with COINS in system engineering in the Dutch infrastructure industry.

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[2] Rijkswaterstaat (the Dutch Road Authority) has launched a BIM implementation program to integrate the departments of realization, asset management, network management, and to ensure information sharing with contractors. The program started with the project called SAA, A9/A10/A1/A6 highways, between Schiphol - Amsterdam – Almere. (Online source: http://www.rijkswaterstaat.nl/en/highways/v_con/pilot_projects)

The strengths of these organizations and their standards need to be combined and introduce a new functionality. Below we introduce this integrated world as a Hybrid scenario.

## 4. A HYBRID SCENARIO FOR BIM AND DISTRIBUTED MODELING FOR ROAD CONSTRUCTIONS

The hybrid scenario offers an environment that enables linking the standardisation initiatives identified earlier: it enables linking BIM (IFC, bSI), GIS (CityGML: OGC) and COINS (Systems engineering and dynamic object type libraries) as illustrated in Figure 1. The resulting semantic models of these initiatives may well be used in the hybrid configuration. These other initiatives will also continue their separate developments, with a link to a future proof, more dynamic, environment. The Figure 2 illustrates the configuration of this dynamic environment.

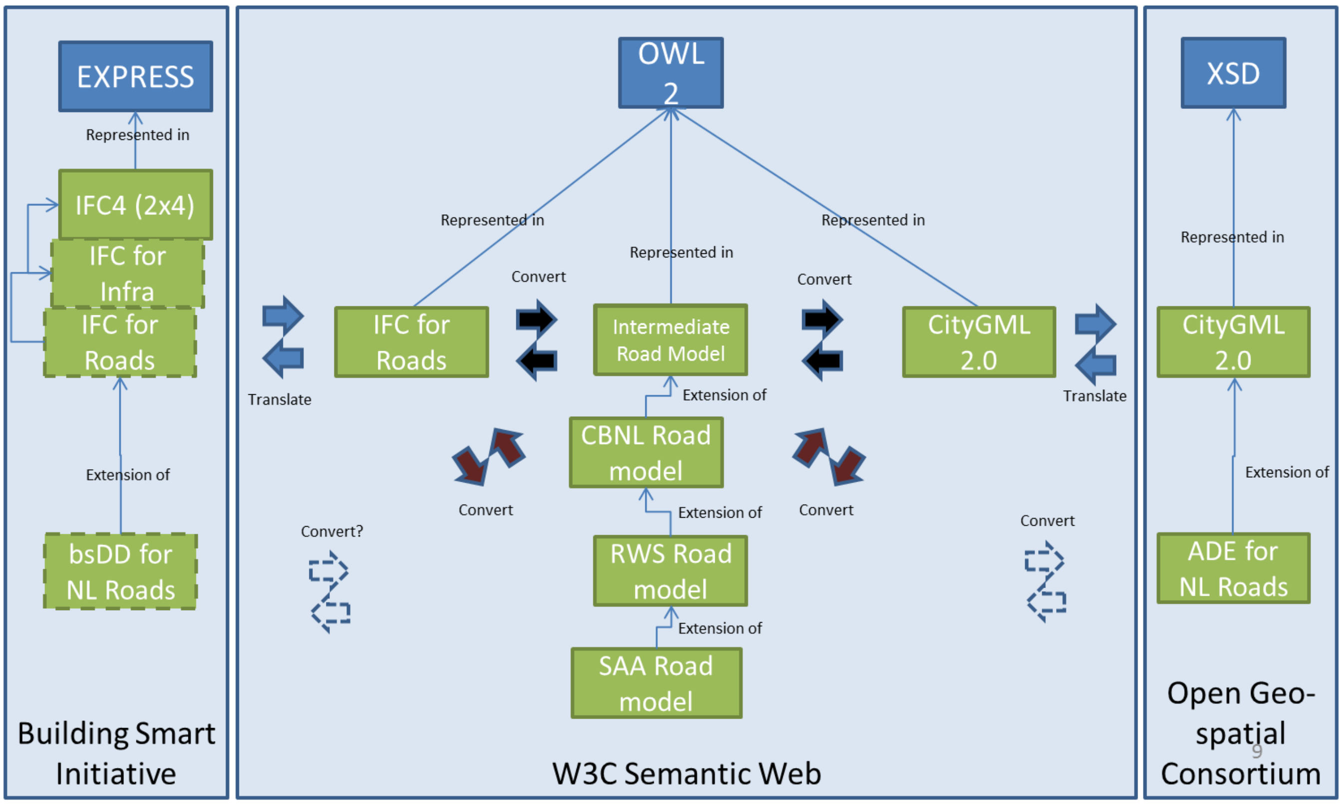


Figure 1: The configuration of the hybrid scenario based on the existing information modeling standards for BIM and distributed modeling for road construction.

An important goal for a hybrid scenario is to develop a future-proof system that supports dynamic library structures. This can be done using the W3C 'semantic web' approach, that is using OWL as fully international, generic and well-defined open standard for the libraries, actually called 'ontologies' here.

An example will be given of how the hybrid scenario can link civil infrastructure information models in BIM and GIS world can be seen in Figure .

The "Semantic Web" with its key component the Web Ontology Language (OWL) is seen as the highest potential to be used in BIM for road construction. As the 'normal' Web (on top of the Internet) integrated so many human-interpreted informal, unstructured, information, the 'Semantic' web promises for the formal, structured, information handled by todays software applications like for BIM and GIS, while still using the Internet as base communication infrastructure. Furthermore, semantic web is also more interesting for the software-vendors to invest in interfaces for such a future-proof system, rather than investing in a system that is based on old, not web-aware technologies.

"Using OWL" here means that modeling mechanisms directly available in this language are reused as much as possible. It also means that needed modeling functionality that is not in this language like 'archetypes', 'decomposition', 'measures/units' and 'requirements' are added as "cleanly" as possible by an *upper ontology*. There are already initiatives for the development of such an upper ontology in the running European projects Odysseus and Proficient (which goes even a step further, by generating geometry instead of linking, from the semantic information). This upper ontology is called *Concept Modeling Ontology*, or *CMO*.

One consequence of using OWL is that on the conceptual level we have 'classes' (sets), instead of 'types'. This has serious consequences for the way specialization is to be interpreted: an instance of a subclass is *by definition* a member of a superclass. Having that in mind, an often used (Dutch) term such as OTB – 'Object Type Bibliotheek' (Eng.: 'Object Type Library') is not really appropriate. Therefore it is better to use the terms from the Semantic Web world being "Classes" combined in "Ontologies".

## 5. DISCUSSION & CONCLUSIONS

- The main challenge of the hybrid scenario lies in its technological development, based on semantic web technology.
- Both buildingSmart IFC (for BIM) and OGC GML/CityGML (for GIS) (and all relevant Inspire specifications) are important standards in infrastructure and will remain important in the coming years. In addition to these standards, there are other important environments with their own languages (e.g. UML/SysML of OMG, various web-based languages by W3C, as well as local/proprietary environments and languages). Mappings between these languages will be the only way to enable communication between these different domains. In addition, dynamic libraries/ontologies are a prerequisite for the required flexibility in complex models.
- The realisation of the hybrid scenario, including creating acceptance by the many parties potentially affected by it, is a large and ambitious undertaking. Large BIM implementation programmes at key users (i.e. road authorities such as Rijkswaterstaat and Trafikverket), are essential for its technical success, and, even more, for its acceptance in the sector.

The hybrid scenario provides a big potential for the midterm use. It combines the strengths of buildingSmart, COINS configurations and incorporates GIS technologies. It supports the main functionalities needed for road infrastructures and it is linked to international standards for both BIM and GIS. However, many actions and issues can be derived with regard to the buildingSmart Initiative, GIS, and semantic web technologies. Furthermore, a good mapping specification is needed, as well as a specification of mapping software tools needed and a plan for development of these tools. The follow-up of this paper will involve the elaboration of the hybrid scenario and definition of the actions needed to operationalize the hybrid scenario.

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