BIM – GIS integration for Asset Management

Investigating the possibilities of integrating 3D BIM asset models in a 2D GIS Web Viewer environment

Talida Boanca

April 2014

Grontmij

WAGENINGEN UNIVERSITY
WAGENINGEN UR

BIM – GIS integration for Asset Management: Investigating the possibilities of integrating 3D BIM asset models in a 2D GIS Web Viewer environment

Master Thesis Geo-Information Science

Talida Boanca

(821106-077220)

A thesis submitted in partial fulfilment of the degree of Master of Science

at Wageningen University and Research Centre, The Netherlands

April, 2014

Wageningen, The Netherlands

.

Supervisors:

Dr. Ir. Arend Ligtenberg, Laboratory of Geo-Information Science and Remote Sensing, Wageningen University

Ing. Ronald van Lanen, Grontmij

Ir. Henri Veldhuis, Grontmij

Thesis code number: GRS-80436

Thesis Report: GIRS 2014-21

Wageningen University and Research Centre

Laboratory of Geo-Information Science and Remote Sensing

Summary

Asset Management (AM) processes are often characterized by high diversity of involved stakeholders, each with their own interests, (often non-interoperable) tools and methods of working, and data types used per asset life cycle phase, based on different standards and norms. This, along with the segregation between the design / construction phases and the operation / maintenance phases of an asset, results in data intensive, complex AM processes and costly, inefficient information management throughout the life cycle of assets.

The aim of this research was to investigate ways of reducing some of the AM complexities listed above, and to facilitate thus AM processes. Two different possible solutions were considered: 3D representation and visualization of AM data, and the integration of different systems and data types used in AM processes. In this case, the systems integration studied was that of BIM and GIS in Obsurv.

Building Information Modeling (*BIM*) is the process of generating and managing data of built facilities and assets during their life cycle. By using BIM models in the design and implementation phases of assets, and transferring the information to the next phases of the life cycle, the total costs of Asset management in its maintenance and operation phases can be greatly reduced.

The test environment for the 3D BIM model integration with GIS is *Obsurv* - a Dutch management system for public space and assets, available as a web-based service (at www.obsurv.nl). Obsurv provides asset information relevant for asset maintenance and budgeting processes.

3D data representation and visualization can help facilitate complex AM processes and increase their efficiency by enabling the storage and visualization of all asset information in one interactive 3D model, facilitating at the same time information sharing between parties involved in different phases of asset life cycle. 3D models of assets also make the understanding of an asset easier across an organization, and help to correctly identify components for maintenance services.

The BIM - GIS integration was tested through the integration of a 3D BIM model of a bridge in Obsurv, the test environment for the case study. The integration was realized at *system* and *data level*. The *system (or application)* level BIM-GIS integration gives users access on the fly to the BIM physical file (saved locally or updated to the cloud) through an API (Application programming interface) DBMS (DataBase Management System) or through the joint use of web interfaces and message exchange. This type of integration does not involve geometric or semantic data transformation between the two systems, being thus more a loose coupling between the two systems. Integration at *data level* is realized through *geometric transformation* (LOD 4 reduced to LOD 2 by grouping, filtering or aggregating elements based on a similar parameter (family name or material), and the *semantic mapping* between the underlying standards - IFC and NEN 2767-4 (soon to be automated through the (inter)national dictionary being developed (the *CB-NL*), mapping terms/concepts from multiple industries (construction, AM, GIS).

Information integration enables more cooperation between different stakeholders involved in AM processes, and can help enhance the quality of AM processes, tools and services. The integration of various working methods and data types (in the design and construction phases) can lead to cost effective asset life cycle management, by allowing stakeholders access to a seamless flow of asset information over its whole life cycle.

Acknowledgements

I would like to thank my supervisors Arend Ligtenberg, Ronald van Lanen and Henri Veldhuis for helping me stay focused and not get lost in details, by providing me with constructive feedback and useful insights. I am also thankful to all the people willing to respond to the interviews and open discussions for the case study.

I also want to thank my loving husband for all the care and support during this thesis and during the entire study. Last, but not least, I want to thank my family and friends for being there for me, and encouraging me throughout my hard, and sometimes overwhelming work.

Contents

List of figures

List of tables

Abbreviations

ABM - Agent-based Modeling

AEC – Architecture, Engineering and Construction

AM – Asset Management

API - Application programming interface

BIM – Building Information Models (Modelling)

CAD – Computer Aided Design

CAE - Computer Aided Engineering

CASE - Computer-Aided Software Engineering

DBMS - DataBase Management System

FM – Facility Management

GIS - Geo Information Systems

GVI – Global visual inspection

PDM - Product Data Management

RFID - Radio Frequency IDentification

SE – Systems Engineering

VR - Virtual Reality

VTA – Visual Tree Assessment

The terms CAD and BIM are used interchangeably

1. Introduction

1.1 Context

The past decennia have seen many developments, and have enjoyed many new information technology discoveries which make the ease of information use beneficial in multiple academic and professional fields. As a result, different scientific and professional fields are becoming more and more interconnected, resulting in multiple practical applications in decision support systems, in domains such as Asset Management (AM).

Asset Management is the process of optimizing an asset lifecycle (design, preparation, implementation, operation, maintenance, demolition and recycling), to optimize their service delivery potential and to decrease the related risks and costs (CIEAM, 2008). The assets referred to in this research project will be limited to infrastructural assets, such as bridges and tunnels.

Stakeholders involved in AM processes vary per asset life cycle, including software suppliers, architects, engineers, builders, owners and others. All these parties use *different types of data, standards, software, process workflows and Organization Document management systems*, making the information management over the whole life cycle of a project very difficult (Vanlande et al., 2008; Motawa and Almarshad, 2013).

The tools and methods used in AM processes are very diverse, depending on the life cycle phase they are used in, and the preferences of stakeholders using them. Some examples are CAD (Computer Aided Design), CASE (Computer-Aided Software Engineering), Programming, Product Data Management (PDM), VR (Virtual Reality), CAE (Computer Aided Engineering), GIS (Geo Information Systems), BIM (Building Information Models) and others (Haider, 2013). Most of these systems store information in a proprietary format, hindering thus information exchange. The absence of a common set of rules to govern the implementation, use and performance of assets and AM tools, leads sometimes to isolated islands of technologies within organizations, impeding technology integration and interoperability (Haider, 2013).

The performance of AM processes, systems and tools used and the performance of assets themselves are assessed in AM with the help of wide variety of quality standards, norms and specifications (Taisch et al., 2011). Several typologies of standards relevant to AM, according to their scope, origin and intent, and the stages of the product life cycle they are used in, have been proposed by Rachuri et al., (2008) and Taisch et al., (2011). The broadest ones are STEP (ISO 10303), MANDATE (ISO 15531), which cover the requirements for most of an assets' life cycle.

1.2 Problem statement

Considering the multitude and diversity of stakeholders involved in AM processes, along with the wide range of available and preferred tools and working methods, each governed by a separate set of standards and norms, AM processes can be described as very dynamic, complex processes, with limited cooperation between stakeholders, and costly assets life cycle (Vanlande et al., 2008; Gursel et al., 2009; Motawa and Almarshad, 2013).

The complexity of AM processes is further increased by the high amounts of different (non-interoperable) systems and data types used, represented mostly in 2D, (Wu et al., 2012), semantically rich information *(*Gursel et al., 2009), fragmented underlying linguistic structures lacking explicit shared semantics (Rachuri et al., 2008), changing information needs and demands*,* and different interpretations of AM and the ways it is implemented (*Wasmer, et al., 2011*). Conflicts of interests as well as conflicts between the methods used can further delay an assets' development process, and increase thus its costs. This diversity in separate and disconnected tools, methods, standards and even semantics used by different stakeholders in different areas and asset life cycle phase, results in information redundancy with fragmented transfer, impeding thus well-informed decision making (Gursel et al., 2009).

All these factors influencing the AM processes can often lead to incomplete information transfer between stakeholders (misunderstanding between different life cycle phases as well as between different working domains, due to different interpretations of underlying concepts), inefficient data and system management across an asset's lifecycle, lack of interoperability between available tools and standards used and communication gaps between project stakeholders (Gursel et al., 2009). This can, in turn, affect the overall efficiency and productivity of AM processes, contributing to delays and financial losses in AM (Regzui et al., 2013), and clarifies the need to adopt a holistic and integrated approach to AM by integration of various working methods, systems and data types (Too, 2011).

Additionally, the increased importance of technological advances, web-based services as well as increased needs for decision-support services, further reinforce the necessity for AM systems integration (Kiritsis 2011).

For more integrative AM processes, a concept from the construction industry – BIM (Building Information Model) can be adapted and used in AM. BIM is the "*process of generating and managing building data (geometrical, geographical and administrative) during its life cycle, through a digital representation of the building process, to facilitate digital information exchange and interoperability"* (Lee et al. 2005). When used only in the start phases of a project (planning, design and delivery), BIM is referred to as *little BIM*; *big BIM* goes a step further, and manages an asset/facility's information over its whole life cycle, from planning to demolition en/of recycling. Even though more complex, due to the higher number of stakeholders involved in different phases of an asset's life cycle stages, big BIM is the type of BIM relevant for the Operation and maintenance phase, which is within the scope of this research project . Any further mention of BIM will thus refer to *big BIM*.

BIM models include 3D representation of the asset to manage, along with all the relevant information about the asset and the corresponding official and administrative documents integrated in the model. At the same time, advances in the fields of CAD and GIS offer new possibilities for data representation and integration, in the form of 3D models, which can further be used as input for BIM. This type of visual representation of an asset allows for rich user interactions and can help improve stakeholders' understanding of an asset and its condition (even stakeholders without a technical background), while the integrated description and documentation of the asset can help reduce the information transfer fragmentation, both between stakeholders involved in different life cycle phases of an asset as well as between different working domains.

BIM and GIS are two very different systems that can be used complementarily in different phases of an asset's life cycle, requiring thus some level of interoperability between them. The differences between the software, standards and data types used by both systems poses some problems to their integration, problems related to the geometry and semantics used in either system, and the requirements for efficient AM processes. A few BIM software packages are Revit, Tekla, Navisworks, Relatics. GIS software relevant to AM are Web services based on WMS or WFS. The standards for data visualization and interoperability are also different between the two systems: BIM is based on the IFC (construction) standard, while GIS uses the CityGML standard for 3D data visualization.

By combining different available technologies, such as BIM and GIS, a new level of system interoperability and stakeholder cooperation can be reached, which can in turn help facilitate the AM processes. Data integration in design and construction phases of an asset in a 3D BIM model, can lead to more cost effective life cycle management (Fischer et al., 2003; Arpinar et al., 2006; Lee et al., 2012). An integrated BIM - GIS model offers a clear overview of existing issues, involved parties, and interactions between them, and spatial influences on AM processes, which can help reduce AM complexity (Hermans, 2013).

This research study is thus aimed at investigating the possibilities of reducing AM complexity through **data and systems integration**, by integrating 3D BIM models of civil-constructions (CAD) with GIS. Issues of data visualization (transition from 2D to 3D) and the lack of interoperability between AM systems (due to underlying different geometric and semantic schema's) are thus addressed in the BIM - GIS integration, by including spatial data about assets, along with their administrative information in one digital 3D asset model, and making it available to other parties through a shared data management system (DMS).

Due to the limited time available for this research, the AM complexity is studied here only for the middle part of an asset's life cycle: operation and maintenance (see figure 1).

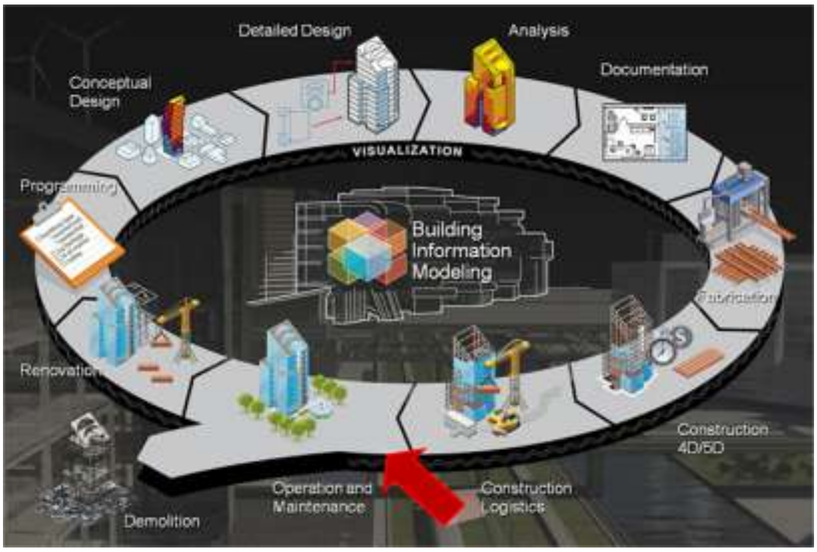


Figure 1 Life cycle process of facilities (www.neuralenergy.info)

For better management of and improved performance of public assets, it is imperative to include spatial information (GIS) with BIM; this should lead to more sustainable construction projects, faster project deliveries and greater design accountability (Flohr, 2011; Hermans, 2013). Considering the wide use of GIS in AM processes (and other spatial developments), and the benefits offered by the integrative BIM approach, the issues of BIM – GIS integration has gained more and more attention in scientific research (Akinci et al. 2008; Benner et al.

2005; Clemen and Grundig 2006; Hijazi et al. 2009; Isikdag et al. 2008; Isikdag and Zlatanova 2009).

Some of the limitations of existing research in this area are the extensive discussions about IFC-CityGML integration and rich semantics of IFC, but *lack* of actual *implementation*, and a *unidirectional conversion* approach, with a focus on converting geometries (mostly from IFC to CityGML) as opposed to a bidirectional conversion between IFC and CityGML. As a consequence, more attention should be paid to semantic and geometry conversions, for the CityGML and IFC integration (Isikdag and Zlatanova 2009; Nagel et al.2009).

The integration of BIM with GIS is dependent on the integration of the underlying (international, open) standards used: IFC (Industry Foundation Classes) for BIM and CityGML for GIS. IFC is an ISO standard for the building industry, used for representing detailed building objects. CityGML is an OGC standard used for visualizing geospatial objects in city models (El-Mekawy et al., 2011).

Due to the differences in software and standards used, the two worlds of BIM and GIS are still dichotomous, requiring thus more research into the complexities of their integration (De Laat and van Berlo, 2011; Song et al., 2013).

In this research paper I would like to further investigate the BIM – GIS integration, building on existing research, and focusing more on the possibilities of extending 3D model applications, for a mixed 2D - 3D representation of information.

1.3 Research objective

The aim for this research is to investigate the possibilities of integrating GIS (2D) with BIM (3D) data (models), in order to explore ways of enhancing the performance of Asset management processes (over the whole life cycle of facilities) (see figure 2).

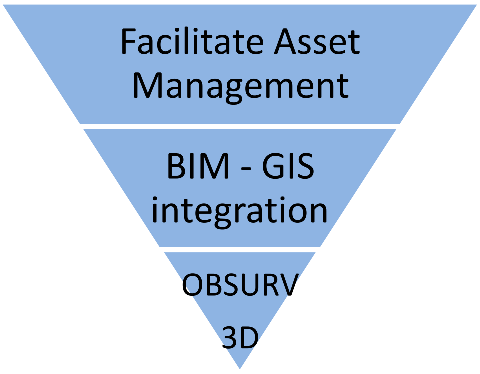


Figure 2 Research objective

The possibilities of 2D GIS – 3D BIM data integration and representation in OBSURV are tested in an already existing AM system – Obsurv, tested through a case study. The scope of this research is further narrowed by focusing only on infrastructural assets managed by Obsurv users, namely bridges.

1.4 Research questions

The research objective will be reached by answering the research questions listed below.

It is assumed (based on existing research) that 3D data visualization and AM data /methods integration will help improve the AM performance. In order to find out how, different issues regarding 3D data visualization and data integration are analyzed through the research questions listed below.

1. What is the added value of 3D data visualization for AM processes?

2. What are the common points and differences between GIS and BIM systems regarding:

   - technical issues (software and applications),
   - data structure: geometry (level of detail), topology,
   - semantics (meaning) and syntactic (wording) issues,
   - standards (IFC, CityGML, NEN 2767-4)?

3. How can detailed 3D BIM models be simplified and integrated with 2D GIS data (in OBSURV)? Which criteria (can and) should be used for the assessment of BIM-GIS integration in OBSURV? The points from the previous two research questions will form the basis for answering this question, which is thus further split up in the following sub-questions:

   - Which user requirements are relevant for (and can be fulfilled by) the BIM-GIS integration?
   - How can the detailed 3D models be simplified? (Criteria and methods of aggregation)
   - What is the role of semantics in BIM-GIS integration?
   - How can standards, norms and specifications help (or hinder) the BIM-GIS integration?
   - Which standards are relevant for BIM-GIS integration in OBSURV?

4. What are the benefits and bottlenecks of BIM - GIS integration?

5. How does the integration of the 3D BIM models help facilitating the performance of Asset management processes? (Validation).

These research questions will be answered with the help of scientific literature, in-depth, structured interviews with relevant parties and through a practical case study (including a prototype integrative model).

By taking into account the basic components and characteristics of BIM and GIS, as well as the use of (open) standards, the research contributes to the increased interoperability of different information models required by Construction and Public Asset Management stakeholders, for present and future applicability.

1.5 Research Methodology

The methods used for the fulfillment of this research are varied, and include: literature study, documents and media consultation, and interviews with actors involved in Asset Management, as well as with professionals responsible for the AM software tested in this project, namely Obsurv.

Obsurv is a Dutch management system for public space, available as a web-based service used by municipalities, provinces, some private parties and Water boards of the Netherlands. It offers asset managers and administrators of public space the possibility to continuously view and manage the state of their assets (roads, structures, drainage, public green, traffic control, etc.). OBSURV provides an information layer over an area (in the form of WMS and WFS maps), relevant for planning, development, management and budgeting processes. It has an intuitive and easy to use interface in a 2D GIS (Geo Information System) environment, and it meets most (open) ICT standards. The necessary information about public objects (such as administrative subdivision, materials used per component, year of construction and necessary up-keeping) is available in an Oracle database, created and updated manually by involved parties, directly through the web service interface. This data can be viewed through an interactive map and tables in the user interface.

The current functionalities of Obsurv are limited to 2D data representation and do not include representation and visualization of assets in 3D. This is seen as an opportunity for enhancing AM processes by improving the performance of Obsurv, through the integration of 3D models of assets in the current 2D environment. 3D data visualization can enhance communication between different parties involved in AM processes, and can help analyze space conflicts between an asset and its environment *(Gursel et al., 2009;* Wu et al., 2012).

Furthermore, the 3D representation of the assets to manage, which is supported by BIM but not yet by Obsurv (using a 2D GIS platform), is considered to enhance decision-making, and thus help improve the asset management processes, by simulating, explaining, and giving visual feedback for decisions (Benner et al., 2005; Kolbe, 2008; Hijazi et al., 2009; Lammeren et al, 2010; Brink et al., 2012). This 3D visualization, along with the completeness of asset data and information integrated in a 3D BIM model, is believed to offer a promising solution to the current fragmented information transfer between different parties involved in different phases of asset life cycle, helping thus improve the AM performance and reduce its complexity.

The data and system integration studied in this research is thus focused on the systems believed to enhance the efficiency of AM performance in the operation and maintenance phase in Obsurv: GIS and 3D BIM. As the public assets to administrate in OBSURV are not yet available in 3D, it is my intention to investigate the possibilities of 2D GIS – 3D BIM data integration and representation in OBSURV.

In the first phase of the research, the context and practice of Asset Management are studied, with the help of a broad array of literature, completed by government and media documents. This is further supplemented by literature on the impact of 3D data visualization and AM data /methods integration on the AM performance.

For a more in-depth understanding of the dynamics of Asset Management processes, interviews are held with different actors involved in Asset Management, such as governmental bodies at both municipality and regional level. The interview questions are open-ended, to allow the participants to freely share their experiences with and wishes for Asset Management tools.

The figure below represents the frame on which this research is built.

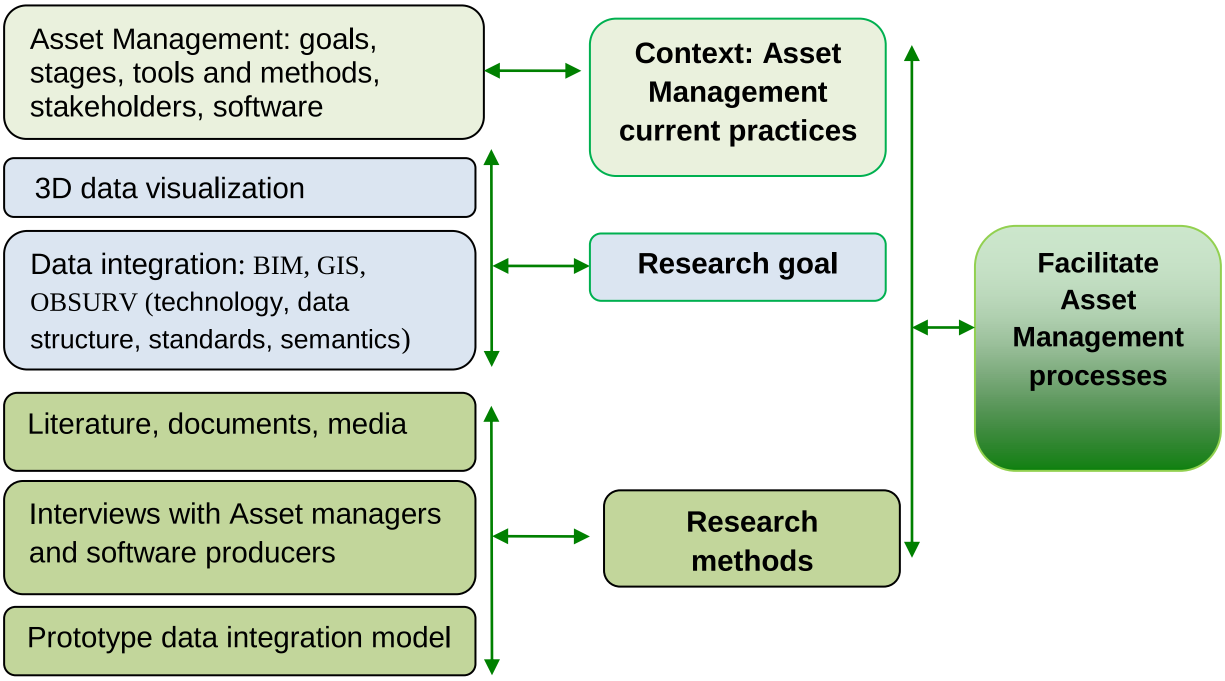


Figure 3 Research setup

The methods used for assessing the research context in which the goal of this research project can be achieved are described in more detail in the following paragraphs, structured thematically in the order of the research questions *(presented as* ***RQ1, 2, 3, 4, 5****)*.

Asset Management

The context and current practices of Asset Management (AM) are studied with the help of scientific literature and other available documents. Factors taken into consideration here are the definition and goals of AM, the standards and specifications used, the life cycle stages of assets, stakeholders involved, tools, software and management methods used by diverse actors in different stages of AM.

For better insight into AM practices and challenges, beside desk study, also interviews are held with asset managers form different governmental organizations in the Netherlands, from both municipal and regional level (a list of interviewed parties and questions is available in appendices 1 and 2).

3D data representation and visualization (RQ1)

3D data visualization is gaining more ground in construction and Asset Management. The first research question is answered with the help of scientific literature, interviews carried out with Obsurv users and through examples of 3D pilot projects in the Netherlands, such as the 3D Pilot NL aiming at 3D country-wide spatial visualization based on international standards, (http://www.geonovum.nl/onderwerpen/3d-geo-informatie/toolkit-3d), of the SIG group (Special

Interest Group) started by a few cooperating private and governmental organizations (Ministry of IenM, Geonovum, Kadaster).

BIM - GIS integration (RQ2,3)

The issues pertaining to data integration are focused in this project on the integration of the BIM-GIS systems, tested in OBSURV, and are grouped in three subparts: the BIM-GIS integration, AM tool performance indicators and the case study.

1. ***(RQ2)*** For the **BIM-GIS integration** part, answering the second research question, the following aspects are taken into consideration: user requirements, technological feasibility, issues regarding the data structure, semantics and the interoperability of the standards used in both systems.

User requirements

In order to identify the user performance and information requirements of stakeholders involved in asset development and management (OBSURV users), structured interviews will be held with some of these parties. Some of the people interviewed are already involved in construction projects using BIM (such as the Oosterweelverbinding project in Belgium); other interviewed parties are municipalities (e.g Rotterdam) and provinces (Gelderland and Noord Brabant) currently using OBSURV for the management of public spaces and assets.

Based on these interviews and literature study, a few indicators will be identified, which will then be used in the design of the prototype model, its testing and its validation.

Technology

For an operational BIM-GIS integration in OBSURV, the technical characteristics of the two systems will be studied and compared, regarding the software packages used (Autodesk Revit, Navisworks, ArcGIS Desktop, Oracle databases), the physical and functional level of detail used, the spatial context, as well as the standards used by each, and their interoperability.

For this purpose, the required software packages will be acquired and used for the prototype model; furthermore, Grontmij professionals in these fields will be consulted (through separate interviews as well as in brainstorming sessions), for a better understanding of OBSURV functionalities, and the technological feasibility (benefits and bottlenecks) of creating 3D BIM models and integrating them in the 2D environment of OBSURV.

Data structure

The differences between BIM and GIS extend also to the data structure, topology, level of detail (LOD) and semantics (discussed in step 4). The representation of 3D BIM models in OBSURV requires the aggregation of detailed 3D BIM objects into a simplified 3D visualization of the administrative subdivision of an object.

The aggregation of detailed objects should take into account parameters such as the user requirements for a specific (LOD), the ontology of objects (regarding their similarities and differences, as well as construction date and need of maintenance of components), and the availability of conversion tools. An assessment will thus be made (based on the existing accounts of previous IFC-CityGML conversion attempts) of the factors relevant for simplification, and will be tested on the 3D prototype model to be integrated in OBSURV.

Semantics

For the Semantic integration of BIM-GIS, the underlying semantic models IFC and CityGML are taken into account (Casey and Vankadara, 2010). Previous studies investigating this interoperability (Semantic web W3C (Berners-Lee et al., 2001; www.w3.org/standards/semanticweb), Ontology Web Language-Services OWL-S (http://www.w3.org/Submission/2004/07/), the Geospatial Semantic Web the CAD/BIM Editor and the WFS-BIM server from Onuma, Inc. (www.onuma.com) will be used as a starting point in researching the role played by semantics in the BIM-GIS integration.

Afterwards, a few concepts representative to the test object represented in the 3D model prototype (e.g. a bridge) to be integrated in the 2D environment of OBSURV will be ontologically analyzed, as both BIM and GIS components, and then commonly defined, for the BIM-GIS integration.

Standards and specifications

Standards and specifications are often used for system interoperability, in order to increase efficiency and to reduce costs of development processes (Lathouwer, 2013). The main players in the fields of AEC (Architecture Engineering Construction) – the BuildingSMART Alliance, and GIS (Geo-Information Systems) - ESRI advocate the use of standards to help produce regular and repeatable data exchanges, and to assist facility owners and operators in solving problems over the whole lifecycle process of facilities (Przybyla, 2010); http://www.buildingsmart.org/; www.esri.com/news/arcuser/0403/overview1of3.html;www.esri.com/news/arcuser/0403/webservices.html).

The aim for this step of the methodology is to find out which standards are relevant for BIM, GIS and OBSURV, and how they influence the BIM-GIS integration. For this purpose, an inventarisation of the existing norms, standards and specification is made, including their provider, users, interoperability with other standards, availability, scope, ease of use, definitions used for (common) objects, and other characteristics relevant for the BIM-GIS integration.

2. **AM tool performance indicators *(RQ3)***

The AM tool performance indicators regarding the user requirements, simplification of detailed 3D BIM models and influence of semantics and standards are determined with the help of scientific literature, and based on the interviews held with OBSURV users (described in the first step of the previous part – user requirements). This, along with the BIM-GIS integration prototype model testing explained shortly below, answers the third research question.

3. **The testing of the BIM-GIS integration *(RQ3)***

The BIM-GIS integration is based on results from literature and existing accounts of previous attempts of BIM-GIS integration (Rees, 2007; De Laat en van Berlo, 2011), and taking into account the findings from the previous focus points of this research, the BIM-GIS integration is tested with a prototype 3D model in OBSURV. The goal is to enable visualization of 3D BIM models of public objects in the 2D GIS interface of OBSURV (See figure 4).

According to the Obsurv users interviewed, 3D visualization of assets is more relevant for bigger assets, such as bridges and tunnels. As such, a 3D prototype model of an asset - a bridge - is constructed (in Autodesk Revit), and developed to a 3D BIM model by integrating all the relevant information in the model. Afterwards, the asset is introduced in Obsurv (administratively and geometrically), and a link is made to the (external) 3D BIM model of the same asset. Important factors to take into account for the BIM-GIS integration are: technology, standards used, data structure, semantics and user requirements.

Also, information about a specific object should be linked to the 3D model. For this purpose, the 3D BIM model of a bridge is used as an example in OBSURV: when the user zooms in on the map, the bridge becomes visible on the 2D map; by clicking on it, the 3D model of the bridge opens in a new window, allowing for visualization of all its (physical and administrative) components; by further clicking on (parts of) the model, extra information about the object becomes available (in yet another new window).

Figure 4 3D BIM model in 2D OBSURV interface

This will be realized by first acquiring and getting familiar with the necessary software packages (OBSURV, Oracle databases, Autodesk Revit, Navisworks, FME). Obsurv is an AM tool provided by Grontmij, available as a web service, based on GIS (a base map on which the assets' location can be shown) and on an Oracle database, containing the administrative asset information. Revit is a Building information modelling software package provided by Autodesk, used for 3D drawing in architecture, structural engineering and construction. Navisworks is a software packages (also provided by Autodesk) that enables architecture, engineering, and construction professionals to review integrated (Autodesk compatible) models and data, for better project and / or asset management. FME Workbench is a Desktop application provided by Safe Software, used for translating and transforming data to different formats.

Afterwards, a 3D BIM model of an object (e.g a bridge) will be built in Revit, containing all the necessary information about each component, which is relevant for future phases of the life cycle, such as maintenance. Based on the results of the previous steps of this methodology, the detailed object model will be simplified (through aggregation of similar components, or filtered), in order to be linked to and visualized in OBSURV.

At the same time, the possibilities of obtaining data about public objects (in a format that can be linked to the 3D model in OBSURV) are investigated. The in-house knowledge of Grontmij professionals will be used as support for this prototype model.

The methods considered for data exchange integration between the CAD/BIM – GIS (Obsurv) systems are the following:

- System level integration (figure 5) - allows users access on the fly to the BIM physical file (see figure below). It involves *geometric transformation* (LOD 4 IFC reduced to LOD 2 CityGML), and *semantic mapping* between the underlying standards - IFC and NEN 2767-4.

Figure 5 System level integration

- Data level integration (figure 6) - by exchanging a CAD (Revit) file among various applications (see figure below). No geometric or semantic data transformation take place: the model is saved locally, or is uploaded to the cloud and linked to Obsurv.

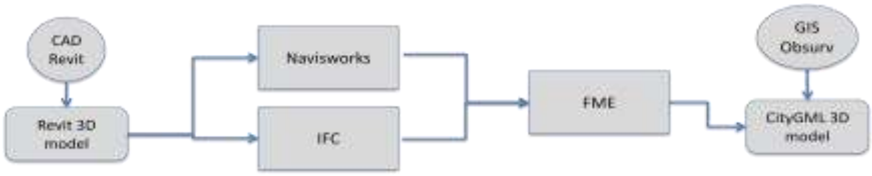


Figure 6 Data level integration

Benefits and bottlenecks of data integration (RQ4)

The benefits and bottlenecks of data integration, as well as its technical feasibility, are studied in this project with the help of available literature, existing previous research in this area, and a practical case study in which the integration of a 3D BIM prototype model is attempted in the 2D GIS environment of the AM tool offered by Grontmij – OBSURV. This answers the fourth research question.

Validation (RQ5)

In this last step, the effects of implementing a 3D model prototype in OBSURV will be assessed by carrying out additional interviews with OBSURV users, using performance criteria of the 3D model as assessment indicators. This should indicate whether and how much the use of 3D BIM models of objects available in OBSURV can help reduce the overall AM complexity. This answers the fifth research question.

In the following chapter, the theoretical framework of this research project is presented.

1.6 Outline

This research is structured as follows:

In chapter 2, the theoretical basis is set for analyzing the Asset Management context, including factors that influence the AM process and performance, such as the tools and standards used, involved parties in different life cycle stages of assets, and AM tool performance requirements.

In chapter 3, based on the theoretical framework, the BIM-GIS integration is tested through different methods in the case study. A prototype integration model is designed and tested: the integration of a 3D Revit model of a bridge in Obsurv is analyzed and tested at system and data level.

In chapter 4 the results of the tests are presented, and further discussed in chapter 5. The research ends with conclusions and a few issues to be considered for further research.

Figure 7 summarizes the framework on which this research is built.

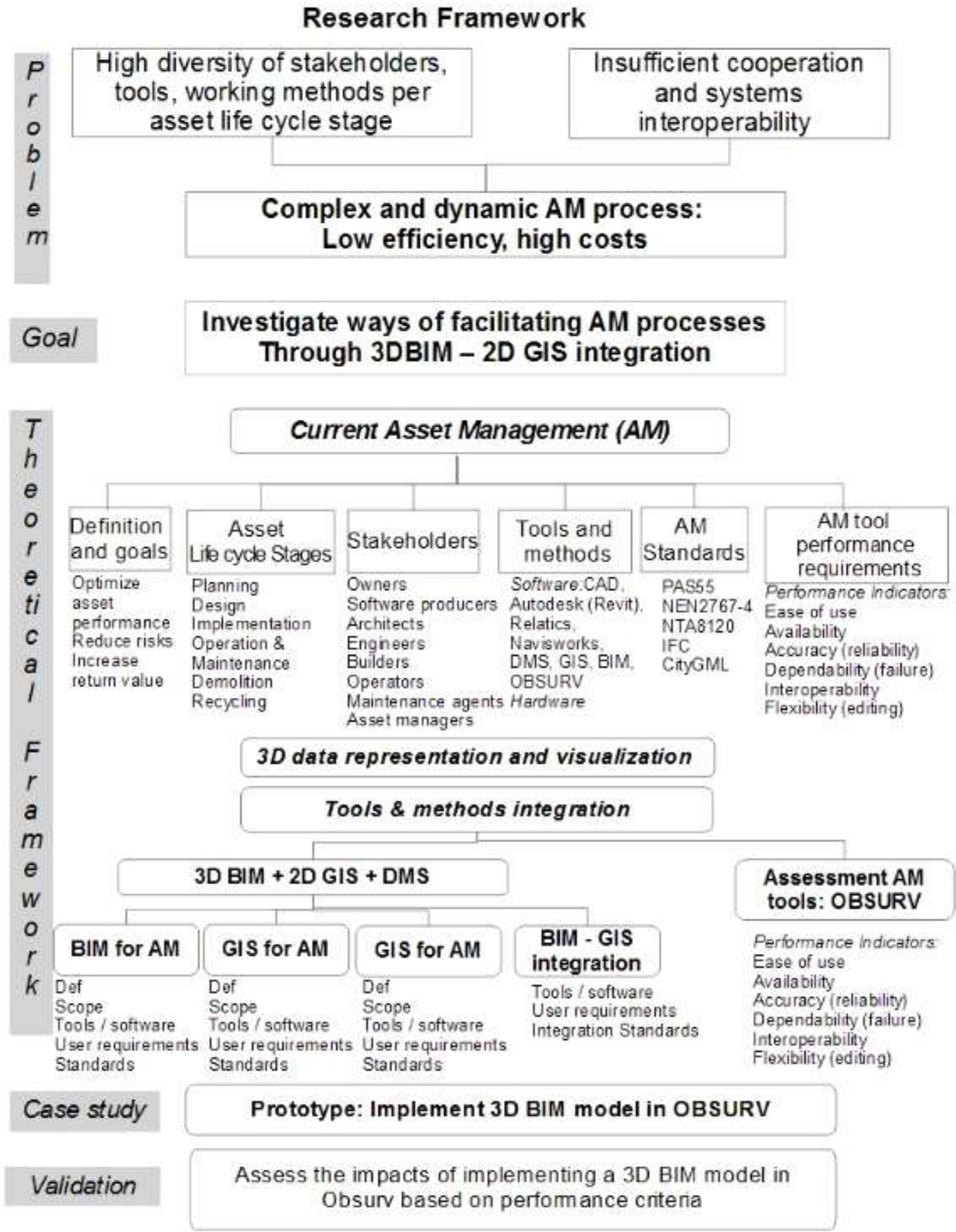


Figure 7 Research framework

2. Theoretical framework

The schematic representation of the theoretical framework (Figure 8) is part of the Research Framework (Figure 7), and it helps maintain the overview over the concepts discussed in this chapter, and their interrelations, and is shortly explained here.

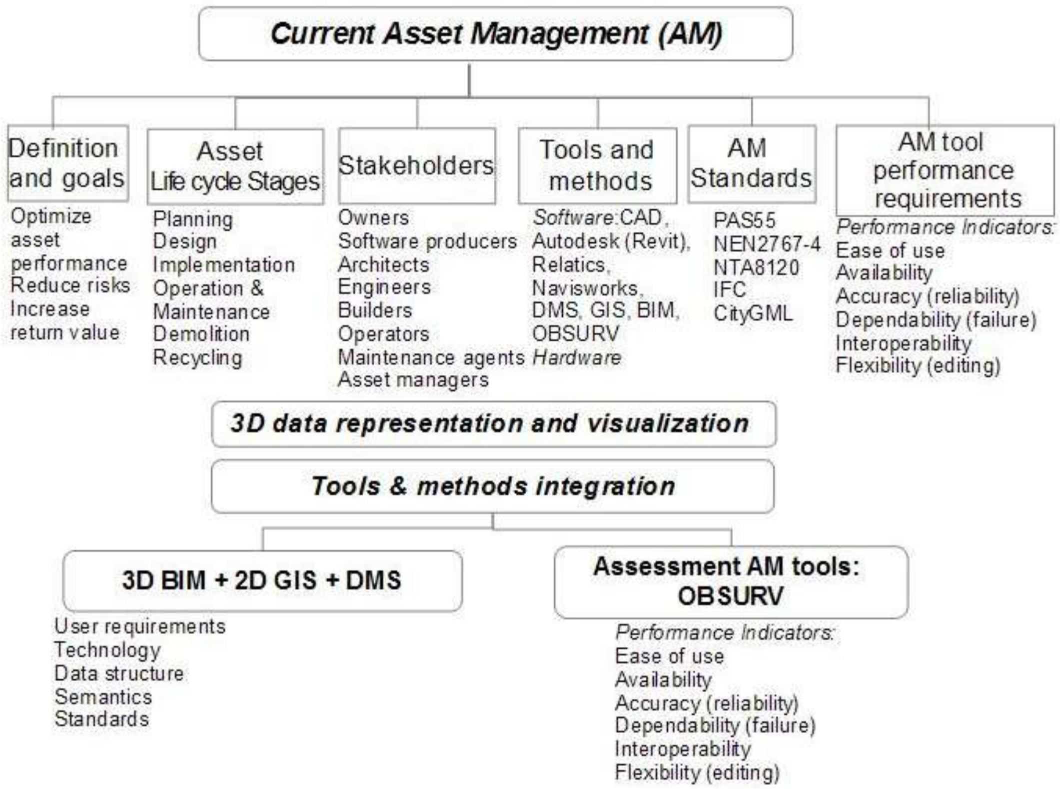


Figure 8 Theoretical framework

First the context of Asset Management (AM) is studied: what AM is, what the AM life cycle stages are, who is involved in AM processes, what the tools and methods (Information systems) used are, the performance assessment and requirements for information systems and other tools used in AM (Life Cycle Assessment – LCA and Product Life cycle Management - PLM) and the standards, norms and specifications used in AM.

After mapping the context of AM, its main challenges and complexities are defined, namely the high dynamics and diversity of the AM process, due to the multiple involved parties (in different life cycle stages) with different tools, software and working methods, leading often to inefficient and costly AM.

This research is thus focused on how these complexities could be reduced. Two factors are considered, which are believed to help facilitate the AM processes:

- 3D data representation and visualization
- Data, tools and systems integration: after a short introduction on data / systems interoperability and integration, the issue is narrowed down to the integration of BIM

(Building Information Models), GIS (GeoInformation systems) and DMS (data management systems). This step is further divided in three sub-steps:

- Each system (BIM, GIS, DMS) is defined separately, including their architecture and data structure, available technologies, standards used, semantics; afterwards, their integration is studied based on the same 4 aspects - data structure, available technologies, standards used, semantics, plus an additional one - user requirements. The user requirements are limited to the users of the test environment for the case studied in this project – Obsurv.

- After the issues relevant to BIM - GIS – DMS integration are documented, a list of criteria is made, for the performance assessment of the AM tool used in the case study: Obsurv. The criteria are based on AM performance goals from the literature studied, as well as the wished of the Obsurv users interviewed.

- Based on the two previous steps, the BIM - GIS – DMS integration is tested by integrating a 3D BIM model of a bridge, with all the pertinent information and documents linked to it, in the 2D GIS environment of Obsurv.

The validity of the proposed solution of facilitating the AM process through data/systems integration is assessed by comparing the completion of a specific AM maintenance task in the traditional – current – method, without using 3D BIM models, with the proposed new method – integrated 3D BIM - GIS – DMS model in Obsurv.

For this purpose, the AM task is decomposed in multiple activities; the costs per activity are estimated, (including completion time, number of stakeholders involved, and methods/ resources used per activity). Afterwards, the impact of integrating the BIM - GIS – DMS model in AM maintenance in Obsurv can be evaluated by estimating the completion costs of the same AM task (and activities) while using the prototype model.

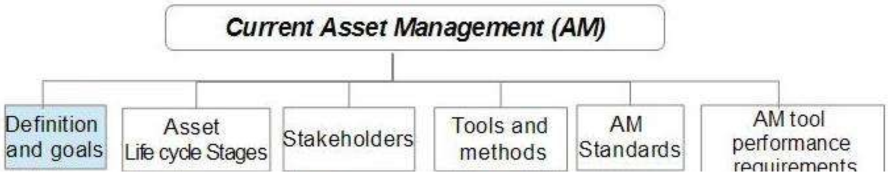
These steps are discussed in more detail in the following sections.

2.1 Asset management

In this chapter the context of Asset Management (AM) is shortly described, by taking into account AM definitions, goals, asset life cycle stages, stakeholders involved in them, tools and methods used, standards and norms relevant to AM and AM tool performance, following the order in figure 7.

For the purpose of this study, the AM tool used (and investigated) is the software package for management of public assets offered by Grontmij – OBSURV (www.obsurv.nl). Each of the following subchapters about AM will start with a general context of AM, and will then be narrowed down on Obsurv as AM system, and its positioning in the broader context.

2.1.1 AM definition and goals

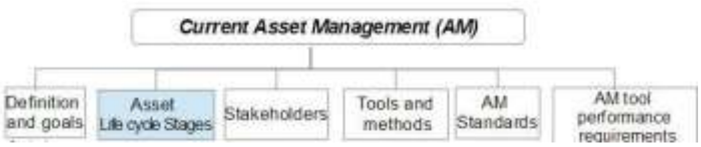


Asset management (AM) is defined as a set of disciplines, methods, procedures and tools for optimizing an asset's lifecycle, creating, enhancing and preserving its value function (including the economic benefits) (Haider, 2013), by scrutinizing performance and making strategic decisions in all phases of an assets lifecycle (CIEAM, 2008; Too, 2010; Kumar et al., 2011).

The core objective of asset management processes is to create value for the organization stakeholders (Jones, 2000; Humprey, 2003; Too, 2010), preserve the operating condition of an asset to near original condition, and achieve cost effective asset performance by linking decision-making with information (Jones, 2000; Sklar, 2004; Too, 2010; Haider, 2013).

In this research project, AM processes are focused on the maintenance of assets owned and administered by Obsurv users (municipalities, provinces and Water boards), assets such as bridges, tunnels, street lights, sewage and green areas.

2.1.2 Asset life cycle stages



AM processes are usually carried out on three levels (Haider, 2013): operational, tactical or management, and strategic. The *operational level* includes the activities necessary to ensure the expected asset performance; the *tactical* or *management level* involves planning and decision support to *ensure asset availability, quality, and longevity*; and the *strategic level* - a long term vision of asset management, is aimed at responsiveness to internal as well as external challenges: understanding the needs of stakeholders, market trends, and linking them to the tactical and operational level activities (Haider, 2013).

An asset's life cycle is characterized by three phases (Kibert, 1994; Shen et al., 2007; Haider, 2013):

- BOL (Beginning Of Life), including conception and feasibility studies, design (or planning), procurement and construction (or manufacturing, implementation, development);

- MOL (Middle Of Life), including use/operation, service and maintenance;

- EOL (End Of Life), including disassembly and refurbishing, disposal, recycling.

While the efficient information management of an asset is important over its whole life cycle, the focus of this research is more on the MOL phase – the operation and maintenance phase for which Obsurv is used.

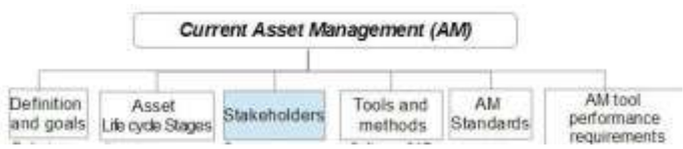
The *AM process in Obsurv* consists of three steps: inventory, inspection and budgeting.

First, an *inventory* of existing assets is made: assets are drawn on the map in the correct location, and their administrative and geometrical characteristics are described in a decomposition (description per component of asset) which is stored in an Oracle database.

Afterwards, assets are physically *inspected* in the field through different methods: for example VTA – visual tree assessment or GVI – global visual inspection. Frequency of inspections depends on the type and size of the organization and of assets. The findings of an asset's condition are updated in Obsurv, under the decomposition of assets.

In the *budgeting* step the costs of maintenance of an asset are calculated based on the year of making, expected life of an asset, and its condition at the last inspection. Also, the emergency of maintenance is taken into account. This way the available funds are distributed accordingly, spreading thus the total costs of maintenance over a specific period of time.

2.1.3 AM stakeholders



People involved in AM (marketers, partners, designers, suppliers, shop floor workers, salespeople, service engineers and customers) often form a diverse group, with different cultural and professional backgrounds, and with different functions in AM processes (Stark, 2005). Within the asset management process, three stakeholder roles can be distinguished: the asset owner, the asset manager and the service provider (Van der Velde et al., 2013).

The *Asset owner* makes strategic choices within a broader societal perspective between long and short term, what, when and where to invest. For example, in the Netherlands, the Ministry of Infrastructure and the Environment (IenM), is asset owner of the infrastructure networks. IenM then must choose strategically between the long and short term options for networks, within a broader context of transportation infrastructure (rail or road), education, health care...

The *Asset manager* makes a link between the asset owner and the service provider. In the Netherlands, Rijkswaterstaat (the central governmental body in charge with the infrastructure networks) is the asset manager of infrastructural assets.

The role of *Service provider* in the Netherlands is fulfilled by private companies or local governmental bodies, such as municipalities using Obsurv. Their activities include operational maintenance actions (such as the replacement of components), and improving asset performance in terms of availability and reliability.

Different roles and main activities in AM processes are described in figure 9.

Asset owner	Asset manager	Service provider
Responsibilities and tasks Overall network policy Targets for performance and condition on a network level Target for acceptable risk profile	Investment strategies Maintenance concepts Technological standards Risk management Network management	Project delivery Maintenance, execution and services Asset data management Project management

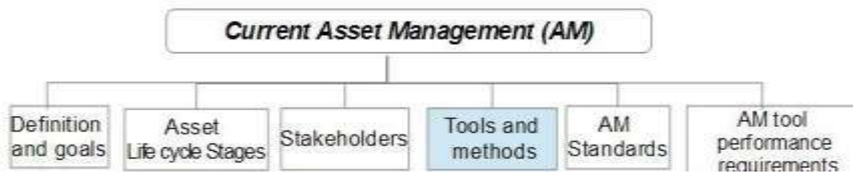
Figure 9 AM roles (Van der Velde et al., 2013)

The high diversity of stakeholders (or agents) involved in AM processes, with different and usually conflicting objectives and available resources can greatly influence the success of AM and the performance quality of assets (Osman, 2012). As such, possible interactions and negotiations between different stakeholder are studied and modeled in the *Agent-based Modeling (ABM) (*Ligtenberg et al., 2004) concept, and should be taken into account in any AM processes. Asset operators, for example, focus more on achieving system - specific objectives, while users may be more concerned with the overall performance of assets. ABM is about aligning the objectives of different agents, such as users, operators, managers, politicians, by repeatedly simulating their dynamic interactions (Osman, 2012).

The *roles taken by Obsurv users* (municipalities, provinces and Water Boards) vary depending on the size of the organization and the amount and size of assets to manage.

These roles can be: *asset manager* (usually also a policy maker) is in charge with the maintenance and budgeting plan, deciding when an asset should be maintained. The asset manager is often supported by a technical application manager with more detailed knowledge in a specific discipline. The actual inspection of an asset and its maintenance work is then carried out by the *asset operator* (or in bigger organizations, external parties are hired to carry out these tasks).

2.1.4 AM tools and methods



One of the main tasks for Asset managers - keeping track of the condition of their assets – proves often challenging due to the incomplete asset information necessary (CERF, 1996). Necessary information in AM processes can include physical (e.g. location and condition);

financial (e.g. service potential, risks and liabilities); and performance (both service and asset performance) data (Too, 2010). A few examples are: customer requirements, functional and design specifications, service descriptions, quality assurance, maintenance information, technical publications, budgeting and user manuals (Stark, 2005).

Information systems that support these types of data in AM can be CAD (Computer Aided Design), CASE (Computer-Aided Software Engineering), CAE (Computer Aided Engineering), data exchange and translation systems and others (Stark, 2005).

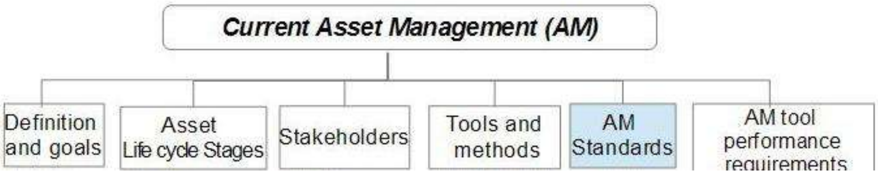
Information systems are an integral part of organizational evolution and have an active role in its maturity: depending on an organization's understanding of technology, and the socio-technical context within which these systems are employed they can facilitate asset lifecycle management by supporting and enhancing asset design, operation, maintenance, and recycling (Haider, 2013).

Effective AM information systems offer an integrated view of asset management information, helping asset managers to form a coherent picture of an asset's value and performance (LGV, 2004; Haider, 2013). It provides possibilities for collection, storage, and analysis of information over the whole life cycle of an asset, providing thus decision support capabilities (Haider, 2013). This can be achieved through IT systems (Bajaj and Bradley 2005; Serafeimidis and Smithson 2003; Haider, 2013). Some examples of such systems are Relatics and Obsurv.

Relatics is an easy to use software package for Systems Engineering, based on semantic technology, that enables users to store and integrate all kinds of project objects and documents. The flexible architecture of Relatics allows for integration with other software systems (www.relatics.com/product/).

Obsurv is an AM tool that makes use of a base map to show the geographical location of assets, and of an Oracle database, to store asset administrative information.

2.1.5 AM standards



Contemporary AM systems store information in a proprietary format, which makes information exchange difficult (Haider and Koronios 2003). There are, however, design/engineering tools which support *integrated product models*, improving the consistency of project information, and facilitate the exchange of project information between different software applications through a shared representational schema. The most notable of such initiatives are the Industry Foundation Classes (**IFC**), and CIMSteel CIS/2 for steel construction projects (Gursel et al., 2009.

Due to the semantic heterogeneity caused by the high number of human agents involved in AM information sharing processes, the industry diversity and of the used AM tools and technologies reflect the need for an integrated and mutual understanding of AM contexts, through standards and norms (Gursel et al., 2009).

Today's standards, particularly in the area of CAD, have led to improvements in productivity, especially in the manufacturing arena, by allowing for increased interactions between supplier and customer and by reducing transaction costs (Rachuri et al., 2008). Assets are required to be compliant with quality standards, providing a full product support and managing suppliers' and customers' relationships. This approach requires an integrated management of all asset information through standardization. *One* shared data model, capable of collecting assets' information along its lifecycle, is still missing. There are, however, multiple standards, norms and specifications aimed at increasing data interoperability (Taisch et al., 2011) through agreement across a large number of users (Rachuri et al., 2008), and decision making based on the same criteria (Humprey, 2003).

Several typologies of standards relevant to AM have been proposed by Rachuri et al., (2008) and Taisch et al., (2011), according to the stages of the product life, the scope, origin and intent of the standards. A few standards are presented here, based on their use in any of the three main stages of an asset's lifecycle (**BOL** - beginning of life, including product design and development, **MOL** - middle of life, including asset operation and maintenance, and **EOL** - end of life, including asset disintegration and recycling (See figure 10).

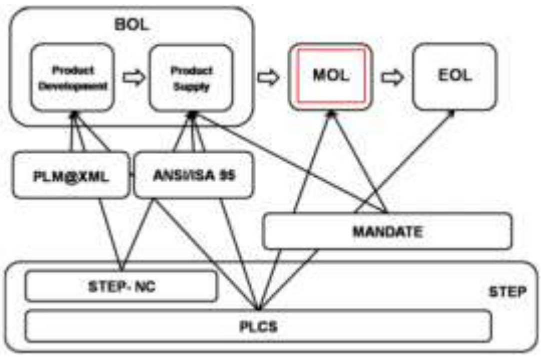


Figure 10 AM standards (Taisch et al., 2011)

Four standards (complementary to each other) are relevant to the entire life cycle of assets (Cassina et al. 2006; Taisch et al., 2011), namely: STEP (ISO 10303), MANDATE (ISO 15531), PLM@XML and ANSI/ISA-95 (or the new ISO/IEC62264 standard which is derived from it). However, only STEP is pertinent to this research project, as it is the basis on which other Building and AM standards are based.

STEP – ISO 10303 is an industry standard for asset representation, including description methods, implementation methods, conformance testing methodology and data specification (Taisch et al., 2011).

The STEP standard for 'Building Information Modeling' (**BIM**) that enables product-model data exchange is the 'Industry Foundation Classes' (IFC) (Lopez-Ortega et al., 2007). **(IFC)** is an open standardized data model for BIM. It contains definitions and shape representations for hundreds of objects, relationships of these objects between each other, and related properties to such objects. IFC is defined by specifications published by buildingSMART International (buildingSMART 2010). This standard will be described in more detail in the integration chapter, when the BIM standards are discussed.

Another widely accepted AM norm for the optimized management of physical assets is **PAS 55** (Van der Velde et al., 2013). PAS 55 aligns very well to a certified quality management system according to ISO 9001 - an initiative has been taken to translate the PAS 55 into an ISO standard (Van der Lei et al., 2011).

Obsurv uses different standards for different types of assets managed: CROW for the management of infrastructure and green areas, WION for the management of cables and pipes and others, shown in table 1.

Table 1 Standards and norms used in Obsurv

Object		Norm
Civil engineering		NEN 2767-4
Underground infrastructure	Cables en pipes	WION
	Sewerage	NEN 3399
Above ground infrastructure		CROW (Municipalities, provinces and waterboards, not RWS)
Green space		Not well defined – sometimes CROW
Traffic signs		CROW 188
Visual quality (not yet active)		CROW 288

The standard from Obsurv most relevant for this research is the **NEN2767-4,** for civil engineering. NEN 2767-4 (http://www.nen2767-4.nl) is a norm used in sectors such as civil technique, engineering and infrastructure, to assess the condition of infrastructural assets such as bridges, sewers and viaducts, in order to determine the required maintenance. This is realized by means of a measuring and recording method: a certified inspector registers the defects of each element, its components and the materials used. The damage intensity is measured based on a condition score card, ranging from 1 to 6 (where 1 is very good and 6 very poor). A condition score of 3 is accepted as operational.

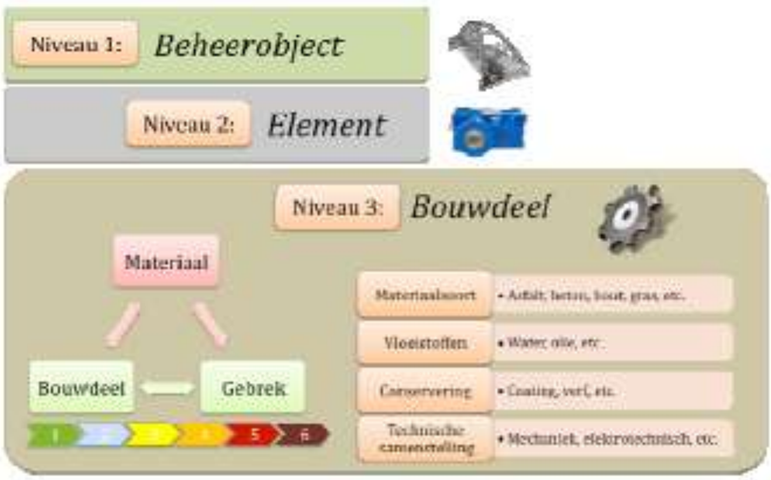


Figure 11 NEN 2767-4 levels

Assets are represented in Obsurv conform the NEN 2767-4 standard on 3 levels (See figure 11): object (e.g bridge), element (e.g. bridge deck), building component (e.g bridge deck general, protective layer). Furthermore, the material of each component is specified at decomposition, along with possible defects which will need repairs.

An example of asset decomposition is shown in the figure 12.

Bridge (fixed) → Bridge deck → Protective layer → Concrete (→ Erosion)

Figure 12 Example of bridge decomposition according to NEN 2767-4

The NEN2767-4 interface is given in figure 13.

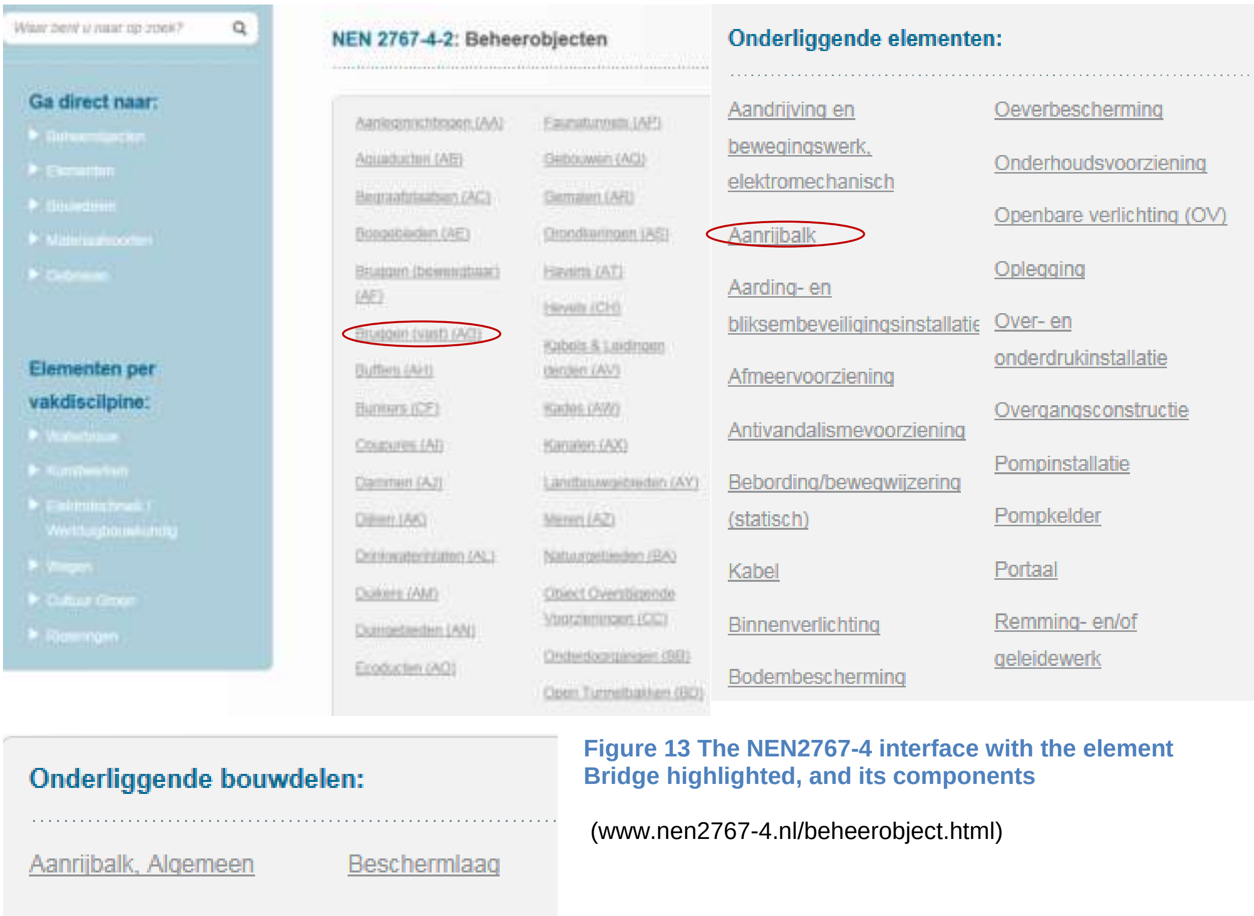


Figure 13 The NEN2767-4 interface with the element Bridge highlighted, and its components

(www.nen2767-4.nl/beheerobject.html)

Although many standardization efforts complement each other, in some cases current standardization efforts are inefficient: some of the standards are extensions of others or are built as an integration of others, while a number of the same functionalities are supported by more than one standard. This proliferation of standards, along with subjective interpretations of shared standards, can lead to misunderstandings and confusion for users, requiring thus increased standards harmonization, which can be realized by mapping the underlying semantics (ontologies) of different standards (Rachuri et al., 2008).

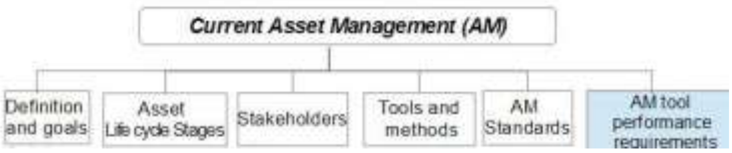
Semantics and ontologies

Ontology is a description, an explicit specification of concepts and relationships between different objects (http://www-ksl.stanford.edu/kst/what-is-an-ontology.html). Ontologies are used to group entities based on their similarities and differences, helping in the development of agreements to use a vocabulary in a consistent (but not always complete) way for knowledge sharing among different agents (Gruber, 1993, 1995).

Semantically rich information modeling language standards, such as the Knowledge Interchange Format (KIF), Web Ontology Language (OWL) and the Resource Description Framework (RDF), support semantic interoperability by information representation in a specific domain (Rachuri et al., 2008). The W3C Web Ontology Language (OWL) is a Semantic Web language designed to represent rich and complex knowledge about things, the way they are grouped and their interrelations. OWL is a computational logic-based language, part of the W3C's Semantic Web. RDF is a standard model for data interchange on the Web by facilitating data merging across different applications, even when underlying schemas differ (www.w3.org/RDF/).

The need for increased standards harmonization through semantic mapping of different standards is addressed (in the Netherlands) through the CB-NL - a Dutch national library of construction and environmental concepts. It includes semantic mappings between multiple standards used in different domains, such as IFC, CityGML, IMGeo, NEN2767-4, and other relevant standards for AM over its whole life cycle. The CB-NL concept / standard will be discussed in more detail in the integration chapter (2.4.5).

2.1.6 AM performance assessment



Performance evaluation is a necessary process for the growth of an organization, and is based on quantitative or qualitative measurement variables, or indicators (Haider, 2013).

Asset management performance assessment refers to the identification and quantification of the expected performance objectives of assets, and the evaluation of a building's lifecycle performance quality. Such assessment activities usually cover multiple phases of an asset's life cycle, and multiple disciplines, resulting in large amounts of information that need efficient management (Gursel et al, 2009).

Asset management performance indicators originate from relevant system objectives and the impact of the assets on the system; they are organization specific, and are thus difficult to classify in one framework (Hall et al., 2004).

Based on the available scientific literature studies, the performance of asset management can be evaluated on multiple levels Too (2010): the performance of the AM *process,* the performance of the *assets* and the performance of the *tools* used.

The *performance* of the *AM process* can be evaluated differently by stakeholders in different domains, based on the organization type and stakeholder values (Haal et all., 2004). An example is the case of the Asset Management programme of the Rijkswaterstaat in the Netherlands (Van der Velde et al., 2013), aiming at: reliable and accurate asset data, stable long-term maintenance programmes, clear objectives and transparent requirements, transparent procurement procedures and life cycle costing.

Asset performance goals, according to Too (2010), are: cost efficiency, Extend service/asset Life, capacity matching, quality and durability, availability, reliability, compliance, market leadership. Some asset performance objectives, studied by Parida (2012), are: higher overall equipment effectiveness, level zero defects and zero accidents, reduction in maintenance days, emergency repair rate, maintenance cost/unit, system reliability, energy saving…

Asset and AM process performance are, however, less relevant for this study: the focus will be on the *performance of AM tools*, and more specifically, the performance of Obsurv – the AM tool used as test environment for this research.

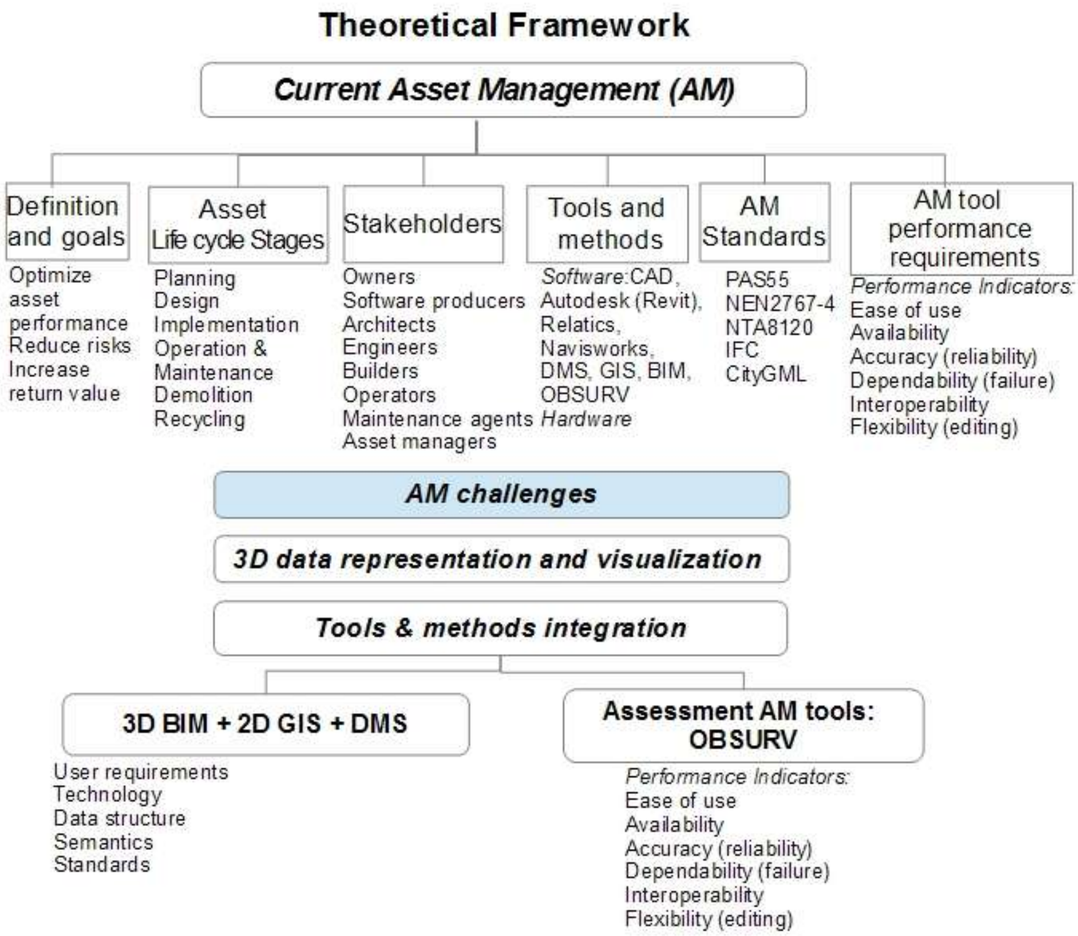
Brown et al. (1994) identifies six generic types of performance measures: customer satisfaction measures; financial measures; product/service quality measures; employee satisfaction measures; operational measures; and public responsibility measures. In this research, however, the AM performance will be focused on the product/service quality performance of the tools used for carrying out the AM processes (namely Obsurv), based on its technological capabilities and user requirements. A financial feasibility study should be realized as a follow up to this research, when the prototype model is fully functional.

Performance data can be gathered from different sources and by different methods, ranging from monitoring measurements, inspection records, design calculations, analogous cases, accounts of past failures, model predictions of future behavior. The measured value of a Performance Indicator may be a numerical value, but could also be a linguistic statement (e.g. ‘‘poor’’ or ‘‘very good’’) (Gursel et al, 2009). In the case of Obsurv, the NEN 2767-4 performance evaluation is measured based on a condition score card, ranging from 1 to 6 (where 1 is very good and 6 very poor). A condition score of 3 is accepted as operational.

The performance indicators for Obsurv are derived from literature study (Gursel at al., 2009) and interviews with the software (Obsurv) users and providers (Grontmij). These indicators are:

- ease of use (self-explanatory user interface, usability on a tablet)
- availability (also offline)
- interoperability with other systems (use of standards that enable data exchange; use of semantics/ontologies understandable by all users)
- flexibility to
  - visualize only parts of the model which are being inspected at a time.
  - update the administrative data about the asset and to register these changes directly in the 3D model.

2.2 AM challenges



The complexity of AM processes can originate from both internal organizational issues, and the failure to align the internal needs and capabilities to external influences. Such issues influencing an asset's management along its lifecycle can be: globalization, multi-cultural environments, mass customization of consumer products, collaborative product development and support, shareholder value, technological advances, evolution of Information Systems, and a shift towards open source software (Stark, 2005), new requirements for new customer service as well as increased needs for decision-support services (Kiritsis 2011; *Parida, A, 2012)*.

Considering the diversity and multitude of stakeholders, tools, methods and standards used in AM presented in the previous chapter, it becomes easier to understand the factors contributing to the complexity of AM processes. This diversity of tools and methods used in AM can refer to any of the following: multiple (types of) processes, systems and formats, multiple definitions and terminology, missing information, conflicting changes with insufficient change tracking, deficient communication of change to all stakeholders (*Wasmer et al., 2011),* organizations value systems and the characteristics of assets (Too, 2011; Van der Lei et al., 2011*)*. Using separate and disconnected tools results in "*information fragmentation and redundancy"*, posing problems for well-informed decision making *(Gursel et al., 2009).*

Furthermore, AM processes are highly regulated, fragmented, data intensive, with increasing data sharing, often lacking effective data integration across the supply chain (Dainty et al.

2006; Zavadskas et al. 2010; HM Government 2011; Regzui et al., 2013). This integration and interoperability of systems is, however, hindered by information systems which are often isolated pools of data and technologies (Haider, 2013). This type of inadequate information management contributes to *ineffective documentation and communication* between project stakeholders, information loss, and reduction of productivity, asset performance, delays and high costs in AM processes (*Gursel et al., 2009;* Regzui et al., 2013).

Also the broad array of standards available for different phases of AM life cycle and the underlying semantics which can be interpreted differently by different parties (*Wasmer et al., 2011)*., are often fragmented and incomplete in coverage, leading to reduced interoperability, becoming thus the "*Achilles heel of integration"* in AM (Rachuri et al., 2008).

This diversity in tools, methods, standards and even semantics used by different stakeholders in different areas and phases of AM, clarifies the need to adopt a holistic and integrated approach to AM, for improved information transfer from one system to another and increased interoperability between various software systems (Lee et al., 2012).

As described above, AM processes are complex, policy driven and information intensive, prone to continuous change, requiring thus a *consistent standard of information* (Haider, 2013)**.** Information integration enables more cooperation between different stakeholders involved in AM processes, and provides a platform for quality analysis for lifecycle decision support. Such an *integrated view of asset lifecycle* requires mutual understanding of AM information and information systems (Humprey, 2003; Too, 2010; Haider, 2013).

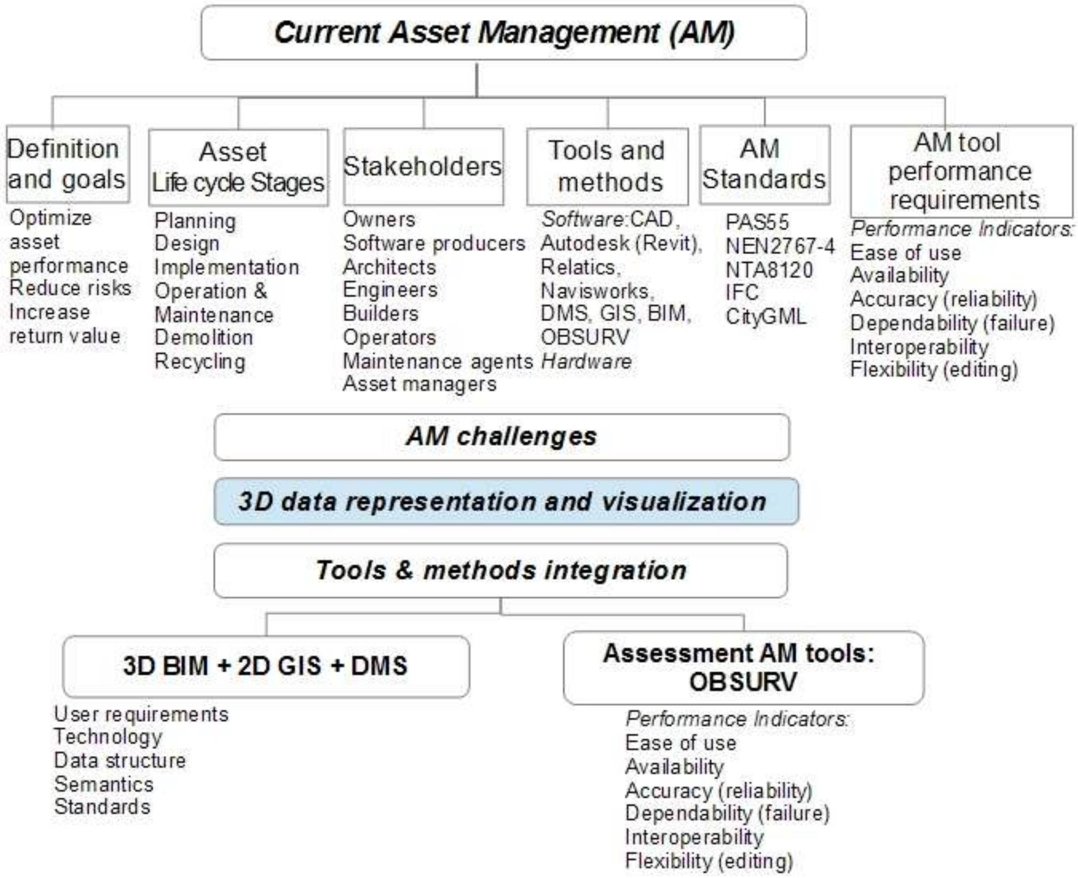
In order to help reduce some of the complexities of AM processes and create shared values and meanings of different AM concepts, two different possible solutions are described and tested in this research: the use of 3D models for data representation and visualization in AM processes, and the integration of (some of the) tools and methods used by different stakeholders.

The use of 3D models is gaining more ground in construction and development domains, thanks to their beneficial effects on working processes, such as improved design visualization which can, in turn, enhance shared understanding and interpretations of information, ease of learning, interoperability (Paar, 2006), and the ability to predict the performance of an asset and the reactions of stakeholders before it is built (Autodesk, 2007).

The integration of various working methods and data types (in the design and construction phases) can lead to cost effective asset life cycle management (Too, 2011), and complete the circle made by the information loops along the whole product life cycle (Kiritsis 2011). This will allow stakeholders access to a seamless flow of information about a product from its design and implementation phase, to operation, maintenance and decommissioning, and back to the designer and producer (Kiritsis 2011), avoiding thus the shifting of costs (and environmental issues) from one phase to the next (Kulahcioglu et al.,2012). The above-mentioned BIM concept offers the possibility of integrating all relevant information about an asset from its construction phase, bringing thus more clarity in the necessity of actions to be taken in the maintenance phase.

Each of these two solutions will now be discussed in more detail.

2.3 3D data visualization



Models with complex data structures that are difficult to comprehend should be accompanied by expressive visual representations to enhance the user understanding of the underlying structure and content *(Gursel et al., 2009).* Compared to 2D data representation, 3D data visualization is more effective in portraying spatial relationships, and can thus help improve task performance (Warren and Wertheim 1990; Rakkolainen and Vainio 2001; Erp et al., 2011). The value of 3D models was already acknowledged in industries such as construction, where a rapid shift from a 2D-based environment to 3D information modeling has been noticed (Lee et al., 2012). Also in the geo-information domain there is a trend towards more 3D geo-visualization, which is "*the process of creating and viewing graphical images of data, spatial contexts and problems, as to increase human understanding of complex spatial dynamic events and interactions"* (Arpinar et al., 2006).

3D information, models as well as the necessary 3D technologies (such as 3D CAD and virtual reality systems) are becoming more and more available. They are being used in many disciplines for explanative and evaluative purposes, as well as to analyze space conflicts and enhance communication and collaboration among involved stakeholders (Wu et al., 2012).

Some of the benefits of using 3D information models are: their capabilities to include multi-layered information for different types of stakeholders involved in the life cycle of assets /constructions, such as designers, contractors, owners, asset managers; furthermore, 3d information models can be used as basis for prefabrication of specific construction assets; moreover, object-based 3D models are useful for collaboration and communication among stakeholders, as well as for storing asset information for the whole life cycle (Lee et al., 2012).

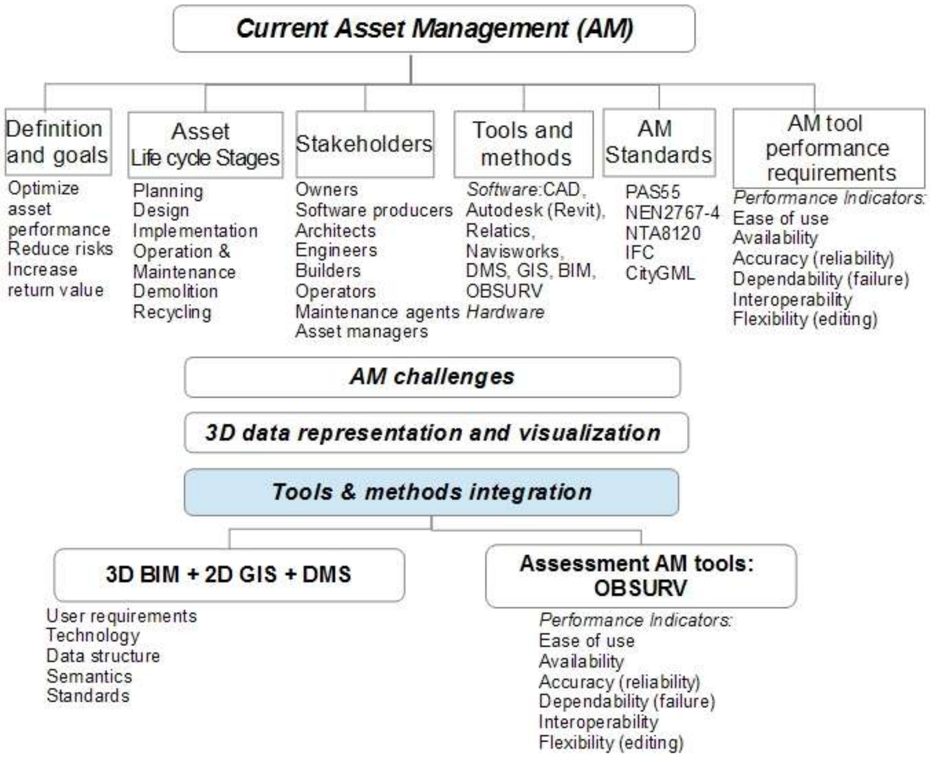
In order to further develop the use of 3D geo-information in the Netherlands, a 3D Pilot project was started in 2010 by Geonovum, Kadaster, the Dutch Geodezy Comission (Nederlandse Commissie voor Geodesie - NCG) and the Ministery of Infrastructure and Environment (IenM), aimed at investigating the issues pertaining to mapping the country in 3D. This was to be accomplished by attempting to create a national 3D standard by working together (with 80 people from 60 academic, private and public organizations involved in the project), and testing it in different areas. The results of the pilot project led to national awareness and insights for a country-wide 3D information system, according to current (inter)national standards. These results are made available in five final reports, accounting for all the achievements and their methods at www.geonovum.nl/onderwerpen/3d-geo-informatie/historie-3d-geo-informatie-nl.

How can 3D data models help facilitate complex AM processes and increase their efficiency? They enable storing and visualizing all asset information and business data (portfolio data, measurements, systems output, attributes) in a single interactive 3D model, making thus the information sharing between parties involved in different phases of asset life cycle more fluent. Furthermore, the visualizing of asset data in 3D format allows for easier understanding across an organization, helps to correctly identify components for maintenance services, helps reduce errors and enhances knowledge transfer by making expert knowledge available in the 3D model (Lee et al., 2012; Wu et al., 2012). Also, by storing the relevant information for assets in databases connected to the 3D model, searches and queries can be conducted on this data, helping thus improve the overall effectiveness of asset maintenance processes, and speed up and improve decision making processes involving multiple stakeholders (Fischer et al., 2003).

Besides its benefits for AM, 3D data implementation within organizations is facing also some bottlenecks. A drawback of 3D asset visualization is that many existing assets are not available in 3D, and the costs of making these 3D models (or laser scanning) all these assets prove too high for some organizations. It is, however, indicated that all new assets, which most of the time are being designed in 3D anyway, be made into BIM models, for easier management in Obsurv. Along with the costs for 3D BIM models implementation in Obsurv, also the attitude of some users may sometimes work against the implementation of 3D visual aids in AM processes: some are already used to the current AM processes, and are not open to learning new ways of working, new software packages, or feel that the type of assets they manage does not require 3D visualization (assets such as infrastructure or waterways).

The next chapter presents data and tools integration as a solution to the complexity of AM processes.

2.4 Systems and data integration



High amounts of (often non-interoperable) data and information are used by different parties during an asset's life cycle processes; depending on the way it is used, managed, stored and shared with other parties, it can be elementary to the success of AM processes (Wu et al., 2012). In an attempt to increase efficiency in AM processes, efforts are made in multiple industries, such as Architecture, Engineering and Construction (AEC), and Asset Management (AM), for more interoperability of data used by different parties.

Data interoperability, which is the first step towards systems integration and collaboration, implies correct interpretation of data by all parties sharing it. Data interoperability is possible through modeling, realized through data and systems integration (Shen et al., 2010). These systems support collaborative information management, sharing and use throughout an asset lifecycle, helping thus integrate processes and information more effectively (Shen et al., 2010).

An integrated information system should have a harmonized (commonly agreed upon), object oriented reference model that enables the interoperable exchange and use of assets information, and contains semantic definitions of objects and their components (Haider, 2011).

A few systems integration approaches are: Web services, a Semantic Web and Building Information Models (BIM). A *Web service* is "a software system designed to support interoperable machine-to-machine interaction over a network" (www.w3.org); a *Semantic Web* is "an extension of the Web expressing content in both natural and computer languages (Shen et al., 2010). The *Building Information Model (BIM)* is a data management system for generating, storing, managing and sharing building information in an interoperable and reusable way (Vanlande et al., 2008), including information about a its construction, management, operations and maintenance (Wu et al., 2012). Even though BIMs were initially modeled for the construction industry, they can be equally useful for asset management. The next sections describe the value of BIM for AM.

2.4.1 BIM (Building Information Modeling)

Definition

BIM – Building Information Modeling (or Management), also referred to as n-D Modeling or Virtual Prototyping Technology, is the process of generating and managing "data-rich, object oriented, intelligent and parametric digital databases of built facilities during their life cycle, used for visualization, facilities management, cost estimating, construction sequencing and spatial relationships collision detection" (Lee et al., 2005; Alexiadi and Potsioy, 2012).

BIM is a set of tasks related to "procuring, generating, using, supporting and maintaining BIM - specific deliverables (as products and/or services), such as 3D models, documents and data required for designing, constructing and operating an asset or a facility throughout its lifecycle" (Succar et al., 2013).

Two commonly accepted definitions of BIM define it as a *technology* and/or as a *process*.

BIM as *technology* or data is a 3D model simulation of a facility/asset and its components, often with links to relevant documents and information about project planning, design, construction, operation and facility management (Azhar et al., 2012). The data, generated by many stakeholders using diverse tools, can be exchanged among them at different phases in the life cycle of construction assets, benefiting thus those sharing it (Vectorworks Architect, 2012).

BIM is the *process* of modeling for the design, construction, use, and management of buildings by well-integrated and cooperating project teams of designers, builders, owners and other stakeholders involved in the life cycle of buildings or facilities (Azhar et al., 2012). Besides team members' expertise (also in the form of 3D models), such processes must be based on effective communication, trust, transparency, information sharing, shared risk and reward, and the use of interoperable technological systems.

BIM as a process facilitates integration (Vanlande et al., 2008), resulting in "better, faster, cheaper" construction processes, by reducing errors and cost over the whole life cycle of buildings or facilities (Vectorworks Architect, 2012).

Scope

Through its digital representation of objects/ assets' physical and functional parameters as well as the building processes, BIM can be used as a shared knowledge resource for asset information (Lee et al. 2005; Vanlande et al., 2008; Azhar et al., 2012). Furthermore, BIM is a platform supporting enhanced interdisciplinary collaboration, helping manage change throughout a building's lifecycle (Sabol, 2008).

BIM characteristics

Some of the main BIM characteristics and features are (Vanlande et al., 2008): the ability to store, share and exchange data; the 3D building geometries are helpful for communicating designs and visualizing complex construction. Furthermore, BIMs are data rich, containing all physical and functional features of an asset over its whole life cycle. Moreover, BIMs are semantically rich, storing high amounts of semantic information on assets and their components based on different standards, such as IFC for construction industry.

BIM software

BIM software is divided here in two types of software, based on their use for BIM as technology, or BIS as a process, or a data management system (DMS).

Software for BIM as technology

BIM technology providers are Autodesk, Bentley Systems, Graphisoft and others. Some BIM software packages are listed below, grouped per provider (Casey and Vankadara, 2010; Flohr, 2011; Vectorworks Architect, 2012). They include:

Autodesk (www.autodesk.com): Revit, Navisworks, used for Architectural design, integrated clash detection, design review and interdisciplinary coordination.

Autodesk FMDesktop offers support for facilities management (FM) - FM:Systems – a system that integrates building information modelling (BIM) and FM (also applicable to AM) solutions (Autodesk, 2007).

Bentley (www.bentley.com): Bentley Architecture, MEP, MicroStation, LEAP, RAM, STAAD, GEOPAK. Specialized engineering applications based on MicroStation and BIM platform, used for building and functional system design, site design and transportation.

GraphiSoft: ArchiCAD 12 – used for object-database technology, and integrated, component - based building design.

Tekla: Tekla Structures, for structural design and detailing, and Tekla BIMsight used for model viewing and clash detections.

Other BIM software packages are Solibri Model Checker, which is a model viewer, and Nemetschek Scia Engineer, used for structural design.

The test data for this research is a 3D Tekla model, exported to IFC format and processed further in Revit Structure and Navisworks, as preparation for integration in Obsurv, the complete procedure of this integration is described in chapter 3 – the Case Study.

Software for BIM as DMS

Data management systems (or data hubs) are systems / software platforms for gathering, using and sharing electronic data (OKFN, 2011). Different stakeholder organizations may choose to use different DMS's for managing their project documents, such as SharePoint, eFileCabinet's Suite of Products, eXo Platform, FileNet, Docuware and others (OKFN, 2011). These are, however, not studied in this research, due to the fact that they are not momentarily relevant for Obsurv, the AM software used as test platform for this research.

An example of a DMS often used in BIM processes is Relatics (www.relatics.com/) – a flexible platform used for construction and asset management projects, to keep an overview of project or asset information, models, documents and user requirements - which are then translated into system requirements for a specific project (See figure 14). Within Relatics, data can be shared with other parties involved in a project, making thus the information transfer between an asset's life cycle stages and between parties smoother and more effective (Autodesk, 2011).

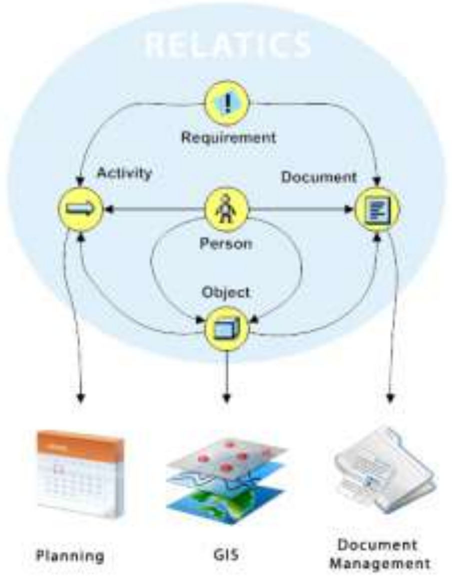


Figure 14 Relatics (*www.track3d.nl/)*

BIM Standards

ICF

One of the standards commonly used for BIM is **IFC** (Industry Foundation Classes) – an international open standard for the construction industry. IFC is an open, ***neutral and software independent*** data exchange format published by buildingSMART International (http://wiki.ibim.nl/wiki/buildingsmart/), used in the construction industry to transfer data between various software applications (www.mittaviiva.fi/hannu/BIM_project/index_bim_basics_en.html).

Figure 15 shows how IFC takes the role of a file exchange format container, to which two different applications can read and write their own data, so that it can be read by the other application. It is used for defining building or asset components, geometry and other physical properties in a specific way, allowing for data transfer between different software applications (Lopez-Ortega et al., 2007; Regzui et al., 2013). It includes data such as textual data, images, structured documents, numerical models and designer/project, manager annotations *(*Cerovsek, T., 2011; Regzui et al., 2013*)*. The IFC specification is developed and maintained by BuildingSmart and has been included in several ISO standards (Regzui et al., 2013; www.ifcwiki.org/index.php/Main_Page).

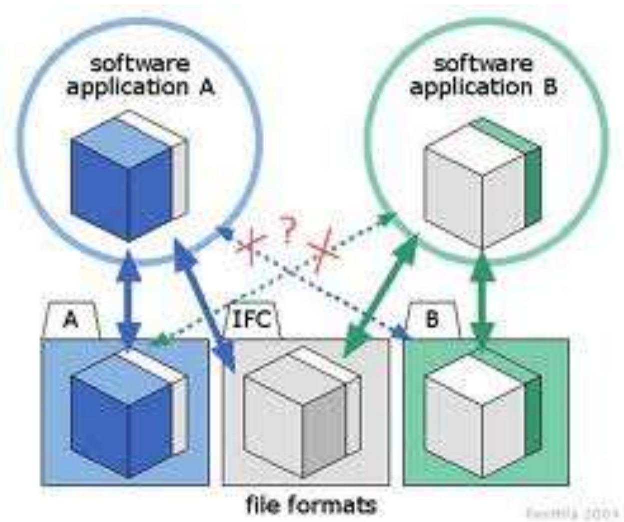


Figure 15 IFC working method (www.mittaviiva.fi/hannu/BIM_project/index_bim_basics_en.html)

Ifc building components are recognized by Software applications through its **IfcWindow** tag (see figure 16).

EXPRESS specification:

```
ENTITY IfcPlate
   SUBTYPE OF (IfcBuildingElement);
END_ENTITY;
```

Inheritance graph

```
ENTITY IfcPlate;
   ENTITY IfcRoot;
      GlobalId                     : IfcGloballyUniqueId;
      OwnerHistory                 : IfcOwnerHistory;
      Name                         : OPTIONAL IfcLabel;
      Description                  : OPTIONAL IfcText;
   ENTITY IfcObjectDefinition;
   INVERSE
      HasAssignments               : SET OF IfcRelAssigns FOR RelatedObjects;
      IsDecomposedBy               : SET OF IfcRelDecomposes FOR RelatingObject;
      Decomposes                   : SET [0:1] OF IfcRelDecomposes FOR RelatedObjects;
      HasAssociations              : SET OF IfcRelAssociates FOR RelatedObjects;
   ENTITY IfcObject;
      ObjectType                   : OPTIONAL IfcLabel;
   INVERSE
      IsDefinedBy                  : SET OF IfcRelDefines FOR RelatedObjects;
   ENTITY IfcProduct;
      ObjectPlacement              : OPTIONAL IfcObjectPlacement;
      Representation               : OPTIONAL IfcProductRepresentation;
   INVERSE
      ReferencedBy                 : SET OF IfcRelAssignsToProduct FOR RelatingProduct;
   ENTITY IfcElement;
      Tag                          : OPTIONAL IfcIdentifier;
   INVERSE
      HasStructuralMember          : SET OF IfcRelConnectsStructuralElement FOR RelatingElement;
      FillsVoids                   : SET [0:1] OF IfcRelFillsElement FOR RelatedBuildingElement;
      ConnectedTo                  : SET OF IfcRelConnectsElements FOR RelatingElement;
      HasCoverings                 : SET OF IfcRelCoversBldgElements FOR RelatingBuildingElement;
      HasProjections               : SET OF IfcRelProjectsElement FOR RelatingElement;
      ReferencedInStructures       : SET OF IfcRelReferencedInSpatialStructure FOR RelatedElements;
      HasPorts                     : SET OF IfcRelConnectsPortToElement FOR RelatedElement;
      HasOpenings                  : SET OF IfcRelVoidsElement FOR RelatingBuildingElement;
      IsConnectionRealization      : SET OF IfcRelConnectsWithRealizingElements FOR RealizingElements;
      ProvidesBoundaries           : SET OF IfcRelSpaceBoundary FOR RelatedBuildingElement;
      ConnectedFrom                : SET OF IfcRelConnectsElements FOR RelatedElement;
      ContainedInStructure         : SET [0:1] OF IfcRelContainedInSpatialStructure FOR RelatedElements;
   ENTITY IfcBuildingElement;
   ENTITY IfcPlate;
END_ENTITY;
```

Figure 16 Decomposition an IfcPlate

(www.buildingsmart-tech.org/ifc/IFC2x4/alpha/html/ifcsharedbldgelements/lexical/ifcplate.htm)

Figure 17 shows the decomposition of IFC elements (in this case an Ifc Plate).

IfcRoot → IfcObjectDefinition → IfcObject → IfcProduct → IfcElement → IfcBuildingElement →IfcPlate

Figure 17 Object decomposition in IFC (here for an IfcPlate)

COINS

Another BIM standard, complementary to IFC, is **COINS** Building Information System (**CBIS**). The COINS system is a coherent system of agreements on the recording, transfer and management of building information.

The COINS Container is a free of charge standard (or data exchange format) used in the construction industry, aligned with information management principles, that allows for the transfer of intelligent building information without any loss of data. It is compatible with other standards such as IFC, VISI, Object libraries, SE and others. (www.coinsweb.nl/wiki/index.php/Information_transfer).

COINS provides a BIM-container interchange format that supports the exchange of Systems Engineering information, allowing for multiple types of data (such as GIS data, 2D drawings, 3D models, IFC models and object type library) to be stored in a database, and to be read by other applications (see figure 18) (www.coinsweb.nl/wiki/index.php/COINS_Building_Information_System).

Figure 18 COINS container (www.coinsweb.nl/wiki/index.php/Information_transfer)

In order to be compatible with the COINS Container format, applications need an interface with reading and/or writing capabilities to a COINS Container, which is already the case with many existing software packages (e.g. Revit, Ticon, Allplan, Smarteam FS, MSProject). The serialization of a CBIM into a physical file takes then the form of RDF/XML. The guidelines for developing an interface are available in the COINS Reference Manual (www.coinsweb.nl/wiki/index.php/Reference_Manual).
(www.coinsweb.nl/wiki/index.php/Information_transfer)

Revit Standard Family classes

Besides the more general construction standards, there are also standards specific to software packages, such as the *Revit Standard Family classes***.** De Revit Standards consist of a complete documentation of established agreements, project template (Object Styles, Text and Dimensions, Material Library, View Templates, View Filters, System Families and Schedules), a basic library (www.nationalbimlibrary.com/Object-Types) and the *IFC Compatible*, for interoperability with systems like ArchiCAD and Tekla (www.hetnationaalbimplatform.nl/actueel/nieuws/lancering-dutch-revit-standards-door-revit-gg/).

Barriers to BIM

Even though widely recognized as a beneficial and necessary data management system within organizations, there are a few issues impeding the implementation of BIM in organizations, grouped here in three categories: organizational, legal and technical (Regzui et al., 2013).

Organizational issues include motives such as: individual BIM competencies, the hesitance to learn using new software and the additional costs involved with adopting a BIM approach (Akin, 2010); the segregated way of working of stakeholders involved in different phases of construction or asset life cycle; limited investment in ICT due to insufficient funds; traditional procurement paths with little collaboration between involved parties.

Legal issues can include some of the following motives: lack of clarity on BIM stakeholders' ownership, roles and responsibilities, or liability; also, IFC data or servers carry no legal obligations.

Technical issues: reduced or lack of compatibility between software products based on IFC (such as data or semantics loss during IFC import and export); fragmentation of BIM data transfer across design, engineering teams and other stakeholders; different data management systems in (sub)organizations; privacy of data and security constraints when stored on BIM servers, as these are managed by a single company (Alexiadi and Potsioy, 2012; (Regzui et al., 2013).

BIM in AM

AM processes are often characterized by segregation between the design / construction phases and the operation / maintenance phases of an asset, resulting in costly inefficient information management throughout the life cycle of assets (Vanlande et al., 2008). It is believed that 85% of the lifecycle costs of a facility occur after the construction phase, as a result of inadequate information management and interoperability issues during operations and maintenance phases (Newton, 2004). These loses could be significantly reduced by using BIM for facility or Asset Management (Azhar et al., 2012). BIM may allow asset managers to participate in an earlier stages of design and construction of assets, and it can enhance the AM processes through its information content about the asset, such as warranty data, administrative characteristics, life expectancy, maintenance recommendations and renovation documentation (Autodesk, 2007; Alexiadi and Potsioy, 2012).

Some of the benefits of using BIMs are the accuracy of geometrical representation, lifecycle data availability (design, construction and operational information) for life cycle costs and facilities management, easier to predict performance thanks to its capabilities to identify clashes by visualizing a building or asset in a simulated environment, information sharing, better coordination among design and engineering work, clearer performance targets and strategies, and increased speed of project / asset delivery (Alexiadi and Potsioy, 2012).

The main advantage of a BIM model for AM is that the information provided about an asset, its components and surroundings, can be transferred into asset operation and maintenance processes. If in the past asset managers were handed over piles of owner's manuals, with the use of BIM, information about asset type, material, dimensions, operation and maintenance manuals, commissioning information, replacement costs and performance data, is available in a single electronic file, accessed by clicking on an asset in the BIM model (Azhar et al., 2012). Or as Reddy (2011) says: with the BIM database, any information is "*just one click away".*

By using BIM models in the design and implementation phases of assets, and transferring the information to the next phases of the life cycle, the total costs of Asset management in its maintenance and operation phases can be greatly reduced (Autodesk, 2007).

2.4.2 GIS (Geo-Information Systems)

Definition

GIS (Geo Information System) is any system that *captures, stores, analyzes, manages, and presents data linked to at least one geographical location* (Chang, 2006). The U.S. Geological Survey (USGS) defines GIS as “a computer system capable of assembling, storing, manipulating, and displaying geographically referenced information or geospatial data”. (http://webgis.wr.usgs.gov/globalgis/tutorials/what_is_gis.htm).

Scope

GIS can function as a decision support system, assist in the solving of real-world problems in various fields such as urban planning, geology, hydrology, surveying and mapping, land and resource management, market analysis and others. Besides data storing and visualization, GIS also offers possibilities for queries on databases and statistical analysis (ESRI, 2008; Kasccaemsuppakorn et al., 2010).

Tools / software

GIS software packages are available in both commercial (e.g., ESRI’s ArcMap Desktop and Server versions, Intergraph, and Autodesk, Obsurv) and open source (e.g., GRASS, QGIS, MapWindow) products (Kasccaemsuppakorn et al., 2010). GIS data includes both geospatial (e.g the coordinates of a vector data or the geographical position of a raster cell) and non-geospatial data (e.g databases containing attributes of features). GIS is interoperable with other systems, being able to read and write to CAD, JPEG, TIFF, ASCHII, GML, KML, PDF and others (Kasccaemsuppakorn et al., 2010).

User requirements

Based on their business requirements, GIS users can be categorized in viewers, general users, and GIS specialists (Lo an Yeung, 2007). Viewers forming the largest class of users, use GIS mainly for visualizing geographic data, and querying it for presentation purposes. For general users, GIS provides analysis operations for supporting decision making (e.g for finding customer location or calculating optimal transport routes). GIS specialists, trained in GIS, provide technical supports to other users (Kasccaemsuppakorn et al., 2010)

If in their early days GIS applications were limited to domains such as land-use and natural resource management, nowadays, thanks to its capabilities to easier create, store and analyze geospatial data (through mapping, measurement, monitoring, modeling, and management), the use of GIS is extended to multiple domains (Kasccaemsuppakorn et al., 2010).

GIS standards

Some of the most used (publicly available) standards within GIS, developed with the aim of increasing availability of useful spatial information and services, interoperable with different types of applications (http://www.opengeospatial.org/ogc), are the WMS (Web Mapping Service), WFS (Web Feature Service), WCS (Web Coverage Service) and WTS (Web Terrain Service) standards. These Web standards are established by the OGC - Open Geospatial Consortium - of 478 companies, governmental and academic bodies, which develop in consensus open interface standards.

WMS is a standard format for publishing maps (a visual representation of spatial data, not the data itself) on the web. It can be downloaded as JPEG, PNG, etc. (www.geonovum.nl/wegwijzer/standaarden).

WFS is a standard format for publishing vector-data maps with capabilities for data queries, based on GML and CityGML data exchange formats. Unlike the WMS, a WFS allows access to features represented in the map and their characteristics, not only whole file-access (OGC, 2005).

INSPIRE

The INSPIRE Directive (INfrastructure for SPatial InfoRmation in Europe) is an European directive requiring the member states to provide geo-information specific to their countries, with metadata on 34 spatial data themes, and make them publicly available through a network of 'services' on the INSPIRE portal. INSPIRE ensures the quality and accessibility of the provided geo-information. (http://inspire.jrc.ec.europa.eu/index.cfm/pageid/47; www.eea.europa.eu/about-us/what/seis-initiatives/inspire-directive; www.geonovum.nl/onderwerpen/inspire/algemeen-inspire). The Dutch national INSPIRE network portal is available at www.nationaalgeoregister.nl.

NEN 3610

NEN 3610 is a general Dutch standard for interchange of geo-information, encompassing other sectoral standards (such as (IMRO for spatial planning, IMWA for water management, IMKICH for cultural history, GRIM for agriculture, environment, infrastructure, topography…). It defines concepts of common objects and attributes, described using UML (Unified Modelling Language) (Reuvers, 2004). The pyramid of conceptual geo-information schema (figure 19) shows a generic to specific standards hierarchy. The more abstract *generic level* is relevant for domains using spatial information. *Sector specific* domains are characteristic to sector requirements, while conforming to the general level standards. The sector specific standards are further tailored to suit *specific organizations*, while remaining interoperable with other sectors.

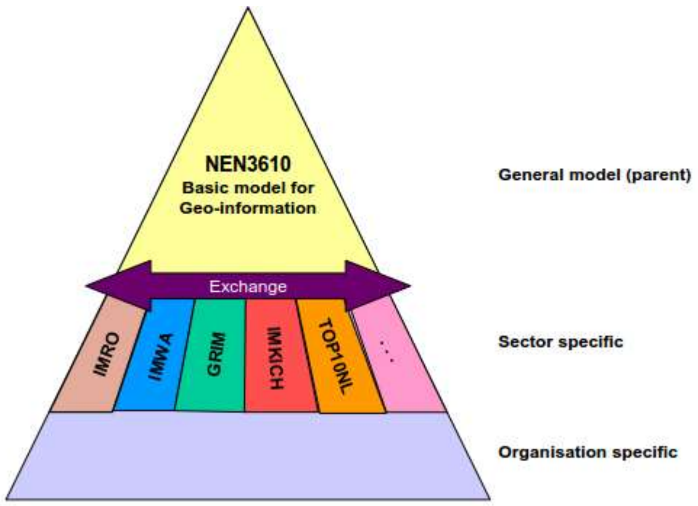


Figure 19 Pyramid of conceptual geo-information schema (Reuvers, 2004)

CROW

CROW is an organization active in the field of infrastructure, public space, transport and safety (www.crow.nl). Together with professionals from different fields CROW draws up recommendations and guidelines, for example for the design and dimensions of transportation infrastructure. These recommendations and guidelines are available online in CROW publications. Even though the CROW guidelines have no legal status, they are nation-wide accepted in the Netherlands, and used as norms (www.crow.nl).

GBKN

The GBKN (grootschalige basiskaart Nederland) (http://www.gbkn.nl/) is a digital large-scale (1:500 to 1:5,000 scale) topographical map of Nederland with a defined minimum content and accuracy, containing the main topography (buildings, roads, waterways), which serves as a substrate and is suitable for various applications. It is soon to be replaced by the BGT.

IMGeo

IMGeo (Informatie Model Geografie) is a Dutch geographic information model managed by Geonovum (commissioned by the Ministry of Infrastructure and the Environment). It consists of a mandatory part - the BGT (Basisregistratie Grootschalige Topografie - Basic Scale Topography) and an optional part - management and topography. The BGT is a digital base map, consisting of geometric objects and management assets (infrastructure, water, green) with their attributes, used by different (governmental) parties in many work processes (http://www.geonovum.nl/onderwerpen/bgt-imgeo-standaarden/algemeen-bgtimgeo).

IMGeo is matched with CROW norms for green management and with the Information Model for Rural Area. The interoperability with the construction industry is ensured through the Dutch standard CAD (NLCS) and the CB-NL.

GML

GML (Geography Markup Language) is an international exchange format managed by the Open Geospatial Consortium (OGC), corresponding to the basic geo-information model (NEN3610). GML defines XML-encoding for transfer and storage of all kinds of geo-information, such as geometry, topography, coverages and sensor data. GML is used in information models such as IMGeo, CityGML/3D and INSPIRE (www.geonovum.nl/onderwerpen/geography-markup-language-gml/geography-markup-language).

CityGML

CityGML is a data model for the representation of the most relevant topographic urban objects in 3D, including their geometrical, topological, semantic and appearance properties (www.citygml.org). CityGML provides a rich semantic framework for representing urban features and their relationships with each other, but is not suited for building AEC data (Rees, 2007).

GIS in AM

Over the years, GIS has undergone a transition process from analogue to digital maps and web services, becoming thus more widely used in diverse industries, such as spatial development, infrastructure, transport, crisis management and emergency response, Asset Management and others (Kasccaemsuppakorn et al., 2010). In this research project, GIS is used through the web service Obsurv, which is using WMSs and WFSs to register and manage the location of assets.

2.4.4 Integration

The term **interoperability** is defined slightly different in information technology: Kasccaemsuppakorn et al. (2010) define Interoperability as "*the ability to exchange heterogeneous information and procedures freely among heterogeneous systems or components*". A mixed definition of the Institute of Electrical and Electronic Engineers (IEEE, 1990) and the worldwide federation (ISO/IEC 2382–1) refer to interoperability as "*the ability of two or more systems or components to communicate, exchange information and allow users to use the exchanged information without requiring much technological knowledge of those systems".*

Considering the (system and data types) heterogeneity, interoperability plays a very important role in information management and systems integration (Sheth, 1999). Interoperable data is thus a prerequisite for integration.

Integration is defined by Alshawi and Ingirige (2003) as "collaboration and sharing the same interoperable project data/information". Through its capabilities to timely and accurately document and include changes in shared information systems, integration is believed to help reduce ambiguity or errors in construction and AM processes (Ajam et al., 2010).

Types of integration

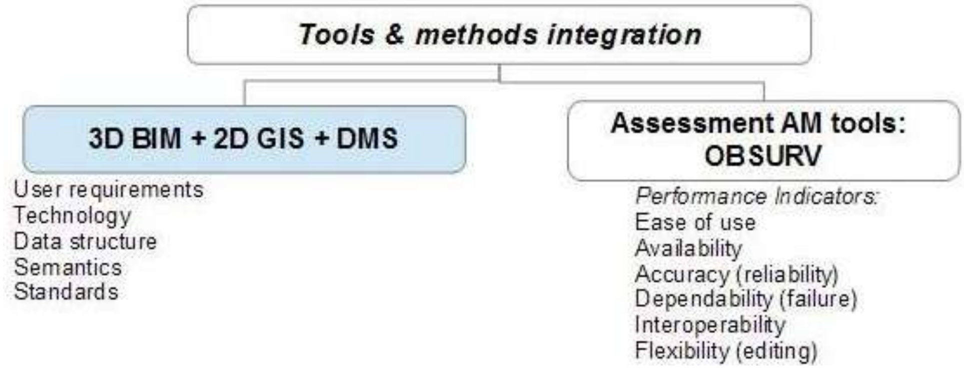
Based on previous research on integration (Li et al, 2006 ; Linthicum, 2003; Erl, 2004; Isikdag et al., 2007; Vanlande et al., 2008), integration can be realized at different levels (here only classified in two): system and data.

Systems (or application) level (also referred to as a service-oriented approach): integration through the joint use of web interfaces and message exchange (i.e. via SOAP/REST web services, an API or a Standard Data Access Interface). In this loosely-coupled integration approach, interoperability requires shared communication languages and protocols, while allowing different systems to use different data models and formats (Shen et al., 2010). There are two ways of system integration and data sharing via Web services: through access to the central project database (storing the BIM) or through access to the BIM file via an API (Vanlande et al., 2008).

Data level, requiring common data models or formats (Shen et al., 2010), involves data replication and federation through file exchange, database replication or the use of shared databases. This way, information from building models (from the construction industry) can be integrated in a geospatial environment (e.g from IFC to CityGML). This transformation is, however, not always error free, as geometric information may be lost in the process, depending on the representations methods used in CAD (BIM) (e.g Constructive Solid Geometry (CSG) and Sweeping) and GIS (boundary representation (BRep)).

Full integration of all asset/project information among all parties is difficult to achieve (Ajam et al., 2010), and the question is if such integration is necessary or desirable. For the purpose of this research project, both methods are tested, and will be explained in the next chapter.

2.4.5 BIM-GIS integration



In order to reach the goal of this research project, namely to investigate the possibilities of integrating BIM – GIS for facilitating AM processes, the common points and differences between the two systems are studied, and their integration is attempted on different technical levels.

In the previous sections of this research project the inefficiencies of AM processes were stressed, with as main issue the fragmented information and lack of data and systems integration along an asset's life cycle. The integration of GIS and BIM/CAD (Building Information Modeling, which are based on CAD) comes thus from a need to include building-specific information in a bigger spatial context provided by GIS (Rees, 2007). An integrated BIM - GIS model has the advantage of offering a clear overview of existing issues, involved parties, and interactions between them, and spatial influences on AM processes (Hermans, 2013), creating thus a controlled platform for more effective AM.

Since BIM is making broad use of CAD systems, the terms CAD/BIM is used interchangeably in this chapter. The main differences and common points between the two systems CAD (BIM) and GIS are now shortly presented.

BIM / CAD vs GIS

Cad and GIS are two quite distinct systems in their goals, scope, and tools and standards used. The main difference between GIS and CAD is that CAD is a graphics program, used to design objects with a high level of geometrical detail (that may not exist), whereas GIS is a system using databases to model large geographic extents of the real world, such as urban, regional and (inter)national scale. When used together, CAD and GIS can help improve the processes of the (construction) projects for which they are employed, by visualizing the designed objects in their environment, and help thus detect possible clashes with other existing elements in that location. Figure 20 schematically shows the scope and overlaps of the two systems.

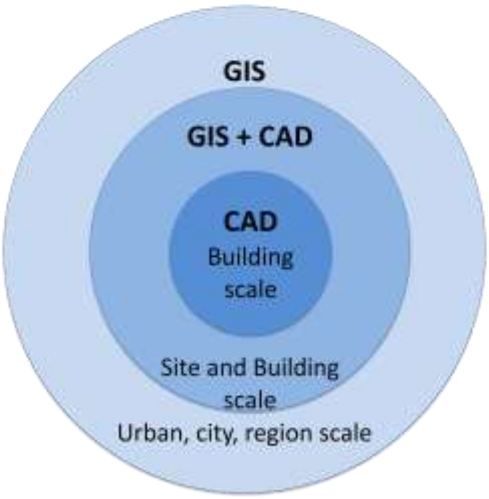


Figure 20 Schematic CAD and GIS scope (Akin, 2010)

Unlike GIS models, CAD models do not usually store topologic or geographical information; also, the semantic schemes used by the two systems are very different, hampering an automatic transformation from one model to the other (Akin, 2010). Some other differences between CAD and GIS software that form the basis for the CAD – GIS integration are listed in table 2.

Table 2 BIM/CAD – GIS differences

	BIM (CAD)	GIS
Goal	digital representation used for design, construction and management of assets	captures, stores, analyzes, manages and presents data linked to location.
Detail	physical and functional detail (composition); detailed geometry	Spatial context: geometric, topologic features (no geometrical detail)
Scope	represent non-existing objects	spatial object representation
Spatial analysis	no spatial analysis	spatial analysis
Users	single user	multiple users in one dataset (Enterprise Geodatabases)
Data types	single drawing files (2D or 3D)	maps combine multiple feature sets (streets, buildings, topography) together; many types of data (photos, videos, databases, sound clips)
Software	Autodesk Revit, Navisworks, Tekla, Relatics	ArcGIS Desktop, Server, web viewers and services (Obsurv)
Standards	IFC, STEP	OGC WMS, WFS, GML, CityGML

Considering the different types of data and tools used by GIS and CAD, the combination of the two systems requires new methodologies and models that integrate detailed objects with real-world phenomena (Kasccaemsuppakorn et al., 2010). For this purpose, a few aspects were taken into account in this research project, such as data structure, user requirements for the level of detail of the asset, the interoperability of software packages used and the standards used by both systems.

The BIM-GIS integration should be studied for different phases of the life-cycle process of facilities: *planning, design, implementation, operation and maintenance, and demolition*. The requirements for information and level of detail (LOD) of the BIM objects in GIS are also directly connected to the phase of the life-cycle process in which it is applied, and should thus be taken into consideration in the integration. Considering the limited time and the scope of this research project, the BIM-GIS integration will be studied only for the operation and maintenance phase of assets' life cycle.

Previous research on the integration of CAD/BIM with GIS has been focused on the geometrical transformation of CAD/BIM 3D models to CityGML, using the familyTrees provided by CityGML per LOD (Level Of Detail) of an object. Detailed accounts of multiple attempts at such transformation (many of which are also automated), some of which have resulted in the development of software extensions and semantic mapping specifications, are shortly described below.

Van Berlo (2009) developed an Application Domain Extensions (ADE) for integrating IFC (BIM) data into CityGML (GIS). Another extension called '**GeoBIM'** helps get semantic information IFC data into a GIS context, including its geometry and semantic properties

(Alexiadi and Potsioy, 2012). Additionally there are also commercial software products contributing to the IFC to CityGML conversion for 3D city modelling, such as *IfcExplorer* (http://www.ifcwiki.org/index.php/IfcExplorer_CityGML_Export) and *Safe Software* (http://www.safe.com/products/desktop/formats.php).

Technical and semantic aspects of CAD (IFC) – GIS (CityGML) transformation have been studied and automated (based on algorithms) by Nagel (2007). His work was complemented in 2009 by Isikdag and Zlatanova (2009), who proposed automatic generation of buildings in CityGML using BIM, based on definition of building semantics and components.

During the *IFC for GIS (IFG)* project initiated by The Norwegian State Planning Authority completed in 2007, a mapping specification was created for translating an XML version of IFG geometry to GML and vice versa (IFG, http://www.buildingsmart-tech.org/future-extensions/ifc_extension_projects/current/ic3).

Other examples of BIM – GIS integration through IFC – CityGML transformation are given by Kolbe (2005, 2008), Isikdag et al.(2007), Hijazi et al. (2009, 2011), El_Mekawy (2011) and others.

Even though the existing research on BIM – GIS integration offers a good overview of the geometrical and semantic issues around IFC – CityGML transformation, this is not sufficient for Obsurv: the user requirements for the BIM-GIS integration in Obsurv are not fulfilled by a simple IFC-CityGML transformation.

Besides the required LOD (from LOD 4 to LOD 2 or 1) transformation, which is dependent on the organization type and asset size, the Obsurv users would also like to see the asset attributes presented in the model in the same way they are in Obsurv, namely based on the NEN 2767-4 standard. This also raises the question whether CityGML is even necessary as an intermediary transformation step, considering the extra costs implied.

Consequently, two different methods of BIM-GIS integration are tested in this project: system and data integration. These are described in more detail in chapter 3.

Table 3 gives a quick overview of the proposed integration method for BIM and GIS for AM in Obsurv, taking into account the tools, standards and user requirements for both systems.

Table 3 BIM-GIS integration methods for Obsurv

	BIM	**Integration method**	**BIM + GIS in AM**
Tools	Revit, Tekla	FME →	Obsurv
Standards	IFC	CB-NL →	CityGML
User requirements (LOD)	LOD4	FME →	LOD2

Tools

Systems integration and collaboration in AEC/FM/AM has gained much interest for research organizations and software vendors, resulting in various development tools which allow for data exchange (Shen at al., 2010), only a few of which will be mentioned here, being more relevant to the current research. These tools function based on international standards (such as IFC), making thus the integration with other systems possible (Alexiadi and Potsioy, 2012). These tools are mostly provided by Autodesk (Revit, Navisworks, Autodesk Buzzsaw, Autodesk 360cloud) and Bentley (Tekla, Tekla BimSight), and are linked to Obsurv through different methods, which will be explained in the next chapter.

Standards

“Best way of integrating BIM with GIS is through harmonized semantics” (Hijazi et al., 2011). Data and systems integration in AM processes require exchange standards (Ajam et al., 2010). The main standard for BIM interoperability is **IFC** (Industry Foundation Classes) - a neutral data format used for defining asset properties in a specific way, for easier data transfer with other applications (Lopez-Ortega et al., 2007; Shen at al., 2010; Alexiadi and Potsioy, 2012; Regzui et al., 2013). A more detailed description of IFC is given in chapter 2.4.1 of this research.

CB-NL

The CB-NL (ConceptenBibliotheek voor Nederland) is a Dutch “*dictionary for construction*” (www.cb-nl.nl). It is a digital description of generic, reusable concepts (types), related to physical built objects, use the spaces, land, roads and water works, and Spatial Environment. The description applies throughout the life cycle of an asset or service. The CB-NL, which has a complex design, but is presented to the user in a simple way, is (going to be) available online, free of charge.

The CB-NL consists of a *core* which includes a few main standards (IMGeo, CityGML, Cheobs from CROW and the Semantic Concepts (SC), and *Source file standards* (such as ETIM, NL-SFB, IFC, IMGeo, NEN 2767-4, Eurocodes, OTL the object dictionary of Rijkswaterstaat, BID - the object dictionary of ProRail, and others.

The core combines the semantic mappings of various source files, helping relate and harmonize various source files with each other. Source file standards are being semantically mapped to core concepts, based on their meanings and appurtenance of a component to a specific class (either a *subclass* – more specialized, or a *superclass* – more generalized) (Geonovum, 2013).

The scope of CB-NL is to map concepts from source file types (and their standards), and connect them based on their definition and shared characteristics. In collaboration with representatives from different industries, source files containing the relevant concepts in that specific industry are determined, and made available for the semantic mapping with the CB-NL core concepts (CB-NL, 2013).

Figure 21 shows schematically how the semantic relations between different standards (e.g IFC and NEN 2767-4) are being mapped. Concepts from two different standards are linked together (via tags) based on communalities between their definitions and characteristics, described in the CB-NL core (to which each standard is semantically mapped in advance) (www.geonovum.nl/onderwerpen/bgt-imgeo-standaarden/nieuws/afstemming-begrippen-conditiemeting-infrastructuur-nen-2767).

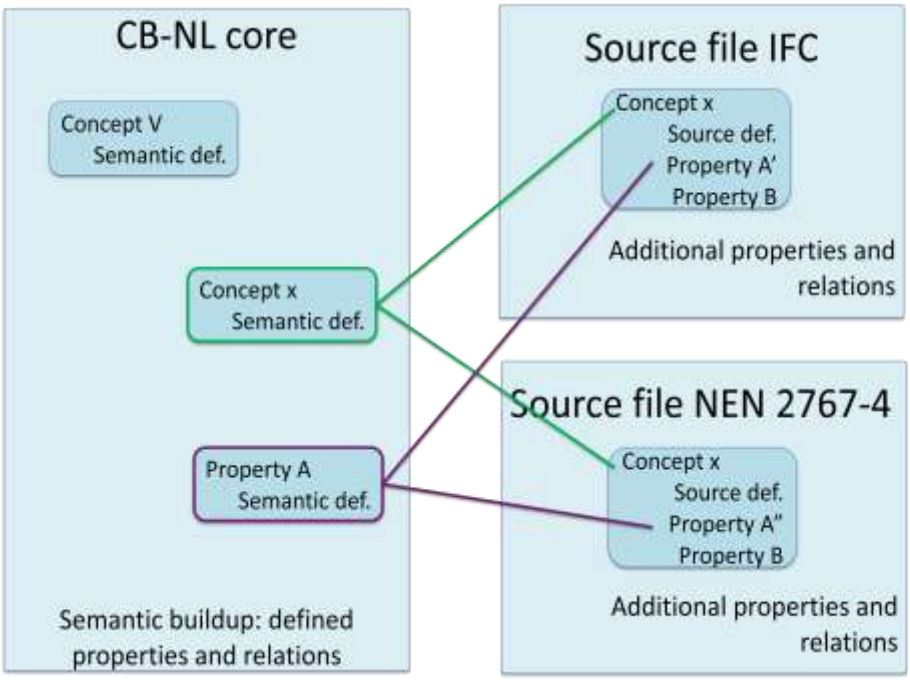


Figure 21 Semantic mapping between IFC and NEN 2767-4 via CB-NL

The CB-NL roadmap for mapping activities with the source files is available at http://public.cbnl.org/upload/forum/nieuws/Roadmap%20CB-NL%20versie%201%200.pdf. The core is expected to be completed in June 2014, and the semantic mapping of the core with the source file standards at the end of 2014.

Upon completion the CB-NL will also be made available internationally as IFD standard: International Framework Dictionary.

User requirements

One important user requirement in AM is the ease of use of the AM tools, which implies flexibility of data representation. 3D models used in the design and implementation phases of the construction processes are often too complex and detailed for the operation and maintenance phase, making AM processes slower and less efficient (Zhu et al., 2011). The level of detail (LOD) should thus be reduced from LOD4 (or higher) in the design phase to LOD2 or LOD1 in the maintenance phase.

Therefore, simplifying the data model through selective representation, by filtering out superfluous objects/components for the maintenance phase while emphasizing essential objects would help improve the performance of AM tool and reduce the time to complete AM maintenance tasks (Zhu et al., 2011). This step is possible in FME, as will be explained in the next chapter.

Based on the theoretical framework presented in chapter 2, a prototype model is designed in the research case study, for the integration of a 3D BIM model in Obsurv. The process and results are presented in the next chapter.

3. Case study: 3D BIM model in OBSURV

The goal of this research is to find ways of further facilitating AM processes, by including 3D models of the assets to be managed in the current AM tools. For this purpose, a prototype model is set up tested out in Obsurv – the AM tool provided by Grontmij, and used by different parties for AM in the Netherlands.

This chapter is structured as follows: first the user requirements for the tool performance are shortly presented, after which the test environment is described. Next, the testing process is described, including the testing data and systems used, based on the two different types of integration mentioned earlier: systems level, with a loose coupling or data level, which is a transformative integration. The chapter ends with the results of the prototype integration testing. These steps are also shown schematically in figure 22.

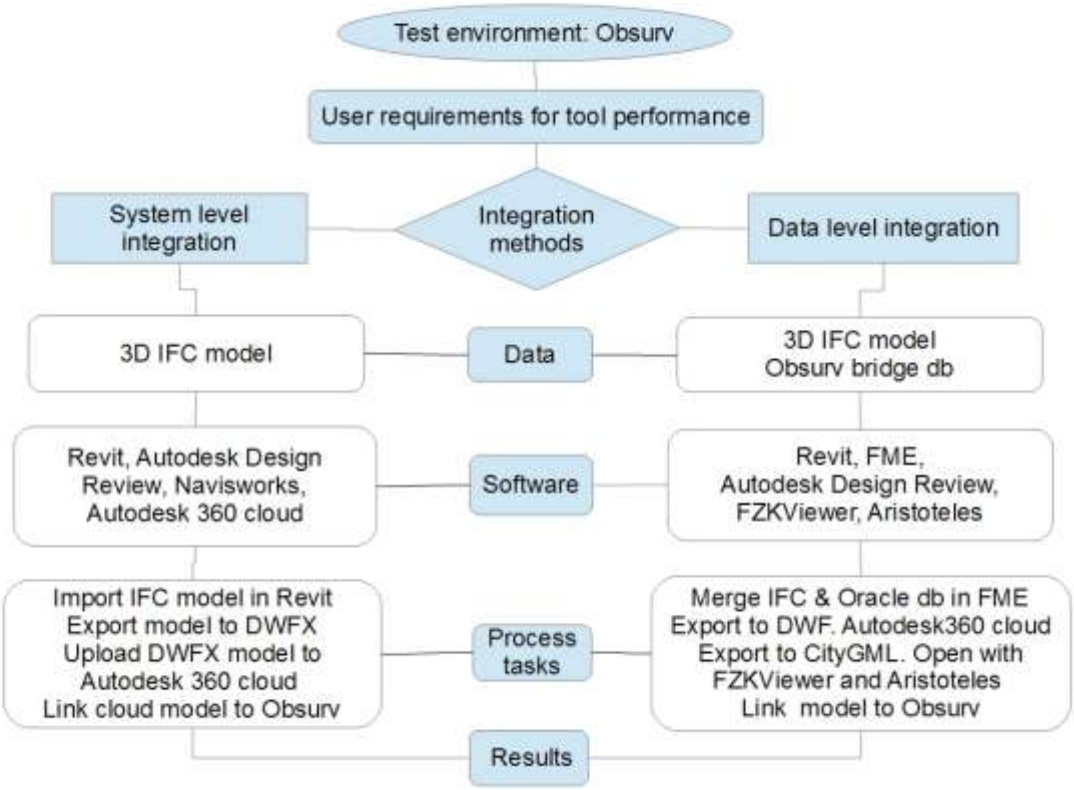


Figure 22 Prototype testing process

3.1 Test environment

The test environment for the 3D BIM model integration with GIS is Obsurv - a Dutch management system for public space and assets, available as a web-based service (at www.obsurv.nl). This service offers asset managers and administrators of public space the possibility to continuously view and manage the state of their assets (roads, structures, drainage, public green, traffic control, etc.). Obsurv provides an information layer over an area, relevant in order to plan development, management and budgeting processes. It has an intuitive and easy to use interface (see figure 23), and it meets the most (open) ICT standards.

Its architecture is based on an Oracle db (Apex), Geoserver and Glass fish.

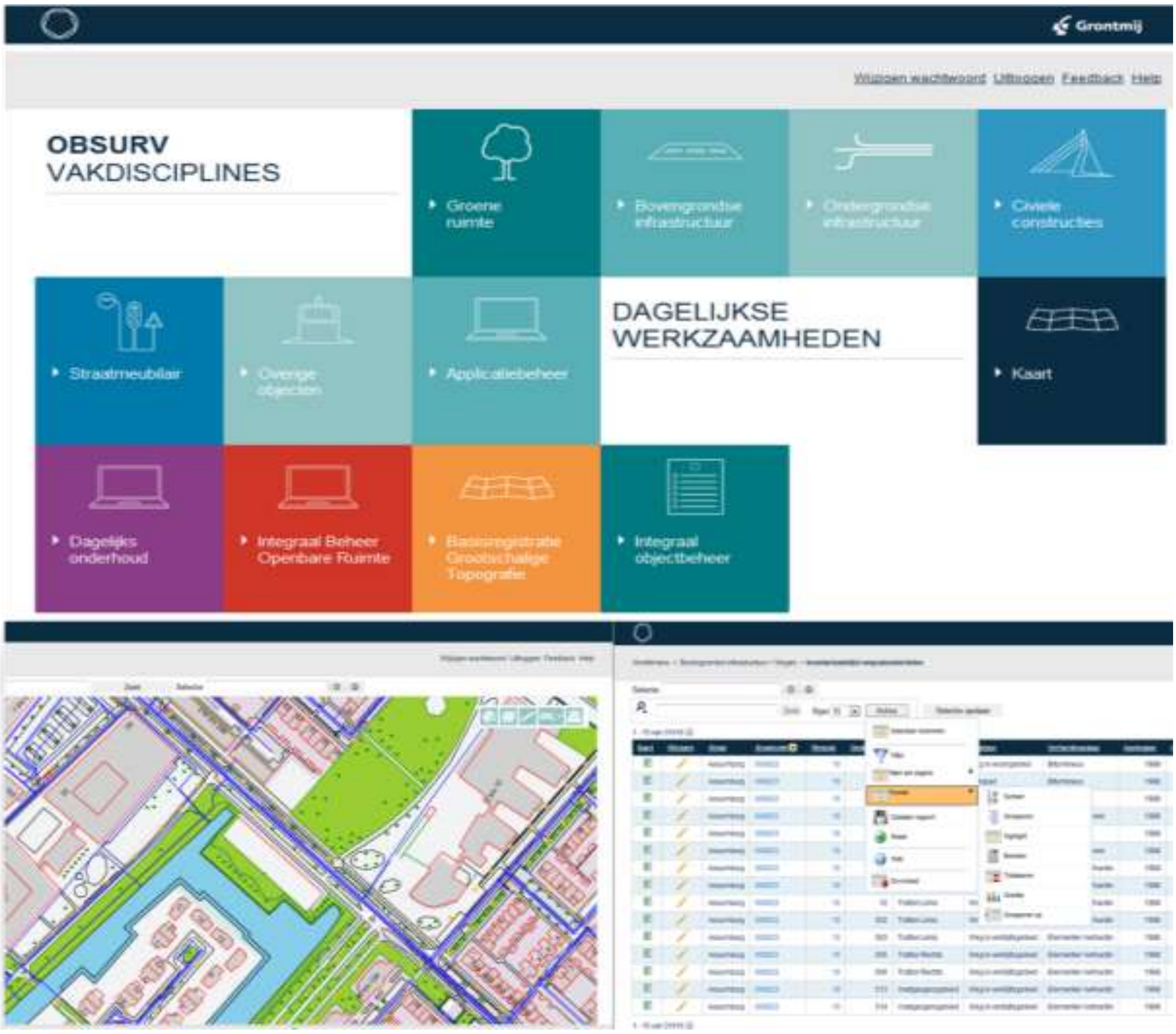


Figure 23 Obsurv

The assets to manage are represented on open layer maps, on which the user can select or draw objects. Currently, the base map is the GBKN, soon to be replaced by the BGT (which is currently being realized by municipalities, provinces and other parties; it is supposed to be ready in 2015). Additional available map layers are WMSs for visualizing and WFSs (URL of the geoserver) for analysis (which becomes available when zoomed in on an area). Users can also connect to Globe spotter for street views, or add satellite photos.

3.2 User requirements for tool performance

The user requirements for the performance of Obsurv were determined based on literature studies and two sets of interviews with Obsurv users:

- First round with dgDialog users interested in switching to Obsurv, containing questions regarding the overall performance of dgDialog, how it could be improved in order to enhance the AM performance, and what their houding was with regard to BIM and 3D models of the objects to manage.

- Second set of interviews focused more on the parties interested in the making and implementation/ use of 3D models in Obsurv, to help perform their AM tasks (Gelderland and N Brabant Provinces). Also, users who were not interviewed the first time showed interest in 3D BIM models in Obsurv for the management of their assets after having seen the result of the prototype model (e.g. the municipality of Utrecht).

Based on these interviews and literature study, the following indicators are derived for the performance of Obsurv as AM tool:

- ease of use (self-explanatory user interface, usability on a tablet).
- availability (also offline).
- interoperability with other systems (use of standards that enable data exchange; use of semantics/ontologies understandable by all users)
- flexibility to:
  - visualize data selectively (in a simplified model, with little unnecessary detail, with the option to filter data per layers, as to visualize only parts of the model which are being inspected at a time).
  - update the administrative data about the asset and to register these changes directly in the 3D model.

These indicators are taken into account for assessing the validity if the model.

3.3 Data and software packages used

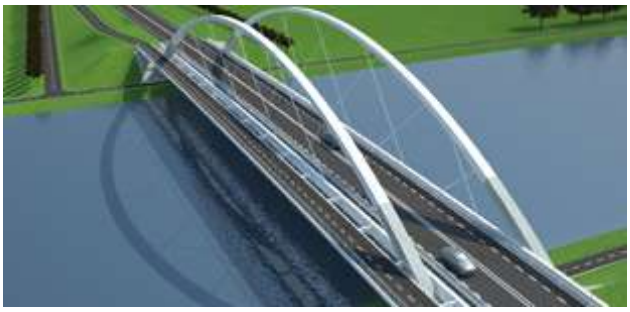


Figure 24 TwenteKanaal Bridge

The test data used for this case study is a 3D IFC version of the TwenteKanaal Bridge (owned and managed by Gelderland Province – see figure 24). The bridge, located on the N348 route, connecting the industrial area De Mars in Zutphen and Eefde, was completed in 2012.

It is a 117 meter long and 15 meter high bridge, made (mostly) of steel and concrete, expected to support 20.000 vehicles per day (see figure 23). The maintenance of the bridge is planned to be carried out with the help of Obsurv, which is why the integration of the 3D model in Obsurv is desirable.

For the BIM-GIS integration process, a few preparation steps were necessary for the data, such as data transformation and semantic mapping between IFC (the standard in which the 3D model was available) and NEN2767-4 – the standard used by Obsurv, in which the model should be presented. These steps are carried out in both commercial and open source software packages, such as Revit, Navisworks, FME, Tekla BIM viewsight, FZKViewer, Aristoteles and others.

A list of available software packages for viewing BIM models in different formats (IFC, CityGML, DWF) can be found in appendix 3**.** More freeware for viewing IFC or CityGML formats are available at www.citygmlwiki.org/index.php/Free_Software; www.ifcwiki.org/index.php/Freeware.

3.4 BIM – GIS integration process

The process of BIM integration with GIS in Obsurv is schematically represented in the figure below (figure 25). The input data (3D model created in CAD design packages such as Tekla or Revit), can be connected to Obsurv in its original format (without geometric or semantic transformation), by visualizing it in an available IFC viewer, such as Autodesk 360 cloud, Navisworks .nwc), Tekla BIM viewsight or FZKviewer. A list of more available viewers is given in appendix 3. Alternatively, in order to simplify the model geometry and to semantically map the two system standards used (IFC and NEN 2767-4) the data has been read in FME, along with the oracle db for that specific object. The resulted model can be written to multiple formats, such as DWF (Autodesk) and CityGML (GIS), and linked to Obsurv through different viewers per file type format (Aristoteles and FZK viewer for CityGML files, and Autodesk viewers for the .dwf format).

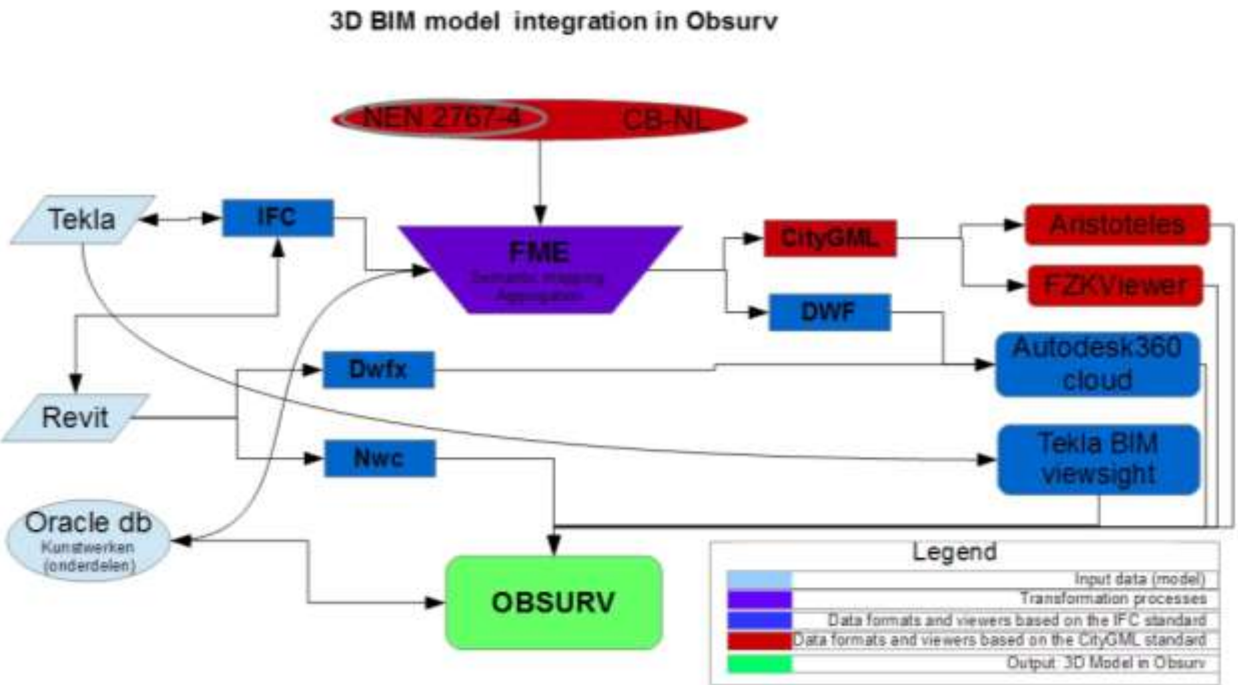


Figure 25 Process of 3D BIM model integration in Obsurv

A more detailed description of the steps taken for the BIM-GIS integration in Obsurv are described in the following sections of this chapter.

Asset decomposition in Obsurv

One of the first steps for AM is the inclusion of a new asset in Obsurv, and its decomposition per element. The IFC model is, however, too detailed for AM, being constituted of about 20000 elements. A simplification of the model is thus required. This can be realized by aggregating similar elements/components in FME (for example aggregating all the components forming the approach slab – aanrijbalk, based on their family name in Revit). This way, the total amount of elements in the decomposition can be greatly reduced, facilitating the process. For the purpose of this research, however, a few elements were added manually in Obsurv, along with their administrative information (See figure 26).

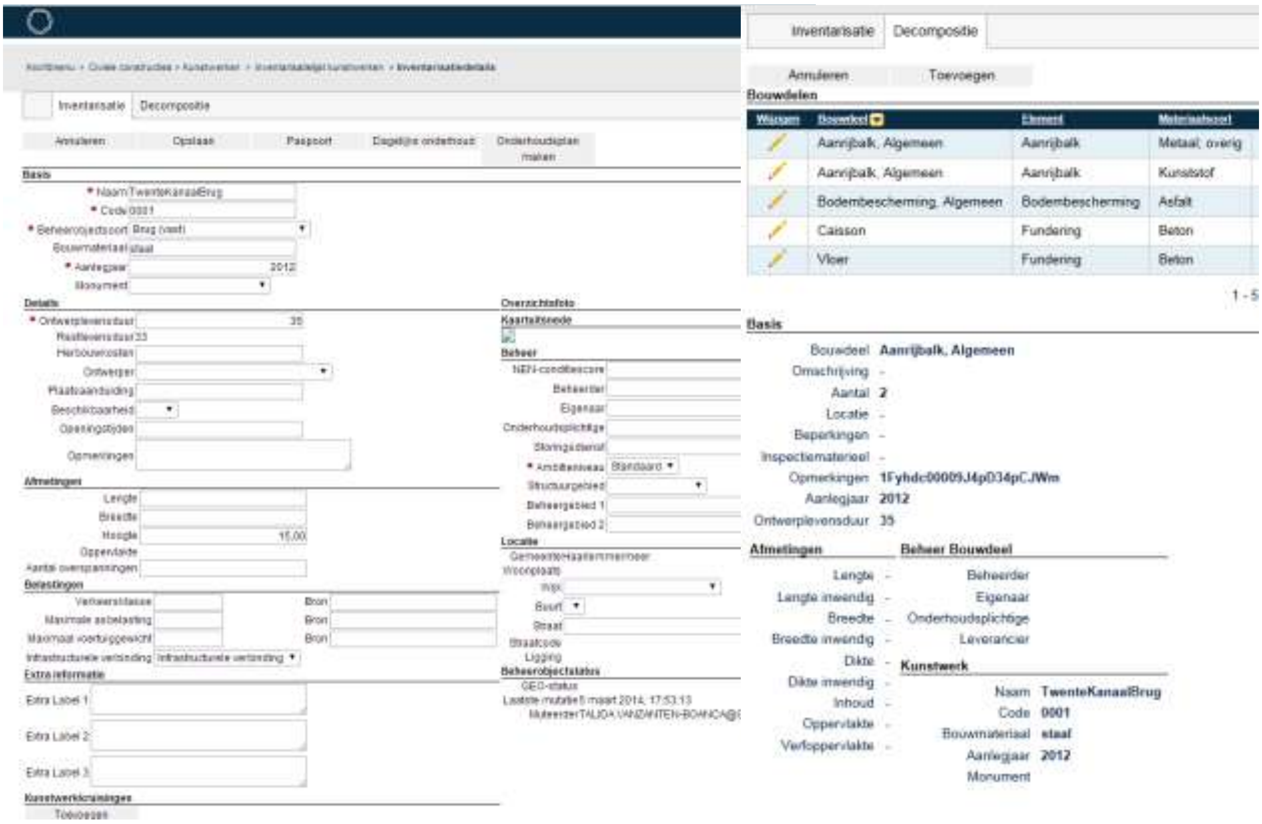


Figure 26 Bridge decomposition in Obsurv

3.4.1 Approaches to CAD – GIS integration

The integration process is tested using two different methods: system integration or loose coupling, and tight, transformative integration. These approaches are described below.

System level integration

One type of integration tested here is the integration of BIM with GIS at **system (or application) level** (also referred to as a service-oriented approach). This can be realized by using an API (Application programming interface) DBMS (DataBase Management System), which allows users access on the fly to the BIM physical file, or through the joint use of web interfaces and message exchange (i.e. via SOAP/REST web services or a Standard Data Access Interface) (Vanlande et al., 2008). This type of integration is more a loose coupling between the two systems, in the sense that there is no real geometrical and semantic data transformation between the two systems.

In this case, a 3D model of the Twentekanaal bridge, received (from the client) in IFC format (exported from Tekla) was read in Revit for data inspection and eventual data addition (mostly administrative data about specific elements). Also, in Revit, links could be made to other documents (such as .dwg plans). (Revit was the available software for testing; otherwise, it might be preferable to proceed with the Tekla version of the model, to reduce the number of intermediary steps in the process; in this case, the Tekla model can be directly exported to and visualized in the open source Tekla BIM Viewsight, from where it can be linked to Obsurv). From Revit, the model was uploaded to the (cost free) Autodesk 360cloud (in .dwfx format) (or in the Autodesk Buzzsaw cloud - a platform for hosting models, allowing for collaboration and data management; this platform is, however, not free of charge), from where it could be linked to Obsurv. An alternative to the cloud storage of the model is exporting the model from Revit to Navisworks, and saving it locally, from where it can as well be linked to Obsurv (figure 27).

Figure 27 Systems integration

The cloud-storage method has the advantage that the model can be directly uploaded to the cloud from Revit (or after being exported to .dwfx first); the local storage of the model in .nwc (Navisworks) format requires an extra process step and extra software, increasing thus the costs of the integration. Alternatively open source IFC viewers (FZKViewer) can be used for the visualizing of the (locally stored IFC) model.

While faster and easier to implement, this method does not fully fulfill the Obsurv user requirements for AM tools, based on which the 3D model of the bridge should facilitate AM processes by presenting relevant data for the bridge maintenance in NEN2767-4 format. This requires a more transformative integration, at data level, presented in the next paragraph.

Data level integration

The second type of integration tested is at **data level**, by using a CAD (Revit) file exchanged and transformed (*geometrically and semantically*) among various applications. This type of integration involves data replication and federation through file exchange, which require common data models or formats and semantic mapping of the object components from the IFC standard to the NEN 2767-4 standard used for infrastructural assets in Obsurv (figure 28).

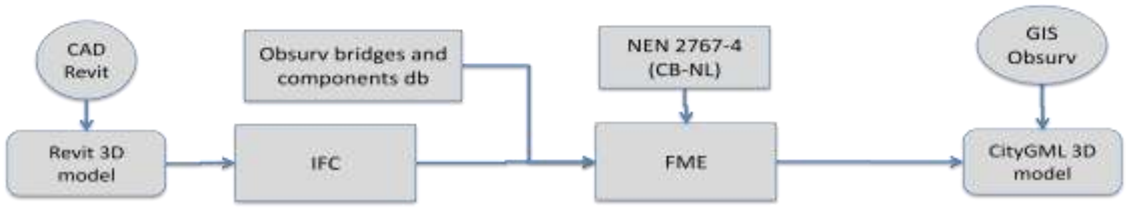


Figure 28 Data integration

Data level integration of BIM and GIS for Obsurv is realized on two paths: the ***geometric transformation***, in which the LOD (Level of Detail) of the detailed IFC model is reduced from a LOD 4 to a LOD 2, and the ***semantic mapping*** between the underlying standards (IFC and NEN 2767-4).

Geometric transformation

The geometric transformation from LOD 4 to LOD 2 was tested through different methods. One way considered was grouping similar elements based on a specific parameter (family name or material); elements grouped in Revit, however, do not remain grouped when exported to other formats or imported in other programs.

Another way was filtering out one or more parameters: in this case, only the non-filtered (- still visible) objects are exported to Navisworks. This makes the model lighter, and more manageable for AM operators, as unnecessary details in the design are not taken with. In Navisworks, the individual filtered sub-models exported can be appended to each other, so that the whole model can still be visualized as a whole. (In order not to lose the original detailed (complete) Revit model, which might be necessary in next phases of the Asset Lifecycle, a link can be made between the Revit and the Navisworks models). The main elements in a model can thus be grouped and exported separately (to .ifc or .nwc files), which can later be aggregated (in FME), if necessary.

An alternative, easier way of aggregating similar sub(elements) is by reading them all in FME and aggregating them based on a common parameter (such as material, object type, location).

However,all these methods require a correct identification of all the elements to aggregate/filter, which would be possible either through a semantic mapping (non-existent at the moment) or by analyzing the model in detail with the help of a professional designer familiar with the construction of this bridge (not easily available for this study). Also, considering the high amount of existing research on the geometrical transformations between BIM-GIS models (Kolbe, 2005, 2008; Isikdag et al., 2007; Nagel, 2007, 2009; Berlo, 2009; Hijazi et al., 2009, 2011; El_Mekawy, 2011; Alexiadi and Potsioy, 2012), some of which have resulted in automation tools for the LOD reduction from 4 to 1 and 2, and the fact that there is no semantic mapping available yet between the IFC and the NEN-2767-4 standards, it seemed more relevant for this research to focus on the semantic mapping.

Semantic mapping

A detailed description of the two standards used by BIM and GIS in this research is given in the previous chapter (Theoretical framework). Here the process of semantic mapping for the prototype integration will be explained.

For testing purposes, only a few (three) of the bigger elements of the IFC model were taken into account. After an inspection in Revit, the IFC model was read in FME. (For ease of use – considering the size of this model - only parts of the model could be imported/ opened in FME by setting a filter on the reader). When read in FME, each model component receives an automatically generated unique global ID (e.g. 1Fyhdc000UFJ4D34pCJWn). Afterwards, the bridge, along with the 4 elements imported in FME for semantic mapping (bridge deck, bike path, bridge ramp) were added in Obsurv. In the bridge decomposition, the global ID code generated in FME was added in the description of each added element. Next, the Oracle databases for bridges and for bridges elements, containing all bridge elements description (added earlier in Obsurv) according to the NEN 2767-4 norm, were imported in FME. In order to avoid unnecessary work by importing the whole oracle db, a filter is set on the FME reader to only import the elements with a specific global ID (which was also entered earlier in the object decomposition in Obsurv). Now a *merge* action was possible between the oracle db (in NEN format) and each imported bridge element (in IFC format), resulting in 3D bridge elements containing all the information from both the original model and from the oracle db.

An example of a bridge elements semantic decomposition in both IFC and NEN 2767-4 is given below. In IFC, the IfcPlate, for example, is a sub-element of the IfcBuildingElement and so on (see figure 29).

IfcRoot → IfcObjectDefinition → IfcObject → IfcProduct → IfcElement → IfcBuildingElement →IfcPlate

Figure 29 IFC element decomposition

It is, however, not clear what exactly this element is, and what its name will be based on the NEN norm. (Visualizing it in the 3D model did, however, help with the identification).

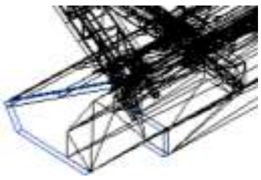
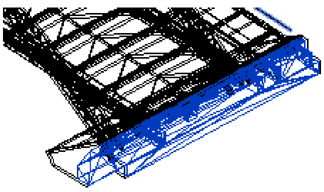
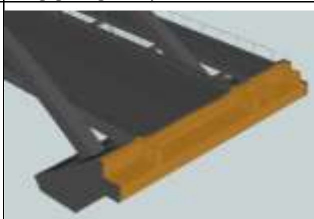
In NEN 2767-4, an *IfcPlate,* depending on its location in the bridge, can be named differently. The plate considered in this example (see table 4) was identified as an *foundation, ground/base* element, made of concrete, and with a specific NEN code for this type of element and material (see figure 30).

Bridge (fixed) → Bridge deck → Protective layer → Concrete (→ Erosion)

Figure 30 NEN 2767-4 element decomposition

When adding the elements in Obsurv, a decision had to be made as to the type of element it actually is. There is no semantic mapping available yet between the IFC and the NEN-2767-4 standards. The semantic mapping could thus not be automated. A semantic mapping of the test elements was, however, realized manually, with the help of a professional in civil works, based on the visual identifications of the elements. Table 4 shows the (manual) semantic mapping of the 3D BIM (IFC) model with GIS (and the NEN 2767-4 norm).

Table 4 Semantic mapping IFC - NEN2767-4

	Revit	**IFC (FME)**	**NEN2767-4**
1	Structural framing: Floors. Betonplaat 113892	IfcPlate	Fundering. Vloer. Beton. 1605 Fundering. kunstwerken Fundatie Beton. 1204
			
2	Structural Framing: Beton 114643	IfcBeam: Concrete C45/55 (geometry: fme aggregate)	Fundering. Vloer. Waterbouw Beton. 1605
			

A drawback of this method is that, as seen in table 4, a perfect semantic mapping was impossible to realize only based on the visual identification of elements, seeing that the first element (IfcPlate) could be at least two different elements in NEN 2767-4: *foundation, ground/base* or *foundation object.* There are, however, efforts to (indirectly) map these two standards with the CB-NL (see integration standards chapter 2.4.5), which should be completed at the end of 2014. This offers a viable alternative to the error prone and time consuming manual semantic mapping.

Another drawback of this data transformative integration is possible data loss in the process, depending on the representation methods used in CAD (BIM) (e.g Constructive Solid Geometry (CSG) and Sweeping) and GIS (boundary representation (BRep)).

The (geometrically modified) and semantically mapped bridge elements were, as a last step of data transformation, exported to different formats, such as DWF and CityGML, which can be visualized with FZKViewer, Aristoteles, Autodesk360 cloud or other viewers, and linked to Obsurv.

3.4.2 Linking the 3D BIM model to Obsurv

Two different ways of linking the 3D BIM model to Obsurv (GIS) are considered here.

One option could be saving the model in a simplified version in the Autodesk 360 cloud. A link can then be made to the object in Obsurv (by adding the URL to the model in the asset decomposition). The model then becomes available for use on any desktop and mobile (tablet) device with a web browser and available internet.

Pros:

Ease of use: in this case, the user only needs a web browser to access both Obsurv and the model in the cloud.

Cons:

The model is only available as a whole, and data cannot be visualized by filtering it per element categories.

Another option is saving the (simplified version of the) model locally and linking it to Obsurv.

Pros: In this case, the user has more flexibility in filtering the data for visualization

Cons: Extra software installation is necessary for viewing the model, depending on its format (Revit, Navisworks, Tekla or Tekla BIM viewsight, FZKViewer, Aristoteles…) locally.

Technically the link to Obsurv is not yet possible, due to Obsurv lacking the necessary functionalities for this purpose. These are, however, going to be built at a later moment, at which point the implementation of this 3D BIM model in Osurv can be realized.

4. Results

The BIM-GIS integration in Obsurv was tested in this research project through two different methods: on system and data level. The results of the two integration methods are presented here.

4.1 System level integration

The system level integration is more of a loose coupling between the 3D BIM model uploaded to the cloud (or locally) and Obsurv, based on a URI/URL link to the decomposed model in Obsurv. In this method, no geometric or semantic transformation of data takes place: the model is merely made available in its original form. The figures below show the Revit model (figure 31) and the .dwfx model uploaded in the Autodesk 360 cloud (figure 32). The input file in this system integration process was an IFC file; the output file can have different formats: if uploaded to the Autodesk 360 cloud, it should be a .dwfx file (based on the IFC standard); if the model is stored locally, and connected to Obsurv, it can be in an Navisworks format (.nwc).

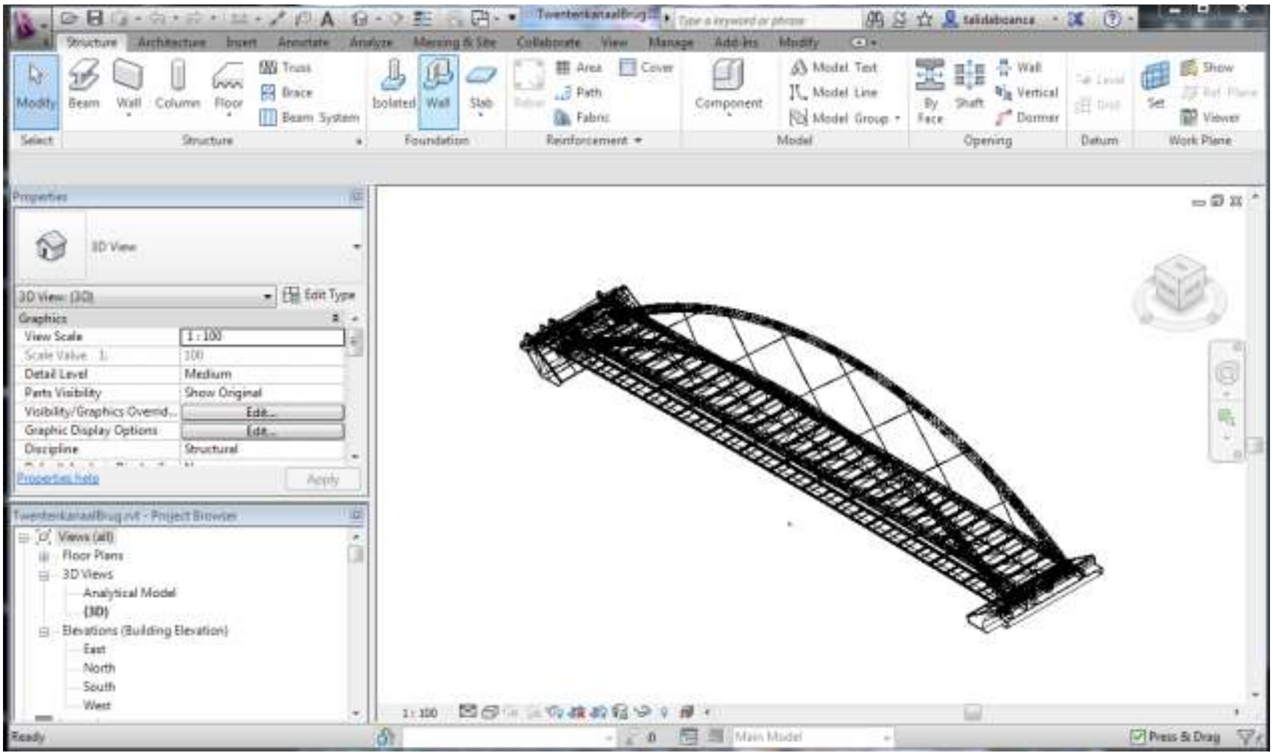


Figure 31 Revit model

This integration method had the advantage that it does not require extra transformation steps, or the software necessary for those steps, saving thus time and money in the process. It does, however, not meet the full user requirements of presenting the data according to the NEN norms, as required by Obsurv.

In figure 32, the green – white striped element (IfcPlate) is selected. Its properties are then shown in the black window to the left. Currently, these properties are the ones the model came with, in IFC format. If the user chooses to see the bridge properties as presented in Obsurv, a few extra steps in FME are required, at a data level type of integration, as explained in the previous chapter.

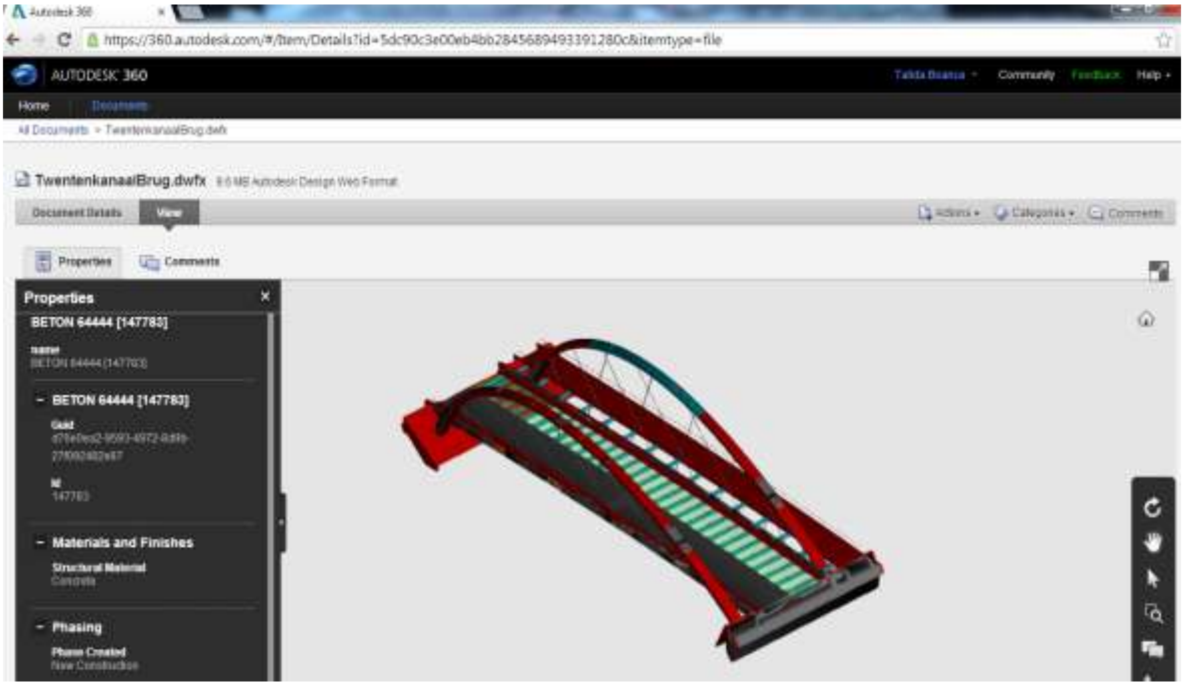


Figure 32 dwfx model in the Autodesk 360 cloud

4.2 Data level integration

The BIM – GIS integration at data level included *geometric transformation* (model simplification from LOD 4 to LOD 2) and *semantic mapping* between the IFC and NEN 2767-4 standards.

Figures 33 and 34 show the results of the BIM – GIS integration process at data level, as described in the previous chapter.

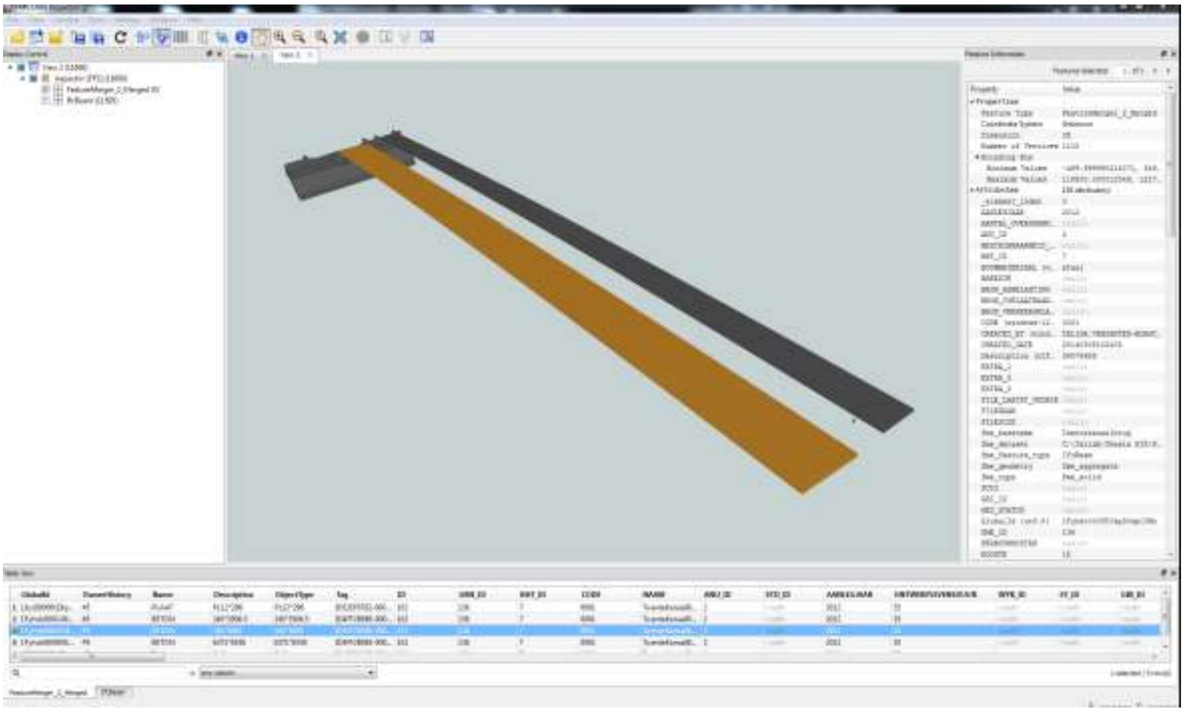


Figure 33 Results of data level integration in FME

The yellow element is selected, showing thus all its properties in the right side window. These are all the original properties of the element, along with the ones from Obsurv.

The input data for this method is the IFC model and the Oracle databases containing the asset information in the NEN2767-4 format. After the geometric and semantic transformations, the output of the process is a 3D CityGML model of the bridge (in this test only three big elements were included). Also, en export is made to a .dwf file, which can be uploaded in the Autodesk 360 cloud, just as was the case in the System level integration type.

Figure 34 shows the same results in the open source FZKViewer.

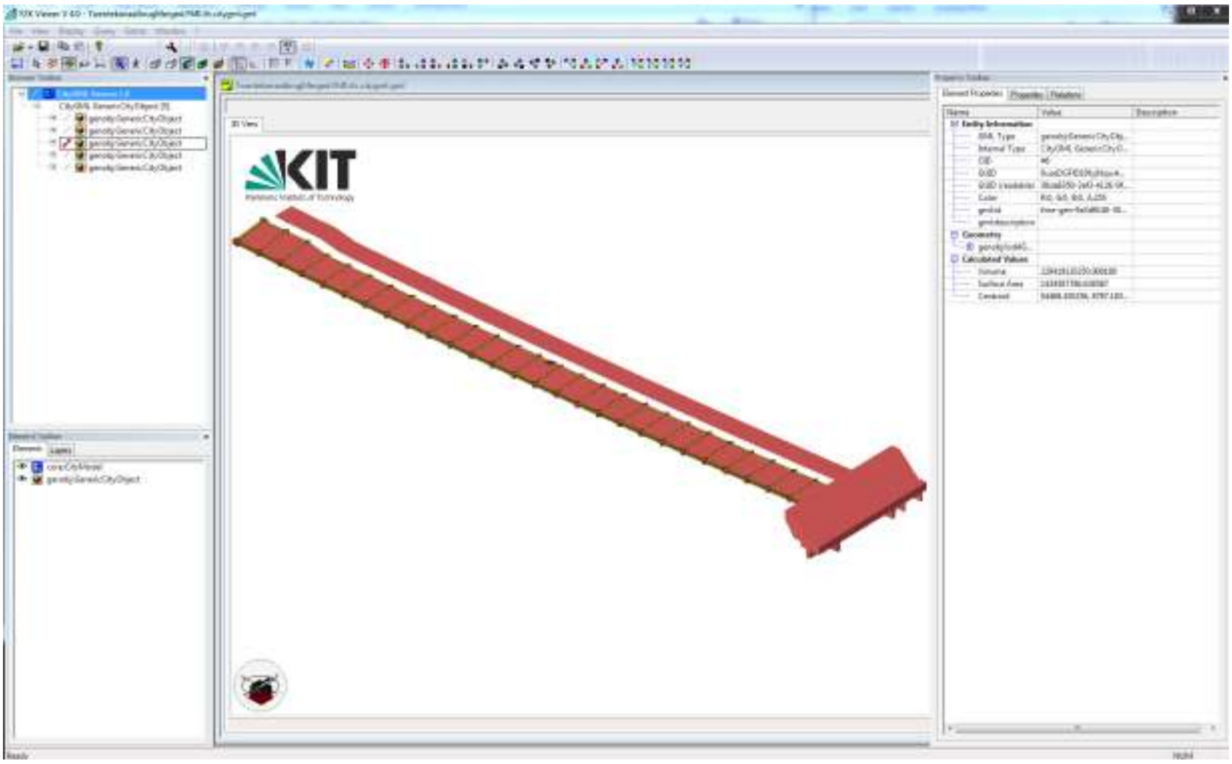


Figure 34 Data integration results in the FZKViewer

This second method of BIM-GIS integration is more time consuming, and requires more transformational steps, and the software necessary for that purpose (FME). It does, however, take into account the user requirements for data visualization based on the NEN2767-4 norms, by semantically mapping this norm with the IFC input. Furthermore, the total costs can be reduced by using open source software packages for visualizing the results (such as FZKViewer for both IFC and CityGML files, or Aristotle for CityGML).

4.3 Interviews results

Interviewed parties such as Grontmij professionals, standards experts and employees of provinces and municpalities using Obsurv are already using BIM models on small scale, in pilot projects. Their experiences with BIM so far were positive, but they were not yet comfortable enough with this new concept and working method as to consider its full implementation in their organizations.

Some reasons for organizations such as Grontmij and Obsurv users to use BIM or not in different construction or AM processes differ per type of company, type of project or asset to manage:

Reasons for using BIM

- Civil engineering companies choose for BIM for the following reasons:

- The whole construction and AM process is easier to manage with BIM
- 3D models of roads / pipes / cables are needed for the design of structures and budgets (a 3D BIM model, for example, can easily indicate how much should be dug for a construction, or how much paint is necessary for the maintenance of a bridge).
- the high amounts of objects to model , and the information to go with it is easier to realize with BIM, and less data gets lost in the process.
- Additional costs incurred in the design phase by the implementation of BIM is believed to be recovered in the later phases of an asset's life cycle, through its faster completion and fewer failure costs thanks to BIM.

- Provinces

- BIM offers a common platform for information management and sharing, rules and working methods, enabling thus improved collaboration between multiple stakeholders.
- 3D models have added value for constructions and asset management, through their clear overview of elements and their components, and possible interactions between them.

Reasons for not using BIM

- Civil engineering companies:

- People would prefer no changes in their traditional way of working: they can meet deadlines and stay within budget if they work the way they always did, and are already used to. Learning how to use new software packages and new working processes does not come easy to everyone, especially not to older employees.
- using BIM for the first time is more expensive, due to the costs of acquiring the necessary BIM software and training people.
- BIM is seen as an investment : the cost – benefit ratio is not equal per asset life cycle phase (it is more expensive in the design phase, but cheaper in the operation and maintenance phase). The problem is, however, that often a company (such as Grontmij) is usually involved in either concept/design/construction phase, or in the operation and

maintenance phase, but not in both. It is thus difficult to win back the money invested in BIM.

- Customer requirements change frequently, are often inconsistent and influenced by politics; as such, a management baseline should be determined to secure the stability of a project, by not allowing changes after a commonly decided upon deadline.
- There are many stakeholders involved in AM processes (owners, managers...), but it is difficult to find one person to take responsibility for one whole system (with many inter-related sub-systems) and manage it throughout its whole life cycle.

• Municipalities

- BIM software is more expensive than other (open source) software packages
- it is too much work, too expensive and too little returned value to invest in new software and training employees (which as reluctant as well to change their ways of working). It is, for the time being, easier to work in the traditional way
- 3D data visualization has no added value for road or sewage management

Besides the interviews with Grontmij professionals and Obsurv users regarding the implementation of BIM with GIS for AM, an additional interview with Marcel Reuvers – Standards expert from Geonovum, helped clarify some issues regarding the technical BIM-GIS integration and the semantic mapping between underlying standards. The results of this interview are presented in the BIM – GIS integration chapter 2.4.5 (page 45), and are further worked into the analysis of the BIM-GIS integration.

The findings of this research along with the main user requirements resulted from the interviews are discussed in the following chapter.

5. Discussion

AM processes are often highly regulated, data intensive, complex processes, due to the high diversity of and multitude of stakeholders and (often non-interoperable) tools, methods, standards and the underlying semantics which can be interpreted differently by different parties, and data types used by different parties in all stages of an asset's life cycle. This, along with incomplete information, inadequate information management, ineffective data integration and deficient communication among stakeholders often result in ineffective and costly AM processes.

The goal of this research was to investigate the possibilities of integrating GIS (2D) with BIM (3D) data (models), in order to explore ways of enhancing the performance of Asset management processes (over the whole life cycle of facilities). This was realized by creating and testing a prototype model of the 3D BIM – 2D GIS integration in Obsurv.

In order to help reduce these inefficiencies and to help facilitate AM processes, two developments are considered and tested in this research: the representation and visualization in 3D of assets to manage in Obsurv, and the (geometric and semantic) integration of BIM with GIS. 3D data visualization can enhance shared understanding and interpretations of information, increase interoperability and help predict asset performance before it is built. Information integration enables more cooperation between different stakeholders involved in AM processes, and can help enhance the quality of AM processes, tools and services. The integration of various systems and data types (in the design and construction phases) can lead to cost effective asset life cycle management, by allowing stakeholders access to a seamless flow of asset information over its whole life cycle.

The main issues studied in this research project can be schematically reduced to two main challenges in AM processes, and proposed solutions for overcoming these issues.

- AM challenges:
  - 2D data visualization is not sufficient for effective AM processes
  - Incomplete and fragmented data transfer between asset life cycle phases due to non-interoperable systems (using multiple standards with different underlying semantics, and various types of geometric representation)

- Solutions:
  - 3D data representation and visualization
  - Systems integration (BIM – GIS), for increased collaboration between stakeholders from different asset life cycle stages

These solutions are analyzed and tested during this research project, helping answer the research questions.

5.1 Research Questions

The research questions were answered through different methods: literature studies, interviews with involved parties and tests run on the prototype model integration.

*The **first research question*** about the benefits and bottlenecks of 3D data representation and visualization in AM processes was answered with the help of scientific literature, interviews carried out with Obsurv users. Research (Warren and Wertheim 1990; Rakkolainen and Vainio 2001; Arpinar et al., 2006; *Gursel et al., 2009;* Erp et al., 2011; Lee et al., 2012; Wu et al., 2012) shows that 3D data models can help facilitate complex AM processes and increase their efficiency in different ways: by enabling the storage and visualization of all asset information in one interactive 3D model, facilitating at the same time information sharing between parties involved in different phases of asset life cycle, which was one of the main sources of AM processes complexities. 3D models of assets also make the understanding of an asset easier across an organization, and help to correctly identify components for maintenance services. Furthermore, the storage of relevant asset information in databases connected to the 3D model allows for searches and queries to be conducted on this data, helping thus reduce the time of AM tasks and improve the overall effectiveness of AM processes.

A drawback of 3D asset visualization is that most existing assets are not available in 3D, and the costs of digitizing all these assets would be too high. It is however indicated that all new assets, which most of the time are being designed in 3D anyway, be made into BIM models, for easier management in Obsurv. Another bottleneck for 3D BIM models in Obsurv is the attitude of users towards 3D: some of the interviewed users are already used to the current AM processes, and feel threatened by having to learn new ways of working, or feel that the type of assets they manage does not require 3D visualization (assets such as infrastructure or waterways). Especially older users were not very happy at the prospect of having to change their way of work.

*The **second research question*** was about the common points and differences between GIS and BIM systems regarding their technology, geometry (data structure), and standards used. BIM was defined as both a *process*, in which stakeholders from different phases of an asset life cycle collaborate in delivering high quality, high performance assets, and as a *technology*, which is basically the 3D CAD model of an asset, with all relevant asset information connected to it. In this research question it is the BIM as technology (or CAD) that is compared to GIS.

The common points between BIM and GIS are not many, the most important one being the fact that both systems are used for AM processes in different asset life cycle phases. The differences between BIM – GIS are, however, many, a few of which are given here: BIM /CAD is a construction technology, object or project specific, focused on designing detailed, (often non-existing) objects, without geographical information or spatial analysis. GIS, on the other hand, is location based, and presents information about multiple existing features (with no geometrical detail) in their spatial context, as well as the interactions between them. The BIM data types are usually single drawing files (in 2D or 3D), while GIS data can be of many types (photos, videos, databases, sound clips). The *software* used for BIM consists usually of design, drawing and data viewing packages, such as Autodesk Revit, Navisworks, Tekla, Relatics, while GIS software includes packages for data analysis and visualization, such as ArcGIS Desktop, ArcGIS Server, QGIS, web viewers and web services (Obsurv). The *standards* used for BIM are mainly IFC and STEP, while GIS standards include OGC WMS, WFS, GML, CityGML, NEN-2767-4, CROW, INSPIRE and others.

Even though very different in most respects, both systems (BIM and GIS) are used complementarily for AM processes, stressing thus the importance of their interoperability. While the high variety of software packages used by both systems plays a major role in hampering their integration (due to their different underlying semantics, standards and data types), it also offers the users a wide array of (both paid and open source) tools to choose from. Thanks to the many efforts to increase systems interoperability, the development of new software (such as Coins and Relatics) as well as semantic mapping efforts between different standards (CB-NL), the differences between these two systems are more manageable, and their integration possible.

The ***third research question*** about the practical BIM-GIS integration in Obsurv has been answered through the different activities of the case study. A few aspects were considered here, namely the user requirements, geometrical simplification of detailed 3D BIM models to a LOD required by AM (LOD2 or LOD1) and the role of standards and semantics in BIM-GIS integration.

User requirements: based on literature study and on interviews held with Obsurv users and Grontmij professionals responsible for designing Obsurv, a few indicators were identified (regarding the ease of use, availability, interoperability and flexibility of Obsurv), to help with the designing of the prototype integration and the testing of its validity. These requirements are discussed in more detail in the answer to the last question, about the validation of the model.

The BIM-GIS integration was tested here at two levels: system and data level.

The BIM-GIS integration at *system (or application) level* (also referred to as a service-oriented approach), can be realized by using an API (Application programming interface) DBMS (DataBase Management System), giving users access on the fly to the BIM physical file, or through the joint use of web interfaces and message exchange. This type of integration does not involve geometric or semantic data transformation between the two systems, being thus more a loose coupling between the two systems. The data can be saved locally, visualized with programs such as Navisworks or open source IFC viewers (FZKViewer) and linked to Obsurv, or it can be uploaded to the cloud and linked to Obsurv. Even though the system level integration may be faster and easier to implement than the data level integration, this method does not describe the asset and its elements according to the NEN2767-4 standard. As such, it may be help facilitate the AM processes through 3D visualization of the model, but does not fully help avoid confusion about the assets' semantics.

The second type of integration tested is at *data level*, realized on two paths: the *geometric transformation*, in which the LOD (Level of Detail) of the detailed IFC model is reduced from a LOD 4 to a LOD 2, and the *semantic mapping* between the underlying standards (IFC and NEN 2767-4). This type of integration involves data replication and federation through file exchange, which require common data models or formats and semantic mapping of the object components from the IFC standard to the NEN 2767-4 standard used for infrastructural assets in Obsurv. The geometric transformation from LOD 4 to LOD 2 can be realized through different methods: by grouping similar elements based on a specific parameter (family name or material), filtering out one or more parameters and exporting them separately to Navisworks, or by aggregating similar sub(elements) in FME based on a common parameter (such as material, object type, location). However, due to much available research on the geometrical transformations between BIM-GIS models for the LOD reduction from 4 to 1 and 2, more attention was paid here to the semantic mapping between the IFC and the NEN-2767-4 standards.

For the *Semantic integration* of BIM-GIS, the underlying semantic models IFC, CityGML and NEN2767-4 were taken into account. Considering the abundance of previous studies investigating the IFC – CityGML semantic mapping for interoperability in different types of projects, and the fact that assets in Obsurv are described according to the NEN 2767-4, which has not yet been semantically mapped with either IFC or CityGML, the IFC – CityGML mapping was not studied further in this research project. The IFC – NEN2767-4 semantic mapping has proved difficult to automate, due to the lack of existing research in the area. A mapping would be possible by following a few extra steps: since the IFC – CityGML mapping has already been studied, and the NEN2767-4 has been semantically mapped with the IMGeo standard (which is also based on CityGML), a mapping between IFC and NEN2767-4 could be realized. A question is, however, raised to its necessity on a project basis, considering that a (inter)national dictionary is being now developed in the form of CB-NL, mapping terms/concepts from multiple industries (construction, AM, GIS), planned to be completed by the end of 2014.

*The **fourth research question*** is about the benefits and bottlenecks of BIM - GIS integration. BIM and GIS are both systems used in AM process, and even though quite different, their integration can benefit the efficiency of AM. The main benefit of integrating BIM with GIS for AM is a clear overview of existing issues, involved parties, and interactions between them, and spatial influences on AM processes, creating thus a controlled platform for more effective AM. By using BIM models in the design and implementation phases of assets, and transferring the information to the next phases of the life cycle, the total costs of Asset management in its maintenance and operation phases can be greatly reduced. Additional benefits of BIM - GIS integration for AM may be increased AM tool performance, easier spatial clashed identification by visualizing a building or asset, information sharing, better coordination among design and engineering work, clearer performance targets and strategies, and increased speed of project / asset delivery. Also, by integrating these two systems, they may become also more interoperable with other systems.

There are, however, also some drawbacks to the BIM-GIS integration, a few of which will be mentioned here. Regarding the semantic integration between the IFC (BIM) – NEN2767-4 (GIS), a complete and error free semantic mapping was impossible to realize (manually or automated) only based on the visual identification of elements. There is, however, a concepts library being developed, which will map these two standards with the CB-NL (see integration standards chapter), which should be completed at the end of 2014. This offers a viable alternative to the error prone and time consuming manual semantic mapping. Another drawback of this data transformative integration is possible data loss when exporting between formats (e.g to IFC).

*The **fifth research question*** is focused on the validation of the research. The effects of implementing a 3D model prototype in OBSURV for facilitating the performance of Asset management processes have been assessed by carrying out additional interviews with OBSURV users, using performance criteria of the 3D model as assessment indicators. The assessment can be realized on two levels: tool performance and process performance.

Tool performance indicators for Obsurv are derived from literature study (Gursel at al., 2009) and interviews with the software (Obsurv) users and providers (Grontmij). These indicators are: ease of use, availability, interoperability with other systems, and flexibility to visualize only parts of the model which are being inspected at a time and to update the administrative data about the asset and to register these changes directly in the 3D model.

- Ease of use (self-explanatory user interface, usability on a tablet). According to the interviewed Obsurv users, the interface of Obsurv is much more user friendly than its predecessor, dgDialog . Also, given the fact that Obsurv is a web service, it can also be used on a tablet with internet access.
- Availability (also offline). Obsurv is a web service, requiring an internet connection at all times. Its availability is thus dependent on the internet access.
- Interoperability with other systems (use of standards that enable data exchange; use of semantics/ontologies understandable by all users). This would be possible with CB-NL. In the current situation, a manual semantic mapping is necessary (via FME)
- Flexibility to:
    - visualize only parts of the model which are being inspected at a time. This could be realized by aggregating components of the bridge based on a common characteristics, so that the model is simplified (shows less details), or by filtering the visualized data (turning off the other layers of the model, if the format allows it).
    - update the administrative data about the asset and register these changes directly in the 3D model. The administrative information can easily be updated in Obsurv, but the automatic update in the 3D model is not (yet) possible, and requires further research.

Process performance (facilitating AM processes). In order to assess the improvements in AM process performance, the AM process should be quantified, and the costs in time and money spent measured. This could be realized by dividing the AM process in activities/ tasks to carry out by different parties responsible for these tasks, including the time and costs (in days and/or hours and hourly rates) necessary to fulfill a task, plus the costs of the necessary materials. These costs should be measured once in the current way of executing AM processes, without the use of 3D models of assets, and once after the (conceptual) implementation of 3D asset models in Obsurv, for comparison. This way an estimate can be made of the time and money saved per task. This measurements need to be carried out later, when the technological implementation 3D asset models in Obsurv is completed.

However, this comparison will be only specific for the type of asset and organization referred to in this research. Other organizations may have different AM processes, and the measurements for other types of assets may result in different outcomes.

5.2 Reflection

A few important issues raised during this research (through interviews and the case study) are discussed in this section.

3D Data visualization

While 3D data representation and visualization is considered to be very beneficial to improving the effectiveness and quality of AM processes, it is surprising how many interviewed Obsurv users showed very little interest in the idea. The main reasons for this were the tight budgets and time frames for completing AM tasks, which are fulfilled comfortably enough using traditional methods of work. Learning new working methods and how to use new software seemed like a glamorous, but unnecessary alternative, especially among older interviewees.

User requirements

User requirements for 3D visualization and for systems integration differ per user and per life cycle phase of an asset: in the design phase 3D models are more detailed than required in the operation and maintenance phase. Also, depending on the type of asset managed, the user may require different levels of detail for asset model visualization (LOD 1 may be enough for a concrete tunnel, but a LOD 2 may be preferred for a bridge, which has more components, of different materials). Furthermore, the software packages used by different stakeholders are often non-interoperable, being based on different standards using different semantics. This diversity in requirements for 3D BIM models and preferences for software used make it difficult to set up an automation process that can easily be used by multiple users.

BIM in AM

BIM is about facilitating information transfer between different parties involved in different stages of an asset's life cycle, information which would otherwise get lost on the way, or be misinterpreted by other parties. This information is implemented in a 3D BIM model of an asset and passed on to the next stage in the life cycle. This is believed to greatly reduce costs of AM processes, especially in the operation and maintenance phase, by eliminating repetitive and error-prone tasks which would result from fragmented information transfer. However, for this process to work properly, it is imperative that the BIM models be realized in the design/concept phases of assets, seeing how the information necessary for operation and maintenance is provided by stakeholders involved in previous stages of the asset's life cycle.

BIM in AM operation and maintenance is thus quite dependent on the willingness and possibilities of designers and project owners to make a BIM model and share it with the other parties. Better yet, the involvement of asset managers in the design and construction phases, can help implement their vision for an asset before it is being built, facilitating thus its operation and maintenance. This is, however, as pointed out by some of the interviewed parties, not always possible. The main reason for this: there is usually not just one party responsible for the whole life cycle of an asset – multiple stakeholders are involved in different phases or segments of an asset's life cycle, after which they turn the results over to the next party.

This issue could be (partly) solved by considering having one *Asset BIM manager* (possibly the asset owner) who will oversee the whole life cycle management of an asset, and coordinate the tasks and stakeholders fulfilling them for best asset performance results. Is this feasible? Is there one person who can take on the responsibility of coordinating all necessary parties and inspire their collaboration, over a longer period of time? Possibly, for small projects which are realized in a short period of time. But assets with a long life span will probably have more than one owner over time, leaving thus its performance quality and the overall AM process efficiency up to the subjective and personal human values.

BIM – GIS integration Process

The BIM – GIS integration is important for the whole life cycle of assets, but due to time limitations for this research, only the operation and maintenance phase (for which Obsurv is used) was studied.

Regarding the technical feasibility of the prototype, it is important to state that some of the software packages and systems used (OBSURV, Autodesk Revit, Navisworks, Oracle databases, CityGML) are not always compatible with each other, requiring extra data transformation steps. As such, the research is less technical, and is focused more on identifying the requirements for the (technical) integration of 3D – 2D data. The tests carried out with the used software packages (Revit, Navisworks, FME, FZKViewer, Aristoteles) were thus more general, and did not investigate complex technical issues, which is beyond the scope of the research.

Data

The data used for the case study of this research was an IFC model exported from Tekla, which was further read in Revit. When exporting data to IFC, some data is, unfortunately, lost, and the geometry of the asset is somewhat altered (www.mittaviiva.fi/hannu/BIM_project/index_bim_basics_en.html). However, due to time constrains and limited knowledge of the software packages used, this issue was not further analyzed.

Test environment

The test environment – Obsurv is an AM tool provided by Grontmij, available as a web service, based on GIS (a base map on which the assets' location can be shown) and on an Oracle database, containing the administrative asset information. The standard used for assessing the quality of the infrastructural assets is NEN2767-4 – a Dutch national standard.

While an overall widely liked and used AM tool, a few points mentioned below) should be considered in its further development.

The main issue regarding Obsurv is its current technical limitation: due to Obsurv lacking the necessary 3D data storage and visualization functionalities, technically the link of the 3D BIM model to Obsurv is not yet possible. This functionality is, however, going to be built at a later moment, at which point the implementation of this 3D BIM model in Osurv can be realized.

Furthermore, considering the difficulties encountered during the geometric and semantic integration of BIM with GIS, a question was raised as to the essentiality of using NEN2767-4 for assessing infrastructural assets: why not use other standards for assets in Obsurv - other standards, such as PAS 55, which are more interoperable with other systems and international ISO standards. What would be the (technical and commercial) consequences of replacing the NEN2767-4 with another standard in Obsurv? Would the Obsurv users accept it, seeing how attached they are to the current way of working? Would it save more costs in the long run, by avoiding extra data translation steps in the system integration processes?

Another issue related to the implementation of BIM in Obsurv is the built-in data management system (DMS) of Obsurv – namely the Oracle db. For a successful implementation of BIM in AM, and its procedural integration with GIS, a more integral DMS is necessary, such as Relatics. Relatics is a platform offering a clear overview of project documents and data which are essential for data management over an asset's life cycle, enabling this way stakeholder cooperation over different asset life cycle stages. However, for the time being, the Relatics – Obsurv integration is a bit too complex and premature. On the other hand, if Relatics is used as the DMS for an asset from its initial (concept, design, and construction) phases, its integration with Obsurv will also become easier (and more relevant).

Integration Testing

One relevant factor in the testing of the prototype model was the fact that the test data – the 3D model of the Twentekanaal bridge was a very heavy model. The opening and running of the model, and additional steps such as translation and exporting to other formats, slowed the process down (and even led to the computer crashing repeatedly).

In order to accommodate different user requirements for ease of use and level of detail of the model, the BIM-GIS integration was studied on two levels: system and data level. The system level integration proposes merely a coupling between the 3D model and Obsurv, without any geometric simplification or semantic mapping. In this case, the user can visualize the data in 3D, but does not have the full procedural BIM – GIS integration. The data level integration, on the other hand, transforms the data geometrically (simplification through detail reduction) and through semantic mapping.

Geometric transformation of data integration is a very complex issue, for which many aspects are relevant: which method is best for the necessary LOD? Is aggregation of similar components (based on a common characteristic) advised? And if so, which common parameter can be used for the aggregation? The Revit family classes or IFC classes? Visual appurtenance to a specific element? How flexible does the model remain, in case the user decides to aggregate/group the elements based on a different common parameter? This geometric transformation is in the end reduced to the semantics used: the names of elements and their components, and the relations between them.

The semantic mapping of data integration proved equally challenging: the manual semantic mapping realized only based on the visual identification of elements between the IFC version of the TwenteKanaak Bridge and its elements decomposed (according to NEN 2767-4) in Obsurv was far from perfect. Additional professional knowledge of civil constructions would be necessary for such a mapping. Or even better – an official semantic mapping between the two standards (IFC and NEN2767-4) would be a good step towards automating the BIM-GIS integration process. Fortunately, there are efforts to (indirectly) map these two standards with the CB-NL (the (inter)national dictionary which maps concepts from multiple industries (AEC, AM, GIS - see chapter 2.4.5), which should be completed at the end of 2014. This offers a viable alternative to the error prone and time consuming manual semantic mapping.

Even though the system level integration may be faster and easier to implement than the data level integration, this method does not describe the asset and its elements according to the NEN2767-4 standard, not fulfilling thus the user requirements for data visualization. As such, it may help facilitate the AM processes through 3D visualization of the model, but does not fully help avoid confusion about the assets' semantics, which requires a data level integration. Data level integration, nevertheless, is more time and money consuming (requiring extra software packages, such as FME, and extra transformation steps of the model); it can, however, use open source software for viewing the model (such as FZKViewer), helping thus reduce the costs. The best method to choose in a particular case depends thus on user preferences.

Validation

As for the validation of the model, to see whether the use of BIM in AM, and the BIM – GIS integration for AM indeed helps facilitate AM processes and improve their performance - this step is currently not possible to realize, due to the fact that Obsurv does not yet technically support 3D data, and should be completed at a later time.

6. Conclusions

AM systems are very complex and dynamic, due to the multiple stakeholders involved in different phases of an asset's life cycle and the diverse tools, data types and working methods the use. 2D data representation, for example, often proves insufficient for AM processes, requiring richer, 3D data visualization. Furthermore, parties involved in the concept/design/construction phases are more focused on the detailed, technically correct design of an asset, while operators and maintenance executors (contractors) are more interested in administrative asset information, such as the expected operation time, intervals for maintenance, and the asset measurements necessary for budgeting the maintenance costs.

The information transfer between stakeholders involved in an asset's life cycle phases is not always optimal, or in the desired format: a 3D CAD/Revit model of a bridge transferred from the design phase, for example, is too detailed for the maintenance phase, increasing the workload of operators; also, it may be sometime difficult for operators or third parties to understand the technical lingo in which the model is described (such as a model description in Ifc classes in the design phase, when in fact it needs to be described by the NEN norms in the maintenance phase).

It is thus important that the information transfer and communication between parties is as clear as possible. This can be realized by implementing BIM in AM from an asset's initial (concept/design) stages, and integrating it with other systems currently used in AM processes, such as GIS. BIM models include 3D representation of the assets to manage, along with all the relevant information about the asset, and the corresponding official and administrative documents integrated in the model.

Asset 3D representation allows for rich user interactions and can help improve stakeholders' understanding of an asset and its condition (even stakeholders without a technical background), while the integrated description and documentation of the asset can help reduce the information transfer fragmentation, both between stakeholders involved in different life cycle phases of an asset as well as between different working domains.

An integrated BIM - GIS model offers a clear overview of issues relevant to AM processes, involved parties, interactions between them, and spatial influences on AM processes, creating thus a controlled platform for data management and more effective AM. This insight into the complexities of AM processes can help better manage them, facilitating thus AM.

Even though existing research on BIM – GIS integration offers a good overview of the geometrical and semantic issues around IFC – CityGML transformation, this is not sufficient for Obsurv: the user requirements for the BIM-GIS integration in Obsurv are not fulfilled by a simple IFC-CityGML transformation.

BIM - GIS integration is tested in this research project through the integration of a 3D BIM model of a bridge in Obsurv, the test environment for the case study. *Obsurv* is a Dutch management system for public space and assets, available as a web-based service, providing asset information relevant for asset maintenance and budgeting processes.

The BIM - GIS integration was tested on two different levels: system and data level. The *system (or application)* level BIM-GIS integration gives users access on the fly to the BIM physical file (saved locally or updated to the cloud), and it does not involve geometric or semantic data transformation between the two systems. Integration at *data level* is realized through *geometric transformation* and *semantic mapping* between the IFC and NEN 2767-4 standards.

The BIM - GIS integration is about cooperation between parties involved in different stages of asset life cycle. Also, very important is the interoperability (technical, semantic) of data types used by both systems, provided by the used shared standards and norms.

The integration of BIM and GIS tested in this research is dependent on the reliability of the software used, and may not apply to future versions of BIM and GIS software, considering that almost every year new versions are released, which are not always backward compatible (with older versions).

User requirements play a very important role in the type of integration desired for a specific asset. They should thus be taken into account in any future integration steps. For the users, with the users!

Even though data level integration may offer a quick fix to the BIM-GIS integration in Obsurv, it is advised to integrate BIM as a process in an asset's life cycle. However, this greatly depends on the BIM integration in the initial phases of an asset's life cycle, and the possibilities (and/or willingness) for cooperation with stakeholders involved in different asset life cycle stages.

Collaboration between stakeholders involved in different stages of an asset's life cycle is essential for an increased efficiency and reduced complexity of AM processes. By involving asset operators and managers in the design phase, the desired performance of an asset can be included in its design and construction. This can thus result in better asset performance and more effective, less costly AM processes.

Since the BIM and GIS systems do not speak the same language, the semantic mapping of the different underlying standards is essential to their integration, at both system and data level.

Also, while it may seem easier to develop an own semantic mapping between different standards in Obsurv, this is a quite error-prone and time consuming process. It may be more advantageous to (wait for and) use the CB-NL for any semantic mapping (automation) necessary.

BIM in AM is in its initial phases, being applied in pilot studies for small scale projects. Even though it is acknowledged as a solution to the current complexity issues in AM processes caused by the diversity of systems, data types and standards used, organizations are still reluctant to adopt an integral BIM implementation. Reasons for this reluctance are the hesitance to learn new working methods (and new software packages), the implementation costs (which are seen as an investment in the concept/design phase of an asset's life cycle, with the risk of not gaining it back in later phases, and the reservation of some to share all the asset information with other parties. Knowledge is power, and is not shared too easily.

The implementation of BIM in AM is, however, the first step necessary to take for a BIM-GIS integration in AM. Overcoming these reasons users have not to BIM is thus the stepping stone to a more efficient and less costly AM.

Future research

A few issues raised in this study require further research. These are listed below.

One important issue is the data loss when exporting it to other formats (such as IFC). It is not yet clear how much data is lost in such a process, and what its consequences are. But it can affect the quality of a 3D model, and it should thus be studied in more detail.

The geometric BIM-GIS integration should be tested by using the methods described in this research and/or others described in other existing studies (referred to in this research project). For exact parameters and other user requirements (such as LOD), this step should include the client providing the data in setting up the testing platform.

The semantic mapping of IFC and NEN-2767-4 should be tested with the help of the CB-NL when it becomes available. Also, a tool for process automation will be available from the CB-NL, which should help automate the BIM-GIS integration, and it deserves thus further investigation.

Another issue needing further research is related to the validation of the prototype model, namely the costs avoided by the use of 3D BIM models in AM. This can be realized when the technical issues for the integration of BIM and GIS are resolved. A possible method to carry out this research is by dividing the AM process in tasks to carry out by different parties responsible for these tasks, including the time and costs (in days and/or hours and hourly rates) necessary to fulfill a task, plus the costs of the necessary materials. These costs should be measured once in the current way of executing AM processes, without the use of 3D models of assets, and once after the (conceptual) implementation of 3D asset models in Obsurv, for comparison. This way an estimate can be made of the time and money saved per task, helping thus assess the AM process performance with the use of a BIM-GIS integrated systems.

Last, but not least, the integration of Obsurv with Relatics is an issue which may prove beneficial for facilitating AM data sharing and information transfer. It should thus be investigated in detail.

7. References

1. Akinci, B., Karimi, H., Pradhan, A., Wu, CC., Fichtl, G. (2008). CAD and GIS interoperability through semantic web services. ITcon 13:39–55.
2. Akin, O. 2010. CAD/GIS Integration. Rationale and Challenges. In CAD and GIS integration / editors, Hassan A. Karimi and Burcu Akinci.
3. Ajam M., Alshawi M., Mezher T. 2010. Augmented process model for e-tendering: Towards integrating object models with document management systems. Automation in Construction 19 (2010) 762–778.
4. Alexiadi, C., and Potsioy C. 2012. How the integration of n- dimensional models (BIM) and GIS technology may offer the potential to adopt green building strategies and to achieve low cost constructions. TS08J - Building Information Modelling – BIM, 6061. Available at http://www.fig.net/pub/fig2012/papers/ts08j/TS08J_alexiadi_potsiou_6061.pdf.
5. Alshawi M., Ingirige B. 2003. Web-enabled project management: an emerging paradigm in construction. Automation in Construction 12 (4) (2003) 349–364.
6. Arpinar, I.B., Ramakrishnan, C., Azami, M., Sheth, A., Usery, E.L., Kwan, M.P. 2006. Geospatial Ontology Development and Semantic Analytics. In Transactions in GIS, 2006, 10(4): 551–575.
7. Autodesk. 2007. REVIT. Building Information Modeling. http://www.casetech.com/references/bim_and_fm_jan07_1_.pdf. Accessed on 14-01-2014
8. Autodesk, 2011. Autodesk FMDesktop. Accessed at http://usa.autodesk.com/adsk/servlet/pc/index?id=8140558&siteID=123112 on 15-01-2014.
9. Azhar S., Khalfan M., Maqsood T. (2012). Building Information Modeling (BIM): Now and Beyond. Australasian Journal of Construction, Economics and Building, 12 (4) 15-28
10. Benner J., Geiger A., Leinemann, K. (2005). Flexible generation of semantic 3D building models. In: Groger, G., Kolbe, T. (eds) Proceedings of the 1st International Workshop on Next Generation 3D City Models, Bonn, pp. 17–22.
11. Berlo, L. Van (2009). CityGML extension for Building Information Modelling (BIM) and IFC. Free and Open Source Software for Geospatial (FOSS4G), Sydney (2009).
12. Berners-Lee, T., O. Lassila, and J. Hendler. (2001). “The Semantic Web.” Scientific American.
13. Brink, Van Den, L., Stoter, J., Zlatanova, S. (2012). Establishing a national standard for 3D topographic data compliant to CityGML. International Journal of Geographical Information Science, Volume 27, Issue 1, 2013.
14. Brown, C. (2005) A Holistic Approach to the Management of Electrical Assets within an Australian Supply Utility. Sydney Graduate School of Management. Sydney, University of Western Sydney.
15. Casey, M.J. and Vankadara, S. (2010). Semantics in CAD/GIS integration. In CAD and GIS Integration. Edited by Hassan A. Karimi and Burcu Akinci. 2010. CRC Press. Taylor & Francis Group. International Standard Book Number: 978-1-4200-6805-4.
16. CB-NL, 2013. Accessed on 20-02-2014 at www.cb-nl.nl/blogitem.aspx?id=10150.
17. CERF. 1996. Level of Investment Study: Facility and Infrastructure Maintenance and Repair. Washington D.C., Civil Engineering Research Foundation.
18. Cerovsek, T. 2011. A review and outlook for a ‘Building Information Model’ (BIM): A multi-standpoint framework for technological development. In Advanced Engineering Informatics 25 (2011) 224–244.
19. Chang, K.T. (2006). Introduction to Geographic Information Systems. 3rd Edition. McGraw Hill. (ISBN 0070658986).

20. CIEAM (2008) CRC for Integrated Engineering Asset Management. Brisbane, CRC CIEAM.
21. Clemen, C., Grundig, L. (2006). The industry foundation classes-ready for indoor cadastre? In: Proceedings of XXIII International FIG Congress, Engineering Surveys for Construction Works II, Munich, Germany.
22. EC, Communication from the Commission to the Council, the European Parliament and the European Economic and Social Committee – Towards an Increased Contribution from Standardisation to Innovation in Europe, European Commission, Brussels, Belgium, 2008. http://europa.eu/rapid/press-release_IP-08-422_en.htm?locale=en
23. EC, European Interoperability Framework 2.0, in: IDABC (Ed.), European Interoperability Framework for Pan-European eGoverment Services, European Commission, Brussels, Belgium, 2008. http://ec.europa.eu/idabc/servlets/Docd552.pdf?id=19529
24. El-Mekawy, M., Ostman, A. and Shahzad, K. (2011). Towards Interoperating CityGML and IFC Building Models: A Unified Model Based Approach. In T.H. Kolbe et al. (eds.), Advances in 3D Geo-Information Sciences, Lecture Notes in Geoinformation and Cartography, DOI 10.1007/978-3-642-12670-3_5, # Springer-Verlag Berlin Heidelberg.
25. Erl, T., 2004. Service-Oriented Architecture: A Field Guide to Integrating XML and Web Services, Upper Saddle River, Prentice Hall.
26. Erp, J.B.F.van, Cremers, A.H.M., and Kessens, J.M. 2011. Challenges in 3D Geo Information and Participatory Design and Decision. In T.H. Kolbe et al. (eds.), Advances in 3D Geo-Information Sciences, Lecture Notes in Geoinformation and Cartography. Springer-Verlag Berlin Heidelberg 2011.
27. ESRI, 2008. What Is GIS? http://www.gis.com/whatisgis/index.html Accessed on 31 March 2014.
28. Fischer, M., Haymaker, J., Liston, K. 2003. Benefits of 3D and 4D models for facility managers and AEC service providers. In Raymond Issa, I. Flood, W. O'Brien: 4D CAD and Visualization in Construction: Developments and Applications. A.A. Balkema Publishers. Sweets & Zeitlinger B.V. Lisse.
29. Flohr, T. (2011). A Landscape Architect’s review of Building Information Modeling Technology. Landscape Journal 30:1-11.
30. Galloway AR. Protocol, how control exists after decentralization. The MIT Press; 2001.
31. Geonovum, 2013. Accessed on 2-04-2014 at http://www.geonovum.nl/onderwerpen/bgt-imgeo-standaarden/nieuws/consultatie-mapping-nen-2767-4-en-imgeo; http://www.geonovum.nl/onderwerpen/bgt-imgeo-standaarden/nieuws/afstemming-begrippen-conditiemeting-infrastructuur-nen-2767 Accessed on 2-04-2014
32. Gursel, I., Sariyildiz, S., Akin, Ö., Stouffs., R. 2009. Modeling and visualization of lifecycle building performance assessment. Advanced Engineering Informatics 23 (2009) 396–417.
33. Gruber, T.R. 1993. A translation approach to portable ontologies. Knowledge Acquisition, 5(2):199-220, 1993.
34. Gruber, T.R. 1995. Toward principles for the design of ontologies used for knowledge sharing. Presented at the Padua workshop on Formal Ontology, March 1993, later published inInternational Journal of Human-Computer Studies, Vol. 43, Issues 4-5, November 1995, pp. 907-928.
35. Haider, A. 2013. Information Systems for Engineering and Infrastructure Asset Management. Springer Gabler.
36. Haider, A., Koronios, A., and Kumar, A. 2011. An Object Oriented Road Asset Information Model. In J. Mathew et al. (eds.), Engineering Asset Management and Infrastructure Sustainability, DOI: 10.1007/978-0-85729-493-7_24, Springer-Verlag London Limited 2011.

37. Hall et al., 2004 Hall, J,W., Le Massurier, J.W., Bakker-Langman, E.A., Davis, J.P. and Taylor, A. A decision support methodology for performance-based asset management. Civil engineering and Environmental Systems. Vol. 21, No.1, March 2004, pp. 51-75.
38. Hermans, W. 2013. In Perspectief. ArcGISActueel. IP/AGA nr.3. 2013. ESRI Nederland. Available at http://magazine.esri.nl/nl/magazine/6357/735930/movares_met_gis_overzicht_in_bim.html
39. Hijazi I., Ehlers, M., Zlatanova S., Isikdag, U. (2009). IFC to CityGML transformation framework for geo-analysis: a water utility network case. In: Maeyer P de, Neutens T, Rijck M de (eds) 3D GeoInfo, Proceedings of the 4th International Workshop on 3D Geo-Information, Ghent University, Ghent, pp. 123–127.
40. Hijazi I., Ehlers, M., Zlatanova S., Becker, T., van Berlo, L. 2011. Initial investigations for modeling interior utilities within 3D Geo Context: transforming IFC-interior Utility to CityGML / Utility NetworkADE. In Advances in 3D Geo-Information Sciences, Lecture Notes in Geoinformation and Cartography. Springer-Verlag Berlin Heidelberg.
41. Humprey, B. (2003) Asset Managenent, in Theory and Practice. Energy Pulse: Insight, Analysis and Commentary on the Global Power Industry.
42. IAM, 2008. Institute of Asset Management. London, Institute of Asset Management. Accessed on 13-01-2014 at http://theiam.org/.
43. IEEE Standard Computer Dictionary: A Compilation of IEEE Standard Computer Glossaries, New York, NY: 1990.
44. Isikdag U., UnderwoodJ., Aouad G., Trodd N. 2007. Investigating the Role of Building Information Models as a Part of an Integrated Data Layer: A Fire Response Management Case, Architectural Engineering and Design Management, 3:2, 124-142.
45. Isikdag, U., Underwood, J., Aouad, G. (2008). An investigation into the applicability of building information models in geospatial environment in support of site selection and fire response management processes. Advanced Engineering Informatics 22:504–519.
46. Isikdag, U., Zlatanova, S. (2009). Towards defining a framework for automatic generation of buildings in CityGML using building Information Models. In: Lee J, Zlatanova S (eds) 3D Geoinformation and Sciences, Springer, Berlin, Heidelberg, pp. 79–96.
47. ISO/IEC 2382–1. http://transition.fcc.gov/pshs/techtopics/tech-interop.html
48. Jones, P. A. (2000) Diamond in the Rough? – Asset Management as a route to value creation. London, Institute of Asset Management.
49. Kasccaemsuppakorn P., Roongpiboonsopit D., and Karimi H.A. 2010. Current Trends and Future Directions in GIS. In CAD and GIS integration / editors, Hassan A. Karimi and Burcu Akinci.
50. Kibert, C. J. 1994. Establishing principles and a model for sustainable construction. In Proc of First International Conference of CIB TG 16 on Sustainable Construction. Tampa, Florida, USA, 1994, p. 3–12.
51. Kiritsis, D. 2013. Semantic technologies for engineering asset life cycle management. In International Journal of Production Research, Volume 51, Issue 23-24, 2013. http://dx.doi.org/10.1080/00207543.2012.761364.
52. Kolbe, T. H. (2008). Representing and Exchanging 3D City Models with CityGML, In: Lee J., Zlatanova, S., Lecture Notes in Geoinformation and Cartography, 3D Geo-Information Sciences, Springer, Berlin-Heidelberg.
53. Kulahcioglu, T., Dang, J., Toklu, C. 2012. A 3D analyzer for BIM-enabled Life Cycle Assessment of the whole process of construction. In HVAC&R Research, 18(1–2):283–293, 2012.

54. Kumar, D., Setunge, S., Patnaikuni, I. 2011How to Develop a Practical Asset Management Tool? In J. Mathew et al. (eds.), Engineering Asset Management and Infrastructure Sustainability, DOI: 10.1007/978-0-85729-493-7_40, Springer-Verlag London Limited 2011.
55. Laat, R. de and Berlo, L. van. (2011). Integration of BIM and GIS: The Development of the CityGML GeoBIM Extension. In T.H. Kolbe et al. (eds.), Advances in 3D Geo-Information Sciences, Lecture Notes in Geoinformation and Cartography. Springer-Verlag Berlin Heidelberg.
56. Lammeren, R. van, Houtkamp, J., Colijn, S., Hilferink, M., Bouwman, A. (2010). Affective appraisal of 3D land use visualization. Computers, Environment and Urban Systems 34, 465-475.
57. Lathouwer, B. de, (2013). Standards are the key to Civil/GIG/BIM Integration. LiDAR Magazine, vol. 3, no.2. www.lidarnews.com.
58. Lee, J.Y., Choi, S.S., Kim, G.Y., Noh, S.D. 2011. Ubiquitous product life cycle management (u-PLM): a real-time and integrated engineering environment using ubiquitous technology in product life cycle management (PLM). International Journal of Computer Integrated Manufacturing Vol. 24, No. 7, July 2011, 627–649.
59. Lee, K. M., Lee, Y. B., Shim, C. S., Park, K. L. 2012. Bridge information models for construction of a concrete box-girder bridge. In Structure and Infrastructure Engineering. Vol. 8, No. 7, July 2012, 687–703.
60. Lewis, H., Demmers M. 2013. Life Cycle Assessment and Environmental Management. AUSTRALIAN JOURNAL OF ENVIRONMENTAL MANAGEMENT-Volume 3
61. LGV. 2004. Asset Management Policy, Strategy and Plan. Melbourne, Department of Victorian Communities, Local Government Victoria. Accessed on 13-01-2014 at http://www.dpcd.vic.gov.au/__data/assets/pdf_file/0020/38180/AssetManagementPolicy.pdf
62. LI Juan, TOR Yam Khoon, ZHU Qing. 2006. The Integration Methods of 3D GIS and 3D CAD. In Innovations in 3D Geo Information Systems. Editors: Alias Abdul-Rahman, Sisi Zlatanova, Volker Coors. Springer Berlin Heidelberg New York.
63. Ligtenberg A., Wachowicz M., Bregt A.K., Beulens A., Kettenis D.L. 2004. A design and application of a multi-agent system for simulation of multi-actor spatial planning. Journal of Environmental Management 72 (2004) 43–55.
64. Linthicum, D.S., 2003. Next Generation Application Integration: From Simple Information to Web Services, Boston, Addison-Wesley.
65. Lo, C. P., Yeung, A. K. W. 2007. Concepts and Techniques of Geographic Information Systems 2nd ed. Upper Saddle River, NJ: Prentice Hall.
66. Lopez-Ortega,O., Ramírez-Hernández, M. 2007. A formal framework to integrate express data models in an extended enterprise context, Journal of Intelligent Manufacturing 18 (3) (2007) 371–381.
67. Motawa, I.m Almarshad, A. (2013). A knowledge-based BIM system for building maintenance. In Automation in Construction 29, 173–182.
68. Nagel, C. (2007). Conversion of IFC to CityGML; Meeting of the OGC 3DIM Working Group at OGC TC/PC Meeting, Paris (France).
69. Nagel, C., Stadler, A., Kolbe, T. (2009). Conceptual Requirements for the Automatic Reconstruction of Building Information Models from Uninterpreted 3D Models, Academic Track of Geoweb 2009 Conference, Vancouver.
70. NEN, The Netherlands Centre for Standardization, 2010. NEN 2767-4, Condition Assessment of infrastructure Part 1 Methodology. Delft, the Netherlands: The Netherlands Centre for Standardization (in Dutch).
71. Newell, R. G., and Sancha, T. L. 1990. The Difference between CAD and GIS. Computer - Aided Design, 22(3): 131–135.

72. Newton, R.S. 2004.Inadequate Interoperability in Construction Wastes 415.8 Billion. AECNews.com, 13, Article 342.
73. OGC (Open Geospatial Consortium). 2005. Web Feature Service Implementation Specification.
74. OKFN, Open Knowledge 2011. Data Hubs, Data Management Systems and CKAN. OKFN Notebook. Foundation. 2011-04-27. Accessed at http://notebook.okfn.org/2011/04/27/ 29-10-2013.
75. Osman, H. 2012. Agent-based simulation of urban infrastructure asset management activities. Automation in Construction 28 (2012) 45–57.
76. Paar, P. 2006. Landscape visualizations: Applications and requirements of 3D visualization software for environmental planning. In Computers, Environment and Urban Systems, Volume 30, Issue 6, November 2006, Pages 815–839.
77. Parida, A, 2012. Asset performance assessment. In Asset Management, T. van der Lei et al., 2012.
78. Przybyla, J. (2010). The next frontier for BIM: interoperability with GIS. Journal of Building Information Modeling, Fall 2010, pp. 14-18.
79. Rachuri,S., Subrahmanian, E., Bouras, A., Fenves, S.J., Foufou, S., Sriram, R.D. 2008. Information sharing and exchange in the context of product lifecycle management: Role of standards. In Computer-Aided Design 40 (2008) 789–800.
80. Rakkolainen I, Vainio T (2001) A 3D City Info for mobile users. Computers and Graphics 25: 619–625.
81. Reddy, K. P. (2011) BIM for Building Owners and Developers, NJ: John Wiley and Sons
82. Rees, E. van. (2007). BIM data exchangeability with new WFS for GML. OGC workgroup for CAD-BIM-GIS Integration. GEOinformatics.
83. Reuvers, M. 2004. A standard supporting semantics in a Spatial Data Infrastructure (SDI). In Geo-information Standards in Action. Peter J.M. van Oosterom (Editor). Nederlandse Commissie voor Geodesie Netherlands Geodetic Commission 42. ISBN 90 6132 289 8
84. Rezgui, Y., Beach. T., Rana, O. 2013. A governance approach for BIM management across lifecycle and supply chains using mixed-modes of information delivery. JOURNAL OF CIVIL ENGINEERING AND MANAGEMENT. 2013 Volume 19(2): 239258.
85. Sabol, L. 2008. Building Information Modeling & Facility Management IFMA World Workplace November 2008.
86. Shen, Li-Yin, Hao, Jian Li, Vivian Wing-Yan Tam, Hong Yao. 2007. A checklist for assessing sustainability performance of construction projects. In JOURNAL OF CIVIL ENGINEERING AND MANAGEMENT http:/www.jcem.vgtu.lt 2007, Vol XIII, No 4, 273–281.
87. Shen, W., Hao Q., Mak H., Neelamkavil, J., Xie, H., Dickinson, J., Thomas, R., Pardasani, A., Xue H. 2010. Systems integration and collaboration in architecture, engineering, construction, and facilities management: A review. Advanced Engineering Informatics 24 (2010) 196–207.
88. Sheth, A. 1999. Changing Focus on Interoperability in Information Systems: From System, Syntax, Structure to Semantics. In Interoperating Geographic Information Systems, Goodchild, M. F., Egenhofer, M. J., Fegeas, R. G. and Kottman, C. A., Eds. Norwell, MA: Kluwer.
89. Sklar, D. (2004) Principles of Asset Management – The Holistic Model. Energy Pulse: Insight, Analysis and Commentary on the Global Power Industry.
90. Song, Y., Bogdahn, J., Hamilton, A., Wang, H. (2013) Integrating BIM with Urban Spatial Applications: A VEPS perspective. www.igi-global.com/chapter/integrating-bim-urban-spatial-applications/39480. Accessed 29-09-2013.

91. Stark, J. 2005. Product lifecycle management: 21st century paradigm for product realisation. Springer-Verlag London Limited 2005. Printed in the United States of America. ISBN 1852338105.
92. Succar, B., Sher, W., Williams, A. 2013. An integrated approach to BIM competency assessment, acquisition and application. Automation in Construction (2013).
93. Sutton, T., Dassau, O., Sutton, M. (2009). A Gentle Introduction to GIS. Brought to you with Quantum GIS, a Free and Open Source Software GIS Application for everyone. Chief Directorate: Spatial Planning & Information, Department of Land Affairs, Eastern Cape.
94. Taisch, M., Cammarino, B.P., Cassina, J. 2011. Life cycle data management: first step towards a new product lifecycle management standard. International Journal of Computer Integrated Manufacturing. Vol. 24, No. 12, December 2011, 1117–1135.
95. Too, E.G. 2010. A framework for Strategic Infrastructure Asset Management. In J.E. Amadi-Echendu, K. Brown, R. Willett, J. Mathew, Definitions, Concepts and Scope of Engineering Asset Management, © Springer 2010).
96. Too, E.G. 2011. Strategic Infrastructure Asset Management: The way forward. In J. Mathew et al. (eds.), Engineering Asset Management and Infrastructure Sustainability, DOI: 10.1007/978-0-85729-493-7_40, Springer-Verlag London Limited 2011).
97. Van der Lei, T. E., Wijnia, Y. C. and Herder, P. M. 2011. Towards an Asset Management Framework of Asset Characteristics, Asset Environment, Lifecycle Phases, and Management. In J. Mathew et al. (eds.), Engineering Asset Management and Infrastructure Sustainability, DOI: 10.1007/978-0-85729-493-7_40, Springer-Verlag London Limited 2011).
98. Vanlande, R., Nicolle, C., Cruz, C. (2008). IFC and building lifecycle management. In Automation in Construction 18 (2008) 70–78.
99. Vectorworks Architect. 2012. Better designs with better BIM. Available at http://download2cf.nemetschek.net/www_misc/2012/Vectorworks-BIM-Brochure.pdf.
100. Velde, J. van der, Klatter, L., Bakker, J.A holistic approach to asset management in the Netherlands. Structure and Infrastructure Engineering Vol. 9, No. 4, April 2013, 340–348.
101. Wanyama, W., Ertas, A., Zhang, H.C., Ekwaro-Osire, S. Life-cycle engineering: Issues, tools and research. INT. J. COMPUTER INTEGRATED MANUFACTURING, 2003, VOL. 16, NO. 4–5, 307–316.
102. Warren R and Wertheim AH (1990) Perception and Control of Self-Motion. Hillsdale, NJ: Lawrence Erlbaum Associates.
103. Wasmer, A., Staub, G., Vroom, R.W. 2011. An industry approach to shared, cross-organisational engineering change handling - The road towards standards for product data processing. In Computer-Aided Design 43 (2011) 533–545.
104. Wu, I-Chen, Shang-Hsien Hsieh. 2012. A framework for facilitating multi-dimensional information integration, management and visualization in engineering projects. Automation in Construction 23 (2012) 71–86.
105. Zhu Q., Zhao J., Du Z., Zhang Y., Xu W., Xie X., DingY., Wang F., and Wang T. (2011). Towards Semantic 3D City Modeling and Visual Explorations. In T.H. Kolbe et al. (eds.), Advances in 3D Geo-Information Sciences, Lecture Notes in Geo-information and Cartography,Springer-Verlag Berlin Heidelberg 2011.

Websites used:

1. http://www.geoinformatics.com/layouts/cmediageoinformatics/secure/GEO/2007/GEO78/P30-31%20GEO78.pdf Accessed on 29-10-2013
2. http://www.obsurv.nl/ Accessed on 29-10-2013
3. http://www.grontmij.nl/ Accessed on 29-10-2013
4. http://www.relatics.com/ Accessed on 29-10-2013
5. http://www.citygml.org Accessed on 29-10-2013
6. http://www.geonovum.nl/onderwerpen/3d-geo-informatie/toolkit-3d Accessed on 29-10-2013
7. http://nieuwsinkaart.nl/cbnl/ Accessed on 29-10-2013
8. http://www.ifcwiki.org/index.php/IfcExplorer_CityGML_Export Accessed on 29-10-2013
9. http://www.safe.com/products/desktop/formats.php Accessed on 29-10-2013
10. http://www.opengeospatial.org/ogc/programs/ip. Accessed on 29-10-2013
11. http://geostandards.geonovum.nl/index.php/Main_Page. Accessed on 29-10-2013
12. http://www.onuma.com Accessed on 31-10-2013
13. http://www.esri.com/news/arcuser/0403/overview1of3.html Accessed on 31-10-2013
14. http://www.esri.com/news/arcuser/0403/webservices.html Accessed on 31-10-2013
15. http://www.buildingsmart-tech.org/future-extensions/ifc_extension_projects/current/ic3 Accessed on 13-10-2013
16. http://www.wshd.nl Accessed on 31-10-2013
17. http://www.waterschaprivierenland.nl Accessed on 31-10-2013
18. http://www.schielandendekrimpenerwaard.nl Accessed on 31-10-2013
19. http://www.scheldestromen.nl Accessed on 31-10-2013
20. http://www.buildingsmart.org/ Accessed on 31-10-2013
21. http://www.w3.org/standards/semanticweb/ Accessed on 31-10-2013
22. http://www.w3.org/Submission/2004/07/ Accessed on 31-10-2013
23. http://www.w3.org/TR/2004/NOTE-ws-gloss-20040211/#webservice Accessed on 31-10-2013
24. http://standards.build-laccd.org/projects/dcs/pub/BIM%20Standards%20DB/released/content.html/ Accessed on 17-01-2014
25. http://www.citygmlwiki.org/index.php/Free_Software Accessed on 20-03-2014
26. http://www.ifcwiki.org/index.php/Freeware Accessed on 20-03-2014
27. http://wiki.ibim.nl/wiki/buildingsmart/ Accessed on 28-03-2014
28. http://www.ifcwiki.org/index.php/Main_Page Accessed on 29-03-2014
29. http://www.coinsweb.nl/wiki/index.php/COINS_Building_Information_System Accessed on 29-03-2014
30. http://www.coinsweb.nl/wiki/index.php/Reference_Manual Accessed on 29-03-2014
31. http://www.coinsweb.nl/wiki/index.php/Information_transfer Accessed on 29-03-2014
32. http://www.mittaviiva.fi/hannu/BIM_project/index_bim_basics_en.html Accessed on 28-03-2014
33. http://inspire.jrc.ec.europa.eu/index.cfm/pageid/47 Accessed on 29-03-2014
34. http://www.eea.europa.eu/about-us/what/seis-initiatives/inspire-directive Accessed on 29-03-2014
35. http://www.geonovum.nl/onderwerpen/inspire/algemeen-inspire Accessed on 30-03-2014
36. www.nationaalgeoregister.nl Accessed on 29-03-2014
37. www.crow.nl Accessed on 29-03-2014

38. http://usa.autodesk.com/adsk/servlet/pc/index?id=8140558&siteID=123112 Accessed on 30-03-2014
39. http://www.track3d.nl/ Accessed on 2-04-2014
40. www.e-overheid.nl/actueel/nieuwsberichten/intItem/nieuwe-versie-imgeo-bgt/1807 Accessed on 2-04-2014
41. www.geonovum.nl/onderwerpen/geography-markup-language-gml/geography-markup-language Accessed on 2-04-2014
42. http://www.geonovum.nl/wegwijzer/standaarden/mapping-imgeo-en-nen-2767-4-conditiemeting-infrastructuur.
43. http://public.cbnl.org/upload/forum/nieuws/Roadmap%20CB-NL%20versie%201%200.pdf Accessed on 2-04-2014

Appendices

Appendix 1. List of interviewees

Organization	Name interviewee
Rotterdam Municipality	Olivier Herck
Helmond Municipality	Peter Roeling
Roerdalen Municipality	Rudy Stevens
Opmeer Municipality	Paul van Paar
Amstelveen & Aalsmeer Municipality	Irma Smak
Utrecht Municipality	Jasper van Thiel
Uithoorn Municipality	Tinok van Hatem
OSS Municipality	Cees Coensen
Ede Municipality	Eric Sprong
Noord-Brabant Province	C.J.A.M Kees Kohler
Gelderland Province	Anton Vogels
Gelderland Province	Niels Reyngoud

Grontmij	Henri Veldhuis
Grontmij	Adrie Tepas
Grontmij	Ronald van Lanen
Grontmij	Jan van Malenstein
Grontmij	Marcel de Lange
Grontmij	Marieke Steltenpool
Grontmij	Hans Bruinsma
Grontmij	Idoia Martinez
Grontmij	Lans Evert
Grontmij	Martijn van Drunen
Grontmij	Martijn Kouwenhoven
Grontmij	Daniel Vos
Geonovum	Marcel Reuvers - CB-NL expert

Appendix 2. Interview questions

Organization

In which organization do you work? (In which department)

What role does your organization have in the management of public spaces and assets? (What assets does it manage: green areas, infrastructural assets – bridges, tunnels, roads, water?)

What is your role in this organization? Asset manager, policy maker..

What tasks do you carry out?

Asset Management (AM)

How does your organization manage public spaces/assets?

- activities – tasks, methods (policy, inspections)
- involved parties (tasks per department, services carried out by third parties)
- software packages used for AM tasks

BIM

Are you familiar with BIM (Building information modeling)?

Does your organization use BIM in construction and asset management projects?

(If so, how? In which project? Can u tell me more about that?)

Are the assets you manage available in 3D?

Do you think that visualizing the assets you manage in 3D would help facilitate the AM process? How?

Thank you for your time!

Appendix 3. Software packages for viewing BIM models

Software	Supported formats	Functionalities	Open Source
Revit	.rvt, .ifc,	Design	No
Navisworks	.nvc, .dwf, ifc,	Viewer, clash detection	No
Autodesk360cloud	.dwfx	Viewer	Yes
Design Web Format	.dwf		No
Solibri model viewer	.ifc	Viewer	Yes
Solibri IFC optimizer	.ifc	optimizing/compressing IFC files	yes
IFC Viewer	.ifc	Viewer	Yes
BIM Server	.ifc	?	
BIMsurfer (needs BIMserver)	.ifc	WebViewer	Yes
TeklaBIMsight	.ifc, .dwg, .xml	Viewer, clash detection	Yes
FZKViewer	.ifc, CityGML	Viewer	Yes
Aristoteles	CityGML	Viewer	Yes
CityGML-Toolchain	CityGML	Viewer	Yes