3D Spatial Infrastructure for the Port of Rotterdam

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GISt Report No. 67

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Delft University of Technology

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Summary

This report presents the investigations, developments and the result of the project 3D spatial data infrastructure, funded by Next Generation Infrastructures, Maasvlakte 2

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1 Introduction

The continuous development and maintenance of the infrastructure, facilities, logistics and other assets of the Port of Rotterdam requires the management of a broad spectrum of heterogeneous information (HbR, 2010). A large number of public and private stakeholders that include companies, environmental authorities, e.g. DCMR Milieudienst Rijnmond, municipalities, various institutions and citizens are constantly involved in the exchange of critical information. Much of this information concerns interdepended infrastructural artefacts and features that are embedded in a dynamic environment which is in a constant state of transformation. These artefacts are spatially distributed above ground (topography, cadastral parcels, buildings, streets, parking areas), underground (cables and pipes, geological and geotechnical data, tunnels), in the air (sensors for measurement of air quality, radar coverage, camera coverage) as well as in the water. Three general groups of problems can be summarised (Botter, 2012, Zlatanova and Beetz, 2012) :

Lack of dimensionality and common semantics: At present, a substantial part of the data sets that are communicated in the management and design processes of the Port consist of traditional 2D line drawings. As often mentioned in the literature (Emgård and Zlatanova, 2008, Tegtmeier et al 2014, Zlatanova et al 2010) this requires frequent re-modelling and even re-measuring which is resource-consuming. In addition, the meaning transported by these drawing is often weakly structured only by means of layers, colours or pen styles which require human interpretation and make the automation of data integration much harder as compared to object-oriented and semantically rich representations. Rich sematic models as CityGML and IFC are hardly used, due to various integration problems (Beetz et al 2009, 2010, Hidjazi et al 2009, 2010).

Data complexity: Data sets available for design and maintenance process are increasingly complex, large and diverse. This complexity concerns several aspects. *Size*: the semi-automated gathering of high resolution measurement data, such as sensor data and voxel sets of underground information provided by RWS, TNO and City of Rotterdam (GWR), results in large data sets which are challenging to process. *Semantic diversity*: for data based on existing semantically rich data models (i.e. CityGML LOD2 model of City of Rotterdam and IMxxx models of Geonovum) problems arise from matching and mapping different semantic concepts for an integration of heterogeneous data into a single model. *Granularity & accuracy*: with varying geometric and topological detail of available data sets (such as TOP10NL, GBMN, IMGeo2), abstraction, simplification and the provision of multiple levels of detail are necessary to facilitate the decision making process (Arroyo Ohori et al 2012).

Data exchange and interoperability: The majority of data transferred between stakeholders and Port of Rotterdam is encoded in proprietary files (like shape, dwg, dgn) that require the use of a large range of specialized applications and tools with a high total cost of ownership/operation. The extraction of relevant aspects from disconnected source documents and databases, and their transformation into target formats by individual operators is inefficient and hard to automate and therefore labour and time consuming.

This project investigated 3D spatial infrastructure for information management, which can support current and future activities of Port of Rotterdam especially with respect to the extension of the port with the new land of Maasvlakte2.

There are two major aspects in this research: what kind of 3D SII is suitable for Port of Rotterdam and how to evaluate/estimate the efficiency? The following sub-questions are related to the 3D SII:

- Which objects (features) are relevant? (semantics, geometry, topology, appearance, LOD);
- What kind of data structure is most appropriate to maintain the objects, their properties and relationships;
- What kind of mapping technology between different models should be utilised: syntax and structure vs. semantics (ontology);
- Which standard for exchange of information should be used: GML, CityGML, BIM (IFC), IMxxx;
- Which system architecture should be utilised: NORA, OGC web services, RESTful vs. SOAP;
- What visualisation approaches should be followed: thin clients vs. front-end application, mobile vs. desktop environment.

The report is organised as follows:
The next section 2 described the current status and provides more details on the two cases studies.
Section 3 proposes a system architecture.
Section 4 discusses the options for integrated management of GIS data.
Section 5 elaborates on the BIM model.
Section 6 discusses the options for integrated management of GIS and BIM data.
Section 7 presents 3D analyses and visualisation examples for utilisation of the 3D model.

2 Current State: Use Cases

Two use cases have been identified as study scenarios for which the new methods and technologies were investigated: **underground pipe lines** and **quays**. Both scenarios have been identified as critical issues in internal studies of the Port of Rotterdam and other stakeholders such as the City of Rotterdam.

2.1 Underground pipe and cables

The current management of pipes and cables is 2D. The records (geometry and register) are obtained from the Municipality of Rotterdam in the form of 2D drawings (although the existence of 3D records) that are copied in bulk on a regular, yet informal basis. The department MI and Gemeentewerken (Stadsbeheer) ensure the management of the piping network such as improving the network, making extensions or modifications. The port contains a large number of CAD drawings. When received at the Port of Rotterdam the information is organised in a 2D data model (Oracle Spatial), which resembles the structure if the obtained shape files. The data model is used to support various task in design of new facilities and extensions and new pipes and lines. The information can be visualised in the internal 2D viewer RIV (Figure 1) or extracted in excel sheets and analysed (Figure 2). The lack of depth information as well as a proper 3D visualisation (for inspection and control) make many of the analysis time consuming and inaccurate. The current data model is relatively simple: does not maintain topology, different networks can be distinguished only by attributes, clear semantics about components does not exist, no links are maintained to above ground objects or data (streets or houses or AHN).

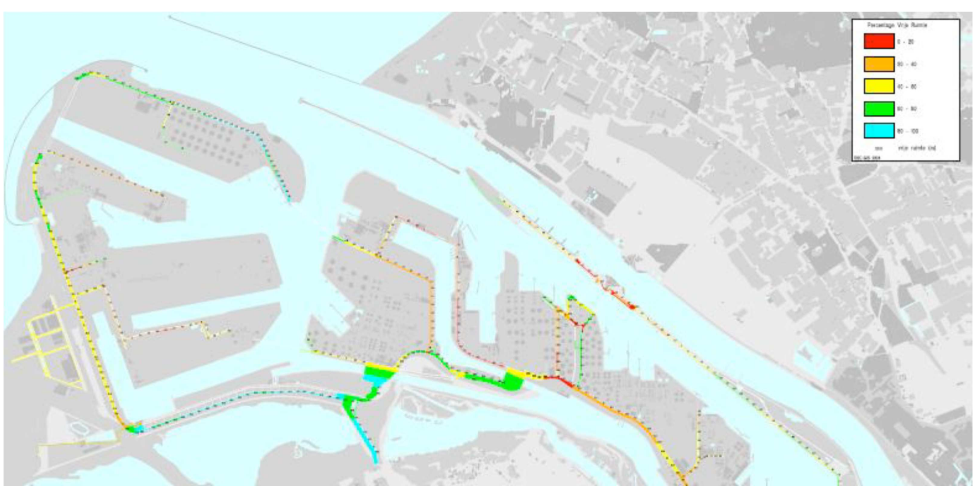


Figure 1: Visualisation in RIV

Veld	Type	Algemene omschrijving	Leidingstrook	Paddestoel	Kabelbedzijde	Verbodsbord
ID	NUMBER(10,0)	Uniek en betekeningsloos ID				
EXTERNE_CODE	VARCHAR2(100)	Sleutelveld in extern systeem	ID bij gemeente Rotterdam	ID bij gemeente Rotterdam	ID bij gemeente Rotterdam	ID bij gemeente Rotterdam
OTY_ID	NUMBER(8,0)	Object type ID (laag nummer)	1275	1276	1277	1278
FUNC_START_DATUM	DATE	Functionele startdatum; start geldigheid van het fysieke object				
FUNC_EIND_DATUM	DATE	Functionele einddatum; einde geldigheid van het fysieke object				
TECH_START_DATUM	DATE	Technische startdatum; datum eerste opvoer in het systeem				
TECH_EIND_DATUM	DATE	Technische einddatum; datum "verwijdering" uit het systeem				
TECH_USER_LAATSTE_WIJZ	VARCHAR2(100)	Gebruikersnaam bij laatste wijziging				
LABEL_JUSTIFICATION	VARCHAR2(2)	Label uitlijning code	leeg	leeg	leeg	leeg
LABEL_ROTATION	NUMBER(16,0)	Label rotatie	leeg	leeg	leeg	leeg
LABEL_OFFSET_X	NUMBER(16,0)	Label offset in X richting	leeg	leeg	leeg	leeg
LABEL_OFFSET_Y	NUMBER(16,0)	Label offset in Y richting	leeg	leeg	leeg	leeg
TEKST_HOOGTE	NUMBER(5,1)	Teksthoogte in meters	leeg	leeg	leeg	leeg
STEUNLIJN_JN	VARCHAR2(1)	Tekenen van steunlijn	leeg	leeg	leeg	leeg
TEKST	VARCHAR2(100)	Weer te geven tekst	leeg	Paddestoel nummer	leeg	leeg

Figure 2: Example of the information stored for pipes and cables

2.2 High-performance quays

At present, a great diversity of information sources, models and software systems is involved in the on-going planning, construction and management of high-performance quays. A quay wall can be seen as an assembly of structural engineering components, a series of logistical units consisting of bollard slots (boldervakken), a piece of real estate or as the target zone of a navigation channel that has been externally contracted for constant excavation to guarantee a certain ship draft (ligplaatsdieptes, baggervakken) for a client (Figure 3a). When frequent re-occurring changes, such as renting out a berth to a new client, have to be organised, presently this is done in an ad hoc process where relevant information is gathered, processed and communicated in an unstructured way involving different internal and external stakeholdersSince information systems only exist within specialized domains (e.g. infrastructural engineering, infrastructural facility management, financial management) and no interfaces between these systems have been formally defined, a high amount of manual, error-prone work is involved in the current practice. . Figure 3b is example of a Revit 3D model of newly designed quay, which cannot be integrated with existing GIS information. This results in high costs due to damage and contract claims, unnecessary excavation and construction, dissatisfied customers and information loss.

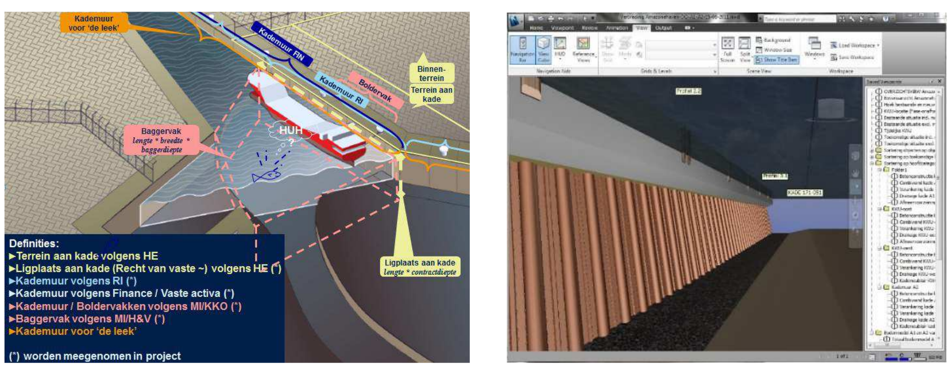


Figure 3: Problems in descriptions of quays (left)and BIM representation (right)

In the context of the 3DSDI project, an extensive inventory of the current requirements, processes, management structures, information flows, data structures and software tools employed across the different departments of HbR has been carried out. The findings of this investigation have been documented in a separate document "3D Spatial Data Infrastructures: Phase 1: User Requirements".

Many of the above mentioned problems can be resolved with a well-structures semantically rich 3D model. Semantically-rich is here understood as a model which contains definitions about the names, geometry (containing rules for validity), topology (relationships between the objects) and appearance of the objects. 3D spatial information has become widely used in daily life. Large companies, small businesses as well as private persons have access to 3D spatial information in various scales and resolutions and the need for integrated modelling (above, below and on the surface) is growing. Much of this information however is not well-structured. At the moment we are facing an important development; from 3D to valid and semantically rich 3D data (Arroyo Ohori et al 2012, Emgård and Zlatanova 2008, Lappiére and Côté 2008, Penninga 2008, Scarponcini et al 2008, Döner et al 2010, Stoter et al 2010). In 2007, the majority of the large companies dealing with spatial information have announced 3D functionality within database technology (Oracle Spatial 2007), Architecture Engineering and Construction (AEC) software (Bentley Inc, Autodesk,), GIS Software (ESRI) and spatial data processing (SAFE). CityGML was accepted as OGC 3D standard (Gröger et al 2007), Building Information Models (BIM) are becoming more mature and the conversion between CityGML and BIM is a hot topic of investigations (Hijazi et al 2009, Hijazi et al 2010, Isikdag and Zlatanova 2009). Geonovum is actively considering extensions of some Dutch Information Models (IM) toward 3D (Stoter et al 2010). A prominent example of these extensions is 3D IMGeo.

All these developments suggest that 3D information management is technically possible, but should be well-tuned for the purposes and tasks of an organisation. One of the major bottlenecks in the process of upgrading to 3D is the data model. The model should be able to provide mechanisms for integrating all data (above and below the ground as well as BIM data) in one application. This is a very challenging task as the data (created for the purpose of the maintaining company) might be with a very specific content (e.g. risicoconturen) or in contrary intended for a very broad range of clients (GBK vlakken). As result the objects might have either very detailed or insufficient descriptions. Furthermore depending on the application, various geometric representations might be used. The current data sets are available as B-reps (most GIS data, many BIM data structures), CSG, meshes (some of the CAD and BIM data) and voxels (underground data). There are several approaches to solving of data heterogeneity:

- Create a new (company specific) model. All incoming data then will be transformed to the new 3D model
- Keep the data in their original descriptions but maintain the needed references between the objects
- Extend existing data models with additional, company-specific structures to accommodate specific information requirements. This approach was leading in this project because of two reasons. Firstly, the discussions with specialists have revealed that the Port of Rotterdam uses data sets from many different institutions and is responsible for the maintenance of very few data sets. Secondly, the study on spatial data needed for the Port of Rotterdam has clarified that most of the features of interest are described in international and national data standards.

In this project, three variants of this approach have been investigated for their feasibility for the specific case of Port of Rotterdam.

3 System Architecture

In order to facilitate interoperability between the different stakeholders identified in the requirement analysis of both case studies – pipes and quays – a number of different approaches have been identified. These are illustrated in this section of the report.

The integrated model is intended to be used in a Service-Oriented Architecture that allows just-in-time extraction and integration of distributed data sources through web services. Such an approach ensures

- Data integrity through separation of concerns: The individual data sources are maintained by small expert teams. If individual nodes temporarily fail, the overall structure will continue to work.
- Up-to-datedness, i.e. always the last version of the data as available to the data manager.
- Efficient management, i.e. distributed and shared responsibilities instead of centralized management.
- Clear agreements on ownership and data management.

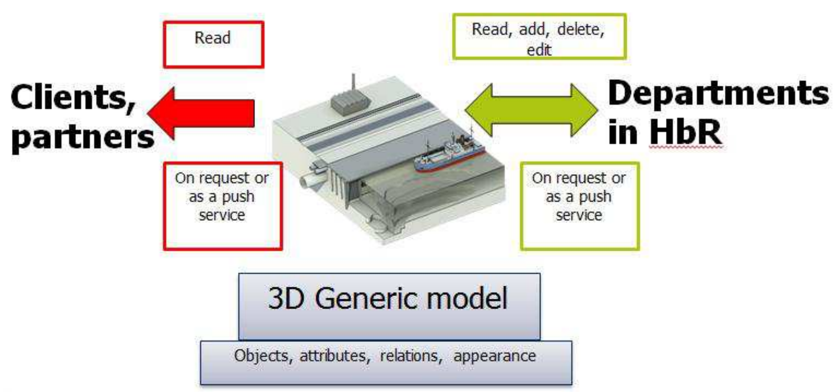


Figure 4:Concept for access and exchange of data

Two approaches have been investigated in the context of this project:

- Central database for objects that are managed by Port of Rotterdam, using state-of-the art commercial off the shelf solutions such as Oracle GIS databases.
- Web services for data that are the responsibility of other organisations, such as the City of Rotterdam or engineering offices working on particular tasks such as quay walls. This approach relies on technologies as the OGC family of geospatial information access standards through e.g. Web Feature Services (WFS) and developments in (spatial) queries of partial Building Information Models (BIM) including concepts such as Model View Definitions (MVD).

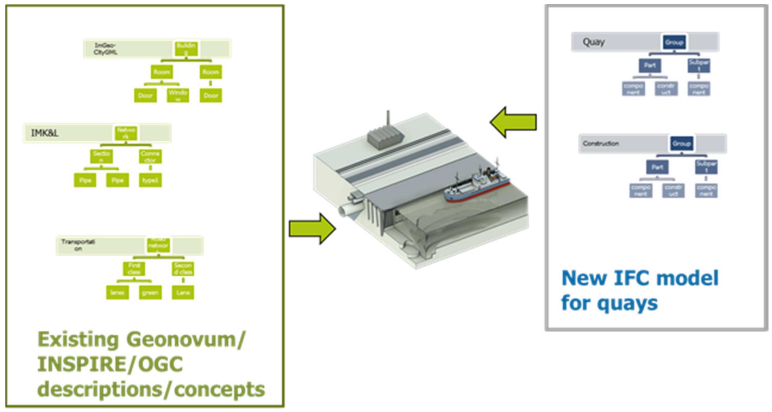


Figure 5: Conceptual view of the data model

Examples:
Quay wall structures in databases exposed with web services and enriched with distributed vocabularies:
For the use case of the new constructions of – among others – quay wall structures in the Amazonehaven area of the Port of Rotterdam, a number of different experiments and test have been conducted. These involved

- The creation of novel explicit schema extensions of the predominant BIM interoperability format Industry Foundation Classes (IFC) for quay walls
- The integration of GIS and simplified BIM data at lower levels of details into common models exposed for online viewing in a dashboard application prototype (Demonstrator 1)
- The creation of novel semantic enrichment facilities for the backward-compatible enrichment of legacy IFC BIM models with RDF vocabularies. This has led to the implementation of a proof-of-concept prototype (Demonstrator 2)
- A demonstration of shared databases with the City of Rotterdam that allow the facilitation and integration of up-to-date data across institution boundaries.

4 3D Integrated Management of GIS Data

In the project, methodological concepts and developments for object-oriented 3D spatial models were investigated, extended and tailored to the purposes of large infrastructures such as the Port of Rotterdam. The process followed two phases:

- A new integrated 3D model for internal use. This approach allows a well-tailored model to be defined that can closely reflect the needs of the Port. However such approach requires a large number of modifications of data sets that are not maintained by Port of Rotterdam.
- A 3D model based on national and international standards. Standards have been considered since the start of the project, but a 3D model based entirely on international and national standards was adopted only in the second phase of the project. Two major developments had impact on this decision:
    - Geonovum as intention to establish relations between all concepts
    - Last developments with BuildingSMART and OGC for harmonisation of concepts.

In this project we have concentrated on the second option for two major reasons:

- Limited responsibility for data sets. Many of the data sets are not maintained by the Port but obtained from various institutions and the Rotterdam municipality. This implies that many of the data sets are already supplied according to national or international standards
- Re-use of concepts. The re-use of concepts and definitions will save time to process data as less conversions will be needed and will reduce errors and information loss while converting from one format to another.
- Awareness of national and international standards. The awareness of available standards will definitely increase the contribution of the Port to the standardisation process. The Port of Rotterdam is excellent cross domain case study where integration of types of data above and below ground, under water design BIM and existing GIS data, 2D and 3D have to be brought together in one environment not only for visualisation but also for analysis.

4.1 A model based on international standards

The set of features (assets), which have to be included in the model considering their semantics, geometry, topology, appearance, granularity or levels of detail (LOD). Moving to 3D, it should be also evaluated how to link the concepts of BIM (e.g. IFC) and GIS (e.g. CityGML). The generic model will give the conceptual view on the information to be managed by the Port. Some sections of it will be implemented as data structure, but many sections will be used only as a reference model to obtain data from clients and partners.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
1	F	F		S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S			
2																						
3																						
4	NAAM	ALIAS	STEREO	IMBAG	IMDBK	IMGEO	IMKAD	IMKL	IMLB	IMLG	IMNAB	IMOOV	IMRO	IMSIKB	IMVA	IMVE	IMVOZ	TOP10NL	IMBRO	DOCUMENTATION	HbR	HbR
5	_AdresseerbaarObject		xsdcomplextype	IM																Een ligplaats, verblijfsobject of standplaats.	t	
6	Ligplaats			IM																Een LIGPLAATS is een formeel door de ge	t	IMVA
7	Nummeraanduiding			IM																Een NUMMERAANDUIDING is een door d		
8	OpenbareRuimte			IM																Een OPENBARE RUIMTE is een door de g		
9	Pand			IM																Een PAND is de kleinste, bij de totstandkor	t	IMGEO
10	Standplaats			IM																Een STANDPLAATS is een formeel door d	?	
11	Verblijfsobject			IM																Een VERBLIJFSOBJECT is de kleinste binr	t	
12	Woonplaats			IM																Een WOONPLAATS is een door de gemeer	t	
13	Gebruiksdoel		enumeration	IM																Een categorisering waarmee het gebruiksdo	t	
14	TypeAdresseerbaarObject		enumeration	IM																De aard van een als zodanig benoemde NUI	t	
15	TypeOpenbareRuimte		enumeration	IM																De aard van de als zodanig benoemde OPE		
16	AfwijkendeBinnendekking		featuretype		IM															-- Definition -- Op de DBK wordt aangegever		
17	Brandcompartiment		featuretype		IM															-- Definition -- Een pand kan bestaan uit mee	t	
18	DBKFeature		featuretype		IM															-- Definition -- Voor de brandweer relevant o	t	
19	DBKGebied		featuretype		IM															-- Definition -- DBKFeature gerelateerd aan	t	
20	DBKLijn		featuretype		NE																t	
21	DBKObject		featuretype		IM															-- Definition -- DBKFeature gerelateerd aan	t	
22	DBKPunt		featuretype		NE															-- Definition -- Verzamelobject voor verschil	t	
23	DBKVlak		featuretype		NE																t	
24	DBKVoorziening		featuretype		IM																t	
25	Foto		featuretype		NE															-- Definition-- Verwijzing naar een foto. -- De	t	
26	GevaarlijkeStof		featuretype		IM															-- Definition -- Gevaarlijke stoffen zijn stoffe	t	
27	Pandgeometrie		featuretype		NE															-- Definition -- Object waarin het pandId sam	t	IMGEO
28	ToegangTerrein		featuretype		IM															-- Definition -- -- Description -- De toegang r	t	
29	BridgeConstructionElement		featuretype			NE														Onderdeel van een brug dat essentieel is va		
30	_AbstractBuilding		featuretype			NE															t	
31	BuildingPart		featuretype			NE															t	
32	CityFurniture		featuretype			NE															t	
33	_Site		featuretype			NE															t	
34	LandUse		featuretype			NE															t	
35	AuxiliaryTrafficArea		featuretype			NE															t	
36	Railway		featuretype			NE															t	
37	TrafficArea		featuretype			NE															t	
38	TransportationComplex		featuretype			NE															t	
39	_TransportationObject		featuretype			NE															t	
40	_AbstractTunnel		featuretype			NE															t	
41	TunnelPart		featuretype			NE															t	
42	PlantCover		featuretype			NE															t	
43	SolitaryVegetationObject	Vegetat	featuretype			NE															t	
44	_VegetationObject		featuretype			NE															t	
45	WaterBody		featuretype			NE															t	
46	_WaterObject		featuretype			NE															t	

Figure 6: An example of concepts taken from IMxxx, which are relevant for the data sets needed for Port of Rotterdam

The data structure, which would be most appropriate to maintain the features, which are maintained by the Port of Rotterdam. At present, many data sets are still maintained by individual departments, although large parts of the information are managed centrally in database management system (DBMS). A central management is clearly a choice that will ensure consistency and re-use of information, but will require a data model that can serve the needs of all departments.

The generic 3D model should incorporate data from GIS (existing) and BIM (design) domain (Figure 4 and Figure 5). While developing the GIS branch of the model, the following principles are taken into consideration:

- Features will be defined only once, but all the properties needed for the work of the Port will be maintained. This implies that all the features will be intelligent objects, having strict definitions and consistently structured properties and relationships.
- Features, which can be identified in existing standards (GIS and BIM) will be re-used. A special attention will be given to the Dutch Information Doman Models. Among those models the topographic large-scale model (IMGeo) and the Information model for Cables and Pipes (IMKL) are most interesting. Relevant features from other models will be re-used as well (Figure 6). Extensions of existing concepts can be defined following the approaches applied in developing 3D IMGeo and linking it to CityGML (e.g. van de Brink et al 2013 and Stoter et al 2010)
- New features will be defined only when similar notations cannot be identified in existing models.

- International standards, discussions and tendencies related to 3D information management will be closely followed and taken into consideration. Special attention will be given to developments within OGC and Web3D.

4.2 Network ADE of CityGML

A critical question in this project was the maintenance of utility networks. Two semantically rich models were studied: the national IMKL and the Network ADE of CityGML (Gröger et al 2008). Both models are intended for exchange of information and does have detailed set of attributes. The semantics of IMKL is more elaborated than Networks ADE, however Network ADE maintains topology. For the scope of this study was of interest what the effort will be to create a topologically correct model from the current pure geometry organization. Therefore the pipes and cables of the of the test area were imported in the topologic model of Network ADE of CityGML (Figure 7). The network was converted to a topological model using the overlay tools of ArcGIS.

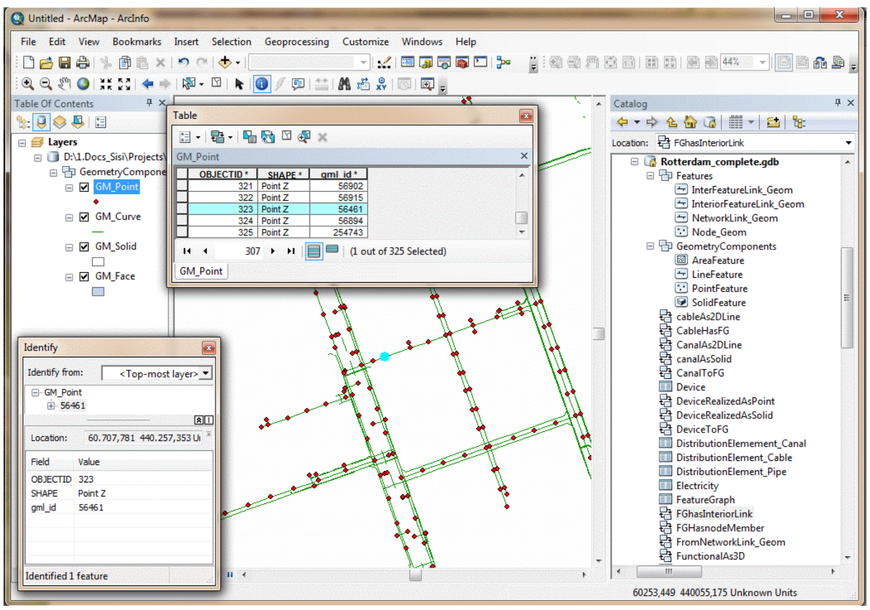


Figure 7: Visualisation of network in CityGML viewer

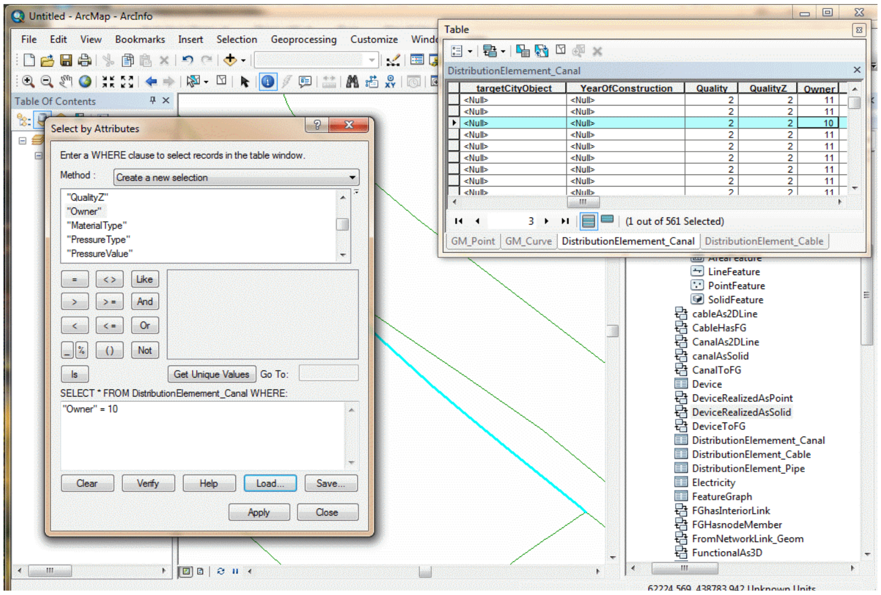


Figure 8: Performing spatial analysis within ArcGIS

The experiments have shown that topology is possible to build at not very high cost but tools are needed for automation of the process. Using Network ADE clearly has advantages:

- Topology, which ensures validity and correctness of the networks.
- The model can be readily integrated in CityGML, which allows various complex analysis to be performed (Figure 8)

Indeed creating a topologically correct model require additional processing of data, which might be further investigated.

5 BIM-Quay Models

For the quay wall use case two different approaches have been carried out and evaluated in the context of the 3DSDI project. They consist of a traditional schema-extension approach combined with investigations of necessary Model View Definitions (MVDs) that go beyond the current state of the art (see 5.1) and a novel approach for harnessing the potential of the Semantic Web initiative to enrich legacy BIM models provided in the IFC format (see 5.2).

5.1 Novel development of a quay wall schema as an extension to the IFC model

In this project the novel IfcQuay model is developed. IfcQuay is intended to be an addition to the established and ISO certified IFC model and describes different types of Quay Walls and its components.

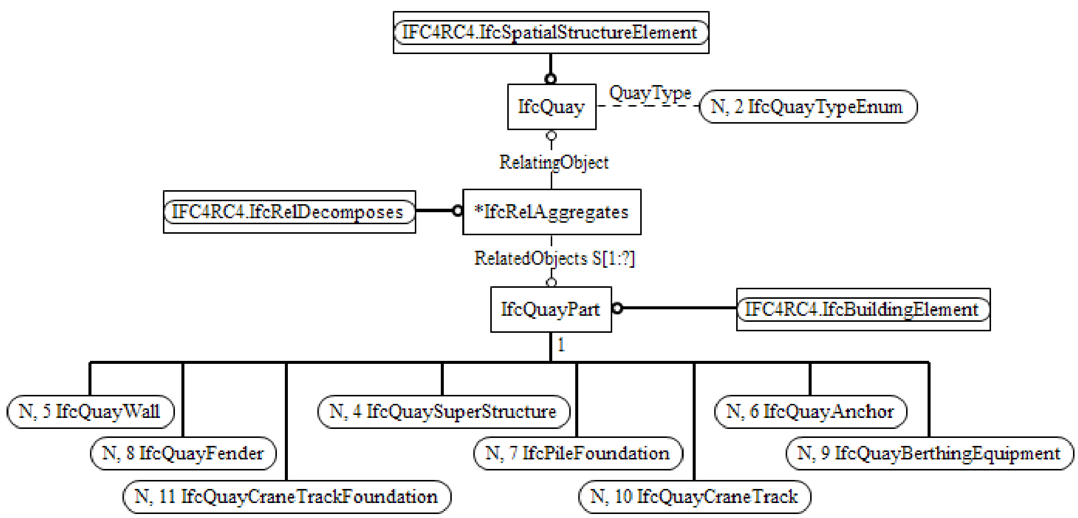


Figure 9 Excerpts of EXPRESS-G diagrams of the suggested IfcQuay super structures

There are two main parts that are explained here:

1. Description of the various quay wall types and their representations and hierarchies in IFC. These mainly include different kinds of super structures and their suggested integration into the overall IFC model. These are illustrated in Figure 9 and Figure 10.
2. Description of the various quay wall parts and the way they are represented as geometry. These are addressing mainly parametric walls and other construction types that are frequently met in quay wall constructions and other civil engineering works, yet no specialized classes have been introduced into the IFC model yet. Beyond that, a number of specific objects such as bollards, fenders and crane track have been included in the model schema. Some graphical examples are provided in Figure 11.

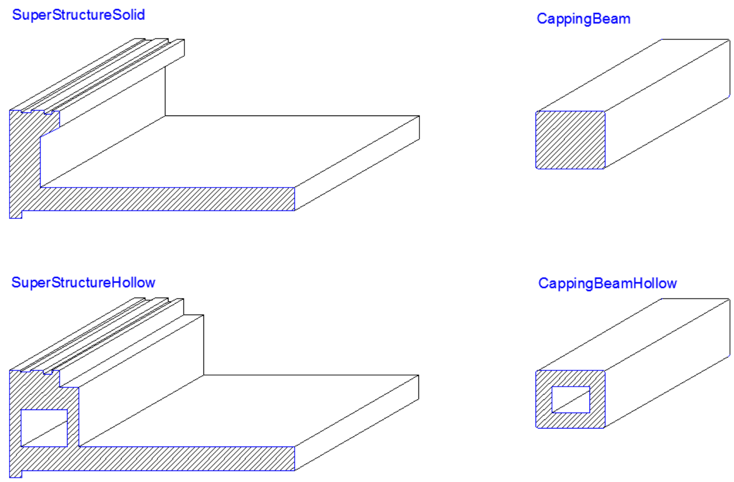


Figure 10 Schematic overview of some of the quay wall superstructures suggested in the IfcQuay extension

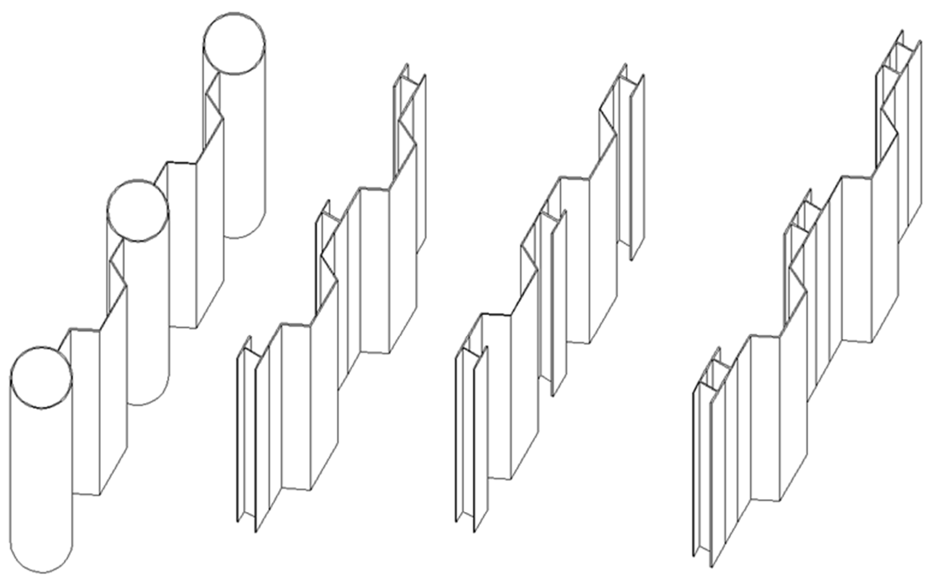


Figure 11 Examples of frequently used engineering structures that have been explicitly modeled in the IfcQuay extension

Both – the superstructures and the individual components have been modelled based on best practices in similar efforts done for e.g. bridges. The report includes the full suggested model extension as an ISO 10303 part 11 EXPRESS schema and will be suggested to the international OpenInfra initiative and the buildingSMART standardization organization.

In order for the suggested model extension to be implemented into civil engineering software including BIM/CAD modellers or integrated into information frameworks and dashboard application systems such as the ones suggested in the 3DSDI framework, it is desirable to limit the scope of the overall model consisting of the base IFC model and the IfcQuay extension. In order to address this re-occurring need to limit the model complexity and implementation effort and in order to allow the fine-grained specification of information requirements, the buildingSMART initiative has standardized the concept of "Model View Definitions" (MVD) (Zhang et al 2013). This mechanism allows the selection and constraining of model constructs from the overall model (currently more than 700 classes and several thousand attributes) using filter mechanisms. Simply put, they can be seen as some sort of shopping cart that allow the collection of specific information structures that have to be supported by a software tool implementation in order to allow specific information exchanges scenarios. At present, the assembly of such MVD is very labour intensive and complex which leads to a slower progress of interoperability agreements in the sector than is desirable. In order to address this, the need to create, maintain and verify such MVDs has been identified by various stakeholders across different domains in civil engineering time and again (Figure 12). In the context of the 3DSDI project a state-of-the-art literature review has been carried out that provides an overview of the various approaches currently existing and discusses their advantages and limitations. Based on these insights, experiments have been carried out using the IfcQuay model as an example to investigate novel ways for the assembly of such structures.

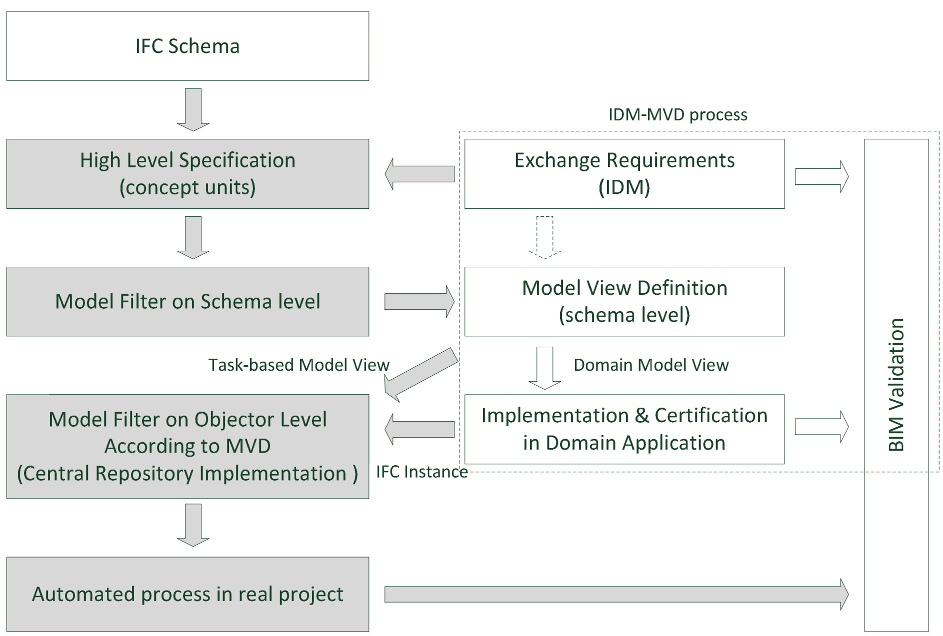


Figure 12 schematic overview for the generation of Model View Definitions (MVD) of IFC models which have been partially applied to the case of the IfcQuay extenstion proposed by the 3DSDI project

5.2 Novel development of semantic enrichment strategies based on legacy IFC models

The implementation effort to support custom model extensions as described above – which are only used by a small community – is considerably high. Moreover, it has to be repeated for each new domain model or internal organization information flow.

In a second phase of the quay wall use case work package of the 3DSDI project, a meta modeling approach has been taken. It not only covers the generic, reusable quay wall model that could also be used outside of the HbR context, but also demonstrates how such models can be extended in a dynamic, yet semantically rigid way. It enables covering in-house information aspects that can be used across the boundaries of individual departments within HbR and typical collaboration external parties such as engineering offices or the municipality of the city of Rotterdam. The key strategic choice in this approach is the use of Linked Data, an aspect of the Semantic Web initiative. In particular, instead of creating the model as an EXPRESS schema extension to the Industry Foundation Classes (IFC) model which then needs to be implemented in each individual software tool, the new information semantics are captured in a machine readable form as OWL/RDF(s)/RDF vocabularies. Such vocabularies can have a wide range of expressivity (ranging from simple data dictionaries to full blown axiomatic systems described in a description logic language), can be used for automatic inferences, consistency checking and can be distributed across network structures. A principal schematic overview of such sematic enrichment is provided in Figure 13.

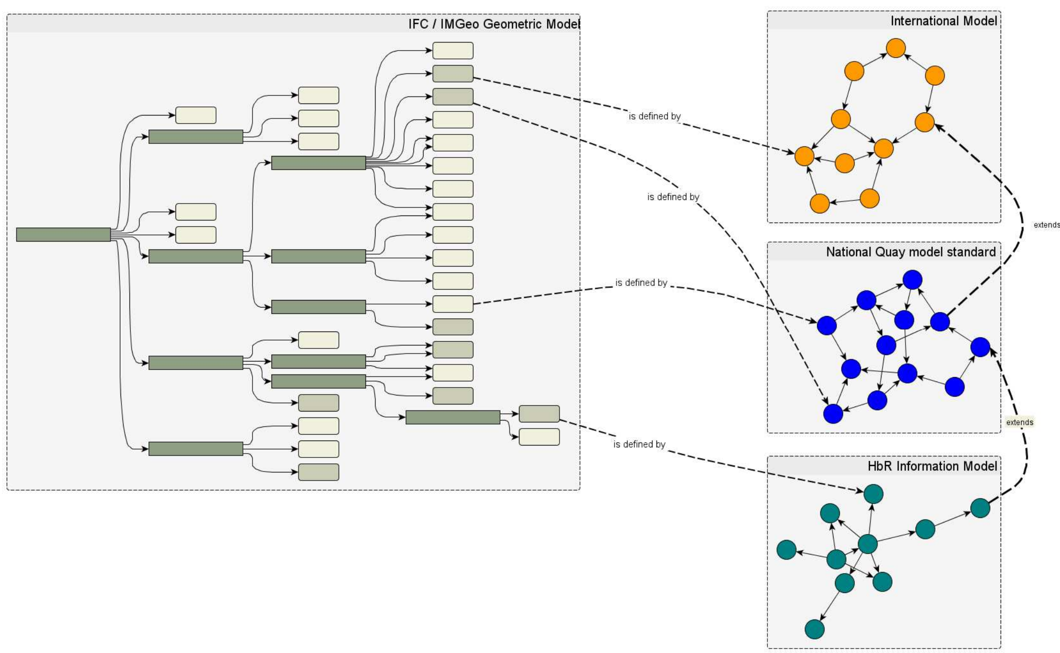


Figure 13 schematic overview of the suggested principles to enrich legacy IFC models with semantically rich information captured in distributed, decentralized and easily extendible models captured in the Resource Description Framework (RDF)

For the particular case of the quay wall, a demonstration scenario is being developed that uses information structures from three distinct repositories on different levels of generality:

1. **Internationally recognized and widely accepted geometric and semantic modelling standards.** As the general vendor-independent carrier of geometric information the Industry Foundation Classes (ISO 16739:2013) model is being used. Where its semantics do not cover information needs by the in-built entities and attributes on a schematic level or the external standardized property sets, internationally recognized concept repositories such as the ISO 12006 based buildingSMART Data Dictionary (bsDD) is being used as an extension mechanism.

2. **Internationally reusable domain-extensions for particular information needs.** Where existing models as the IFC fall short to describe elaborate structures such as quay walls and no viable open alternatives outside the buildingSMART or Open Geospatial Consortium communities exist, new domain models can be defined, exposed and used in model instantiations as e.g. the Amazonehaven area. They should reuse as much as possible from already existing information structures defined on the first tier.
3. **National specifications of existing information models.** In order to provide reusable information structures that allow the further specification of engineering structures including quay walls this third tier can be used. Here, national building regulations, norms and best practices are provided that are instantiated and validated across platforms and tool boundaries.
4. **In-house and project-specific information models.** In addition to generic international and national agreements, information standards, norms and regulations, information management in specific context such as HbR should adhere to individual data models. In the case of quay walls for example, the specific structuring of quays into virtual sub-spaces is unique to the Port of Rotterdam.

The application of this suggested approach has been illustrated in a number of use cases that are illustrated in the report.

The proposed mechanism itself is based on the suggestion of a straight-forward implementer agreement. At its core, the existing modeling structures to augment the schema-level attribution of object instances with properties from so-called Property Sets (PSets) in the IFC model is extended by the notion of resources from the international information modelling and linking construction "Resource Description Framework" (RDF) that is standardized by the W3C organization. As a first step, two information models have been tailored that capture a) the semantics of the quay wall model which has been proposed in the IfcQuay extension as an RDF vocabulary and b) the specific requirements of the HbR with regard to the commission and administration of (new) quay wall structures. While quay wall information structures are generic enough to be likely reused in other – possibly international - scenarios beyond the specific 3DSDI use case, the information structures used within HbR are tightly coupled to a local context and include information in-house specific information such as "BIM-ID", "Object Code" and HbR-department-level provenance data. To reflect this and separate the different concerns, these structres have been captured in distinct vocabularies. Subsequently, these vocabularies are exposed to using standardized information retrieval facilities called SPARQL endpoints. These allow the exploration and use of the data across network boundaries. For the semantic enrichment demonstrator three different vocaublaries have been exposed in three different endpoints which correspond with the scenarios shown in Figure 13.

The mechanism further documented in the report then allows the reference and instantiation of these models from within IFC models generated by legacy CAD and BIM application that are commonly used without additional implementation effort. This is has been validated by testing the enriched quay wall models with a number of legacy applications. Figure 14 illustrates these experiments: Here a screenshot of a commonly used engineering tool is used that has not been altered, yet shows HbR-specific information on an object representing a (part of a) quay wall. While the upper part of this illustration shows how URIs are encapsulated in the IFC structures which point to resources exposed by the SPARQL endpoints, the lower part of Figure 14 shows detailed information about the referred structures.

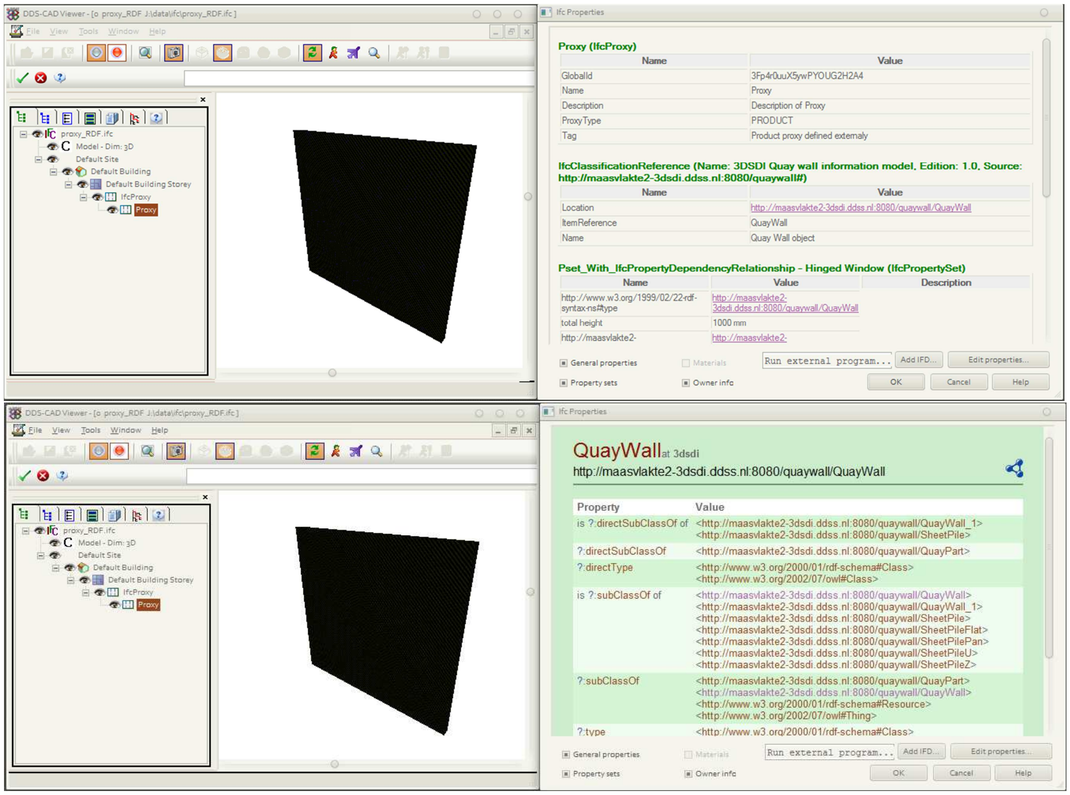


Figure 14 Screenshot of the legacy DDS viewer tool displaying the semantic information attached to a placeholder IfcProxy object that is referring to an information vocabulary for quay walls.

This principle has been applied on a larger scale to a real-world model of a quay wall structure of the Amazonehaven area of the Maasvlakte 2 and is described in detail in section 8 of this document.

6. 3D Spatial Information Visualization and Dashboard Interfaces

To make efficient use of the structured, interconnected information provided according to the model described earlier, data integration and visualization clients are developed. These allow the selection of relevant spatial data from different sources and provide visual means for multi-criteria and multi-dimensional analyses in 2D or 3D to support decision processes. The following visualisation approaches are investigated:

6.1 Web 3D visualization (WebGL-based)

To be able to visualize the 2D pipelines as 3D objects in a 3D-scene, a 3D geometry has to be created (Du et al 2006, Döner et al 2010). The shapes used in this research are cylinders and sphere. The process of re-constructing the 3D pipelines is shown below. There are 5 steps (Figure 15):

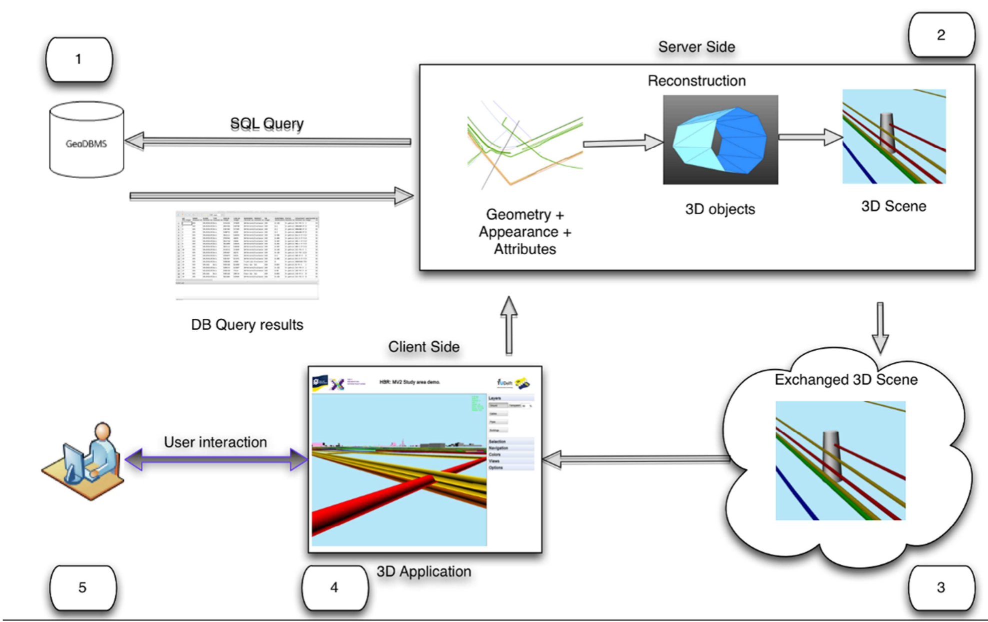


Figure 15 Pipeline for creating 3D pipes from 2D lines (as stored in the database)

1. The reconstruction flow starts with the information stored into a spatial database, from which an arbitrary user request triggers a query (spatial or not) to the data store, producing a series of results organized in tables where each row or record returned corresponds to a feature in the database, composed of a geometry definition and a set of attributes.

2. Given the geometry, the attributes and appearance mapping, the actual creation of the 3D objects starts by choosing a reconstruction approach. The chosen approach transforms the geometric object with lower dimensionality into a 3D object based on its own conversion rules. Depending on the method used, graphical primitives or custom 3D meshes can be used in replacement to construct the objects and reused along the procedure.

3. After all the pipes and cables are reconstructed; the scene is assembled by linking the produced 3D shapes to their appearance, including identifiers, actions and names for object picking (e.g. highlighting their attributes by hovering over with a pointer device).

4. When a scene is finally assembled, it is made available to the 3D engine which parses the information to produce an internal representation suitable for rendering. In this step, the declared objects, materials, identifiers, names and additional information are converted into a scene graph.

5. After creating the scene graph, the objects are displayed to the user as sequences of two-dimensional images producing the illusion of movement. If the user interacts with the scene this requires different elements from those present on the scene, the 3D application redirects that request into a database query, starting a new reconstruction flow and displaying the new elements to the user.

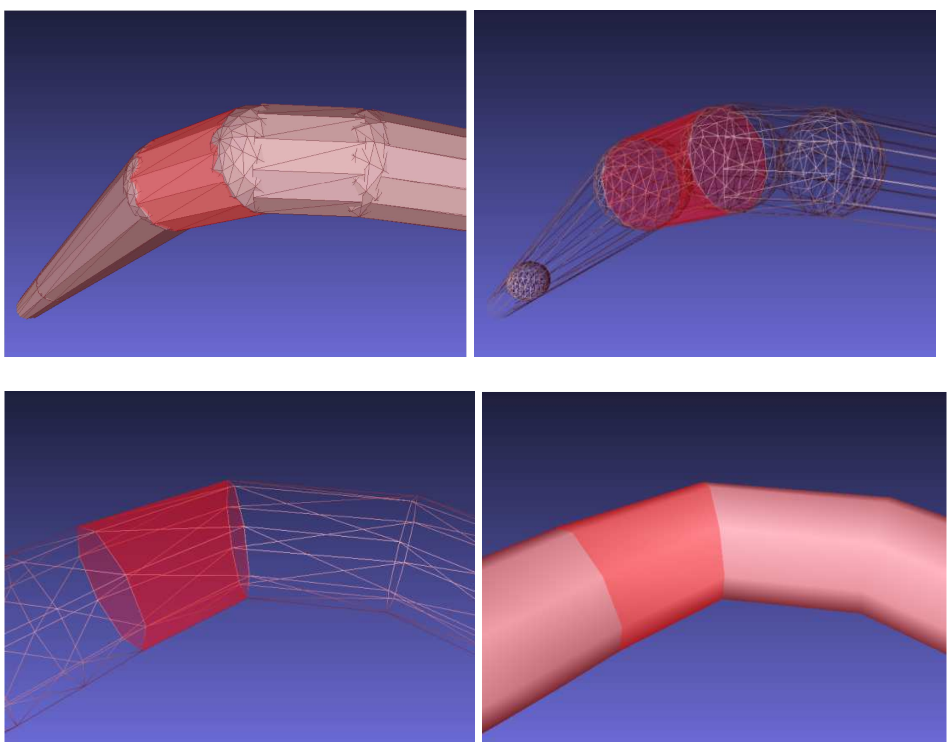


Figure 16: Visualisation of pipelines as 3D objects

Two types of approaches were investigated: split and non-split. In the first approach every segment is recorded as an individual object in the 3D file (with its own characteristics). Each segment corresponds to one straight component, i.e. turns are modelled as sequence of straight components. In the second approach, one pipe line (no matter how many segments) is modelled as one object (Figure 16). Some more variations within each approach were also investigated. 162 pipes and cables encoded as polylines, with an average length of 18.7 segments were tested. The test have shown as best the approach of 'stitching' segments as shown below (Figure 17). More details on the experiments/results can be found in Guerero et al 2013.

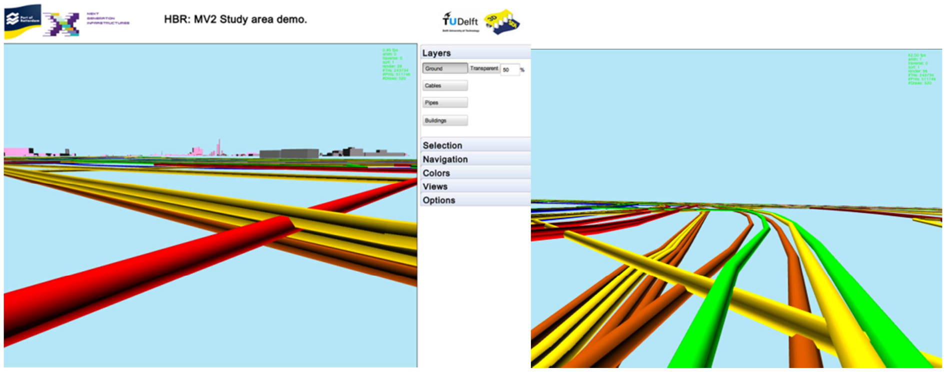


Figure 17: Snapshots of the web environment: http://mapster.com.mx:8080/reddrop/

7. 3D Operations: clip and cross section (slicing)

Tools to create cross sections or perform clipping on 3D data are already available in several GIS software packages or extensions, e.g. ArcGIS. However, most of them are limited to geological cross sections, consisting of extruded 2D polygons, instead of 'real' 3D objects like solids or boundary representations (Heinzer & Williams). Besides these limitations, no open source GIS packages provide such solutions. Software packages that implement cross sections related to 3D design are Autodesk Inventor, Microstation or Dassault Systems Solidworks. These implementations are based on so called clipping planes (OpenGL renderer or a comparable). Clipping planes define the rendered area of the 3D objects, where related attributes and information about the objects are not available when these planes are used as clipping objects. The topological relations (validity of objects) are mostly ensured or can be checked. However, no tools exist to check the status of the attributes. Many use cases require actions like selection of all objects in a given area to perform new development and make financial estimates of possible changes. For such cases, an area is identified and all objects have to be extracted for further analysis. Some of the object at the edge of the area have to be clipped, but they have to remain correct objects holding the same attributes as before the clipping.

Two different operations are implemented, clipping and slicing (Figure 18). The first operation is clipping, where the original model and the reference object should be in the same dimension. The intersection between these two are remaining, which will keep also the result in the same dimension. For example, two 3D objects will result in one 3D object that remains. When the original objects that are clipped are in two different dimensions, for instance a 3D model with a 2D reference object, this is defined as a cross section instead of clipping. The remaining objects of a cross section are always one dimension lower as the original objects, for instance an intersection between a 3D and 2D dataset will be represented in 2D and for a 2D and 1D dataset it will be represented in 1D. Due to the characteristics of the cross-section algorithm the orientation of the cross sections can be arbitrary, so either a horizontal, vertical or diagonal cross section is possible.

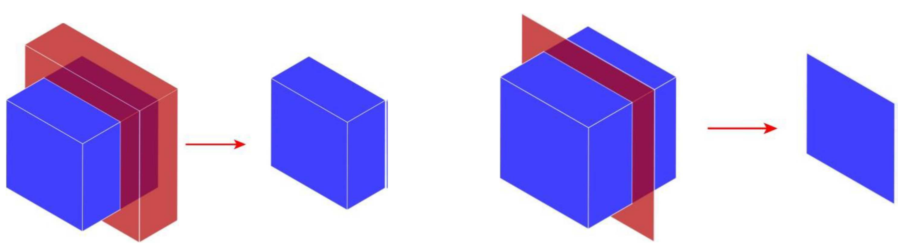


Figure 18: Examples of clipping (left) and slicing (right)

-

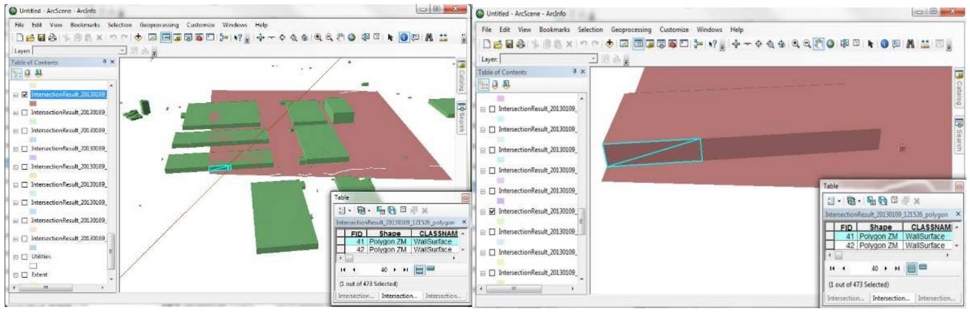


Figure 19: Closing clipped 3D objects: the selected area and the buildings in green to be clipped (left), the selected area and the clipped buildings with correct geometry and preserved attributes(rights)

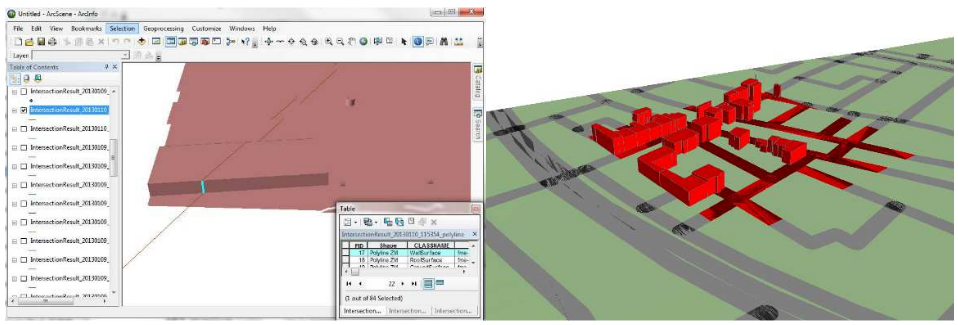


Figure 20: Slicing along a given line with preserved attributes (left), clipped 3D and 2D objects given in red (right)

Figure 19 and Figure 20 demonstrate the two operations implemented in ArcGIS and tested with the data provided for the project. With the help of these operations, all the objects can be extracted from a given area with their attributes. The objects remain valid (closed and with correct geometries) despite clipping or section operations.

8. Description of the Demonstrators

Two so-called 'Demonstrators' are developed for project: one devoted to 3D integration and check of data and the second relate dto semantic enrichment. The demonstrators developed are for the design phase of Quays and is under the following scenario:

- Different 3D GIS data sets (from a database and as GIS files) are loaded in the viewer according to the specified area of interest. These data are sent to the design bureau.
- Design bureau returns design BIM model of the quay accompanied by the changed surrounding GIS objects.
- (check as 'design') This design is checked against the present 3D GIS data. The GIS data are received directly from data providers. It becomes clear that some data have been changed for the period of design (e.g. a new pipe appears)
- The differences between designed and present objects are given visually and as list (IDs: modified, removed). The model is send back for adjustments
- (check as built) The BIM model as built and the actual changes of the surrounding GIS objects are sent to Port of Rotterdam
- A GIS object is created from the BIM quay (according to IMGEO, under 'scheiding')

8.1 Demonstrator 3D Haven

The first demonstrator was intended to illustrate how 3DSDI can support the planning process within the Port of Rotterdam. More specifically the following goals were adhered:

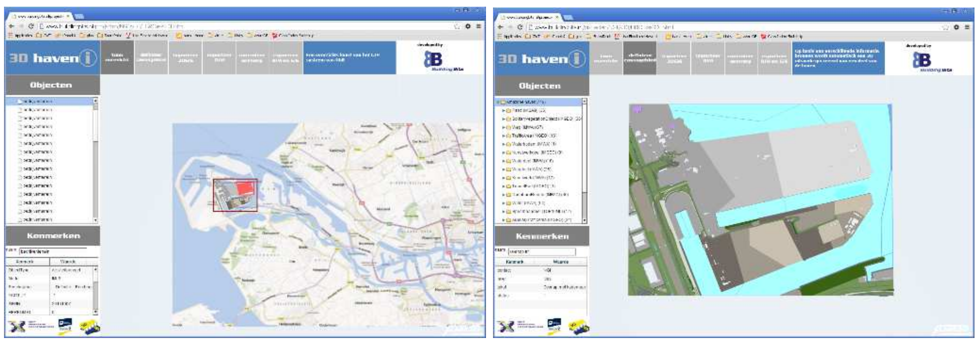
1. Demonstrating the feasibility of 3D spatial infrastructures using current data sources and standards
2. Knowledge dissemination demonstrating new possibilities regarding 3D spatial data infrastructures and their potential impact on day to day processes

To demonstrate goal 1 the various data sources such as GIS shape Files, BIM/IFC, etc were used to create one integrated 3D environment. Object Types and properties of each object are available in the 3D environment.

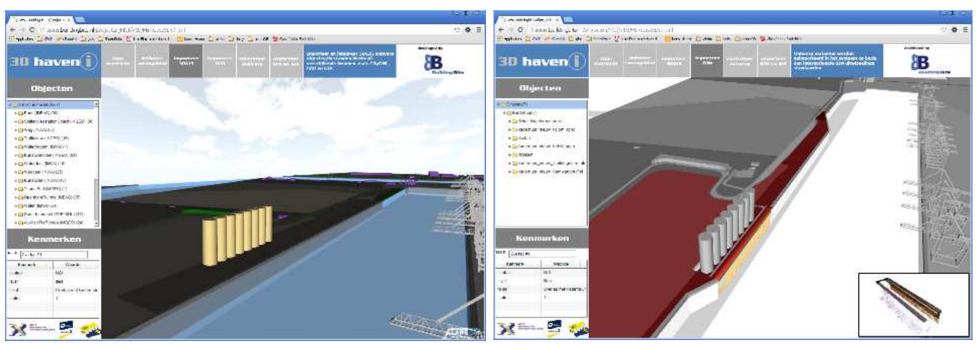
To demonstrate goal 2 from the point of view of 3D spatial data management, a design process of new quay for the port of Rotterdam is formalized and simplified into a 'six steps' procedure. The main goal of this simplification is to communicate the impact and new working methods when an advanced 3D spatial data infrastructure comes into place. The following steps are formalized and demonstrated using the Demonstrator (Figure 21):

1) Select the area of interest (in Dutch: Areaal) for the new quay
2) Get the 2D spatial data (various sources)

3) Construct the 3D environment based upon 2D spatial data (parametrically) and import external 3D data. This model can be exported and delivered to (external) parties capable of designing a new quay.
4) Import the newly designed quay from an IFC/BIM model. (Assuming an external design party has developed a new quay)
5) Check if the new design fits. An integrated 3D spatial information infrastructure is key for (semi-) automated design checks. Clash detections between physical or non-physical (security borders, plannings data, etc) are a good example for automated design checks.
6) In case the quay is built an abstracted version of the 3D model can be inserted into the 3D spatial data infrastructure. Also the 3D CAD model can be stored in case more details are necessary.

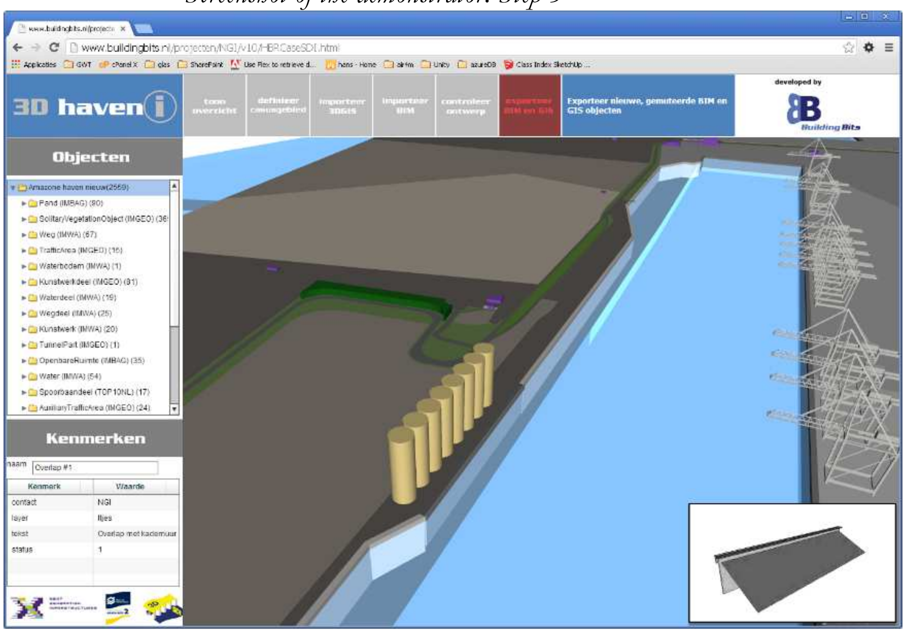


Screenshot of the demonstrator: Step 1, 2



Screenshot of the demonstrator: Step 3, 4

Screenshot of the demonstrator: Step 5



Screenshot of the demonstrator: Step 6

Figure 21: Screenshots of the demonstrator

5.2.1 Programming environment

This Demonstrator is a stand-alone web application residing on the web. This means that it can run in all common internet browsers. The Demonstrator uses a high level 3D API to deal with common 3D tasks such as visualization, interaction and even data management. These days Game Engines provide for a high level 3D API (and more). Popular Game engines today are for example "Unity", 'JMonkey',"Unreal Engine", etc. For the demonstrator "Flare3D", a 3D engine for Flash (Action Script and Flex) has been used. One major reason for this choice was that you only need a web browser with an up to date Flash plugin. Other game engine choices might require a plugin installation. In larger organizations this could require an extra effort in order to view the demonstrator. Another option could have been to use WebGL. This seems to be a technology that is based upon a standard that is adopted these days by all major web browsers. The reason for not choosing WebGL is that you need the latest browser resulting in the fact that the demonstrator would not work in organizations that do not support this (including several organizations within the project). It is however noteworthy to mention that from a technical point of view that a Javascript combination with WebGL (or a higher level API such as ThreeJS) or a Unity environment could be used as well to implement the Demonstrator.

5.2.2 Integrating heterogeneous spatial data information

The first goals of the demonstrator was to 'integrate' various spatial data sources into one 3D environment. The demonstrator uses the following 2D and 3D GIS sources:

- City GML
- IFC /Building Information Model
- GIS Shape files (RD coordinate system)
- CAD files

All these files were converted to Collada files and manually 'put together' for the Demonstrator. Each object in the source files has their own unique ID which is used to 'recompose' the meta data associated with the 3D content. Mapping rules and scripts are applied for (see also Appendix 1):

- Finding the properties and relationships
- Finding 'relevant' properties and skipping others
- (re) compose an object conforming a Geonovum standard.
- Adding extra information such as location, scale and rotation (some CAD models where not geo-referenced so an external (manually set) reference was necessary.

All the 3D objects are manually annotated to provide the necessary data for the Demonstrator. This includes the following annotation:

- Demonstrator TypeObject: 'Existing Object', 'New Design Object', 'Overlap derived object', 'New existing situation', 'NON GIS object', 'Design Error Flag'
- Design Impact property: ' Erased', 'New', ' Modified'

The Demonstrator has been rapidly developed for the above mentioned goals. Its software architecture is also influenced by achieving these goals. In case a similar environment is envisioned for operational usage a slightly different software architecture might be more suitable. From a programming point of view WebGL and/or main stream game engines seem to be viable options. From the point of view of data interoperability it is clear that Geonovum standards can contribute a lot regarding interoperability between various spatial data information sources. Parametric routines can convert 2D GIS data into 3D visualizations. This could be an interesting option when the management of 2D GIS Data is more in favor that its 3D alternative. Integrating BIM/IFC data into a 3D spatial GIS system is viable as well. Storing and managing 3D BIM/IFC models for re-use purposes and being able to use (standard) GIS functionality on these 3D models is currently still very difficult.

8.2 Semantic Enrichment Demonstrator

The suggested approaches to increase the interoperability of 3D spatial data infrastructures in the context of the Maasvlakte 2 with regard to quay walls have also been implemented in a second demonstrator that focuses on the engineering aspects of quay wall models. It is based on the novel approaches developed in the 3DSDI project which have are summarized in section 4 of this report have been extensively described in the separate use case reports in the appendix.

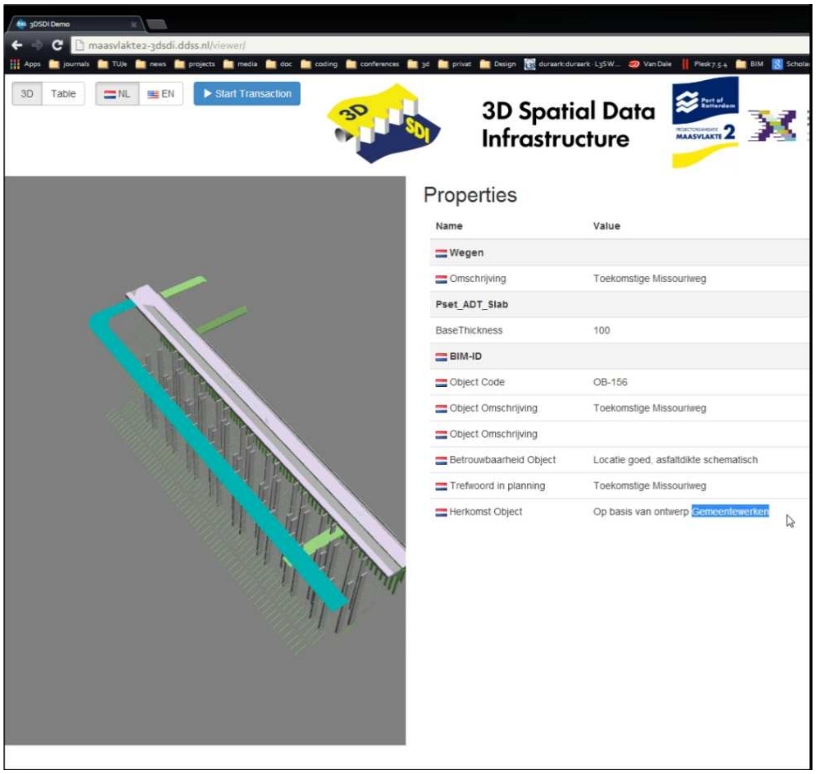
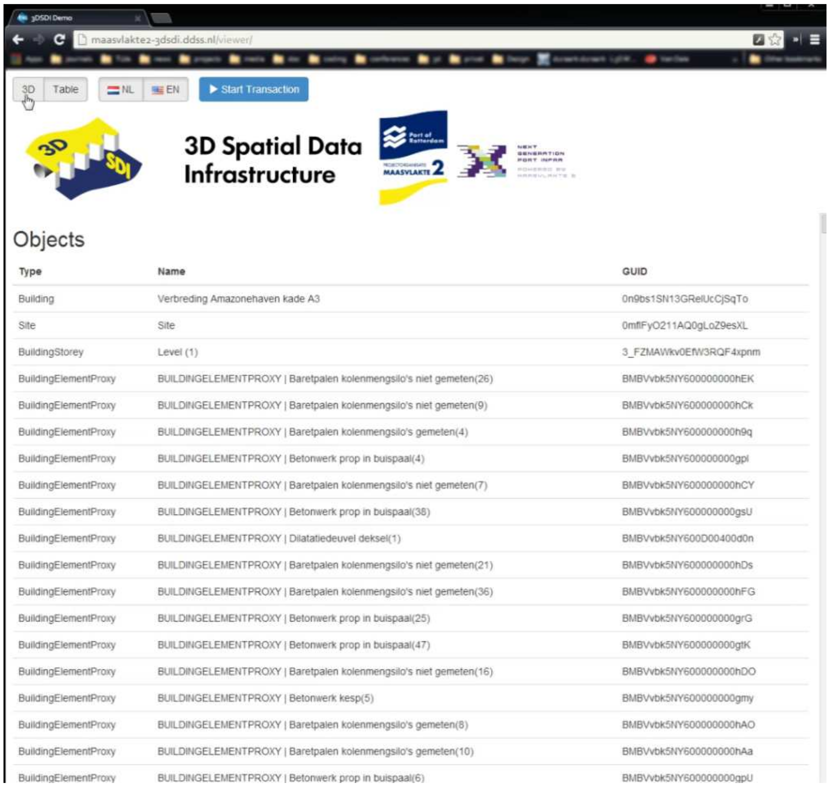


Figure 22 Screenshot of the Semantic Enrichment Demonstrator

As is illustrated in Figure 22, the semantic enrichment demonstrator allows browsing RDF-enriched IFC models using a web interface. The geometry (visible in the grey background area on the left-hand side of the screenshot) is generated as an interactive 3D model in WebGL that is retrieved from a bimserver.org installation on an arbitrary location on the intra- or internet, e.g. at HbR or an engineering office. From within the viewer, all objects can either be retrieved as a tabular overview (Figure 23) of objects (Figure 22) or with their respective geometrical representation. Each object can be inspected for its properties by selecting the geometrical or textual representation interactively. The demonstrator then fetches all IfcPropertySingleValues that have been assigned to the object. As described in section 4 of this document, these properties contain the URIs of the semantically rigid definitions of the properties that have been exposed for the demonstration purposes via SPARQL endpoints. At the run time of this demonstrator, the three endpoints are queried and the human-readable rdfs:lables that have been attached to the class and property definitions are retrieved with standardized "DESCRIBE" queries. The Dutch or English labels can be chosen to be displayed.



Type	Name	GUID
Building	Verbreding Amazonehaven kade A3	0n9bs1SN13GRelUcCjSqTo
Site	Site	0mflFyO211AQ0gLoZ9esXL
BuildingStorey	Level (1)	3_FZMAWkv0EfW3RQF4xpnm
BuildingElementProxy	BUILDINGELEMENTPROXY | Baretpalen kolenmengsilo's niet gemeten(26)	BMBVvbk5NY600000000hEK
BuildingElementProxy	BUILDINGELEMENTPROXY | Baretpalen kolenmengsilo's niet gemeten(9)	BMBVvbk5NY600000000hCk
BuildingElementProxy	BUILDINGELEMENTPROXY | Baretpalen kolenmengsilo's gemeten(4)	BMBVvbk5NY600000000h9q
BuildingElementProxy	BUILDINGELEMENTPROXY | Betonwerk prop in buispaal(4)	BMBVvbk5NY600000000gpl
BuildingElementProxy	BUILDINGELEMENTPROXY | Baretpalen kolenmengsilo's niet gemeten(7)	BMBVvbk5NY600000000hCY
BuildingElementProxy	BUILDINGELEMENTPROXY | Betonwerk prop in buispaal(38)	BMBVvbk5NY600000000gsU
BuildingElementProxy	BUILDINGELEMENTPROXY | Dilatatiedeuvel deksel(1)	BMBVvbk5NY600D00400d0n
BuildingElementProxy	BUILDINGELEMENTPROXY | Baretpalen kolenmengsilo's niet gemeten(21)	BMBVvbk5NY600000000hDs
BuildingElementProxy	BUILDINGELEMENTPROXY | Baretpalen kolenmengsilo's niet gemeten(36)	BMBVvbk5NY600000000hFG
BuildingElementProxy	BUILDINGELEMENTPROXY | Betonwerk prop in buispaal(25)	BMBVvbk5NY600000000grG
BuildingElementProxy	BUILDINGELEMENTPROXY | Betonwerk prop in buispaal(47)	BMBVvbk5NY600000000gtK
BuildingElementProxy	BUILDINGELEMENTPROXY | Baretpalen kolenmengsilo's niet gemeten(16)	BMBVvbk5NY600000000hDO
BuildingElementProxy	BUILDINGELEMENTPROXY | Betonwerk kesp(5)	BMBVvbk5NY600000000gmy
BuildingElementProxy	BUILDINGELEMENTPROXY | Baretpalen kolenmengsilo's gemeten(8)	BMBVvbk5NY600000000hAO
BuildingElementProxy	BUILDINGELEMENTPROXY | Baretpalen kolenmengsilo's gemeten(10)	BMBVvbk5NY600000000hAa
BuildingElementProxy	BUILDINGELEMENTPROXY | Betonwerk prop in buispaal(6)	BMBVvbk5NY600000000gpU

Figure 23 Textual overview of all objects in the Amazonehaven model of a quay wall

9. Conclusions

This research project is carried out in a very important period for the Port of Rotterdam, when the Port has been expanded with the new areas of Maasvlakte 2 and the management of information became project-based. In the existing practice, each project used to build its own 3D model when and if needed. This means that a unique 3D engine is created for each model and each model uses its own formats. The available data from existing source databases is converted to the project model. This is a one-off, time-consuming and costly process. It also creates a unique dataset with its own project specific characteristics, which cannot be re-used for consequent projects. Exchange of data between this project model and external systems, including the source databases, is not provided and can be achieved only at high cost. The major problems were identified as the lack of dimensionality and non-standardized semantics of existing datasets (source databases), data complexity and problems in sharing and interoperability of data.

The 3DSDI research project has addressed many of the challenges in this practice. The activities performed in the period of the project are extensive and can be summarized as follows:

- Investigation of the state-of-the art of technology (organised workshop and prepared report)
- Investigations of the present processes and data management within the Port of Rotterdam (internship and report)
- Specification of use cases and the data needed for the use cases
- Investigating different visualisation approaches (MSc thesis, prototype and publications)Investigation of spatial analysis on the 3DMPoR v.1 (Msc thesis, prototype)
- Development of IFC model for quays. (MSc thesis)
- Development of a model view definition for the quay wall extension to the IFC model (part of a PhD research)
- Developing a topological model for pipes and cables applying an extension to the international standard CityGML (part of a PhD research)
- Discussions on the use of Geonovum models and possible extensions
- Integration of IFC and IMGEO; derivation of a simple IMGEO model for quay from IFC
- Various discussions with experts from Port of Rotterdam and City of Rotterdam
- Discussions with international geo-information standardisation organisations (OGC)
- Coordination with on-going geo-information activities within the Netherlands (Geonovum)
- Discussions of underlying conceptual approaches with standardization organizations (buildingSMART) as well as scientific and best-practice communities
- Coordination with ongoing efforts and initiatives within the Netherlands (CB-NL)
- Developing final Demos

The performed tests, analysis and discussions lead to the following conclusions:

The set of features needed to be maintained by the Port of Rotterdam are quite diverse and covers the entire spectrum of the Dutch domain information models. Appendix 1 lists the features that were used for the demonstrator. These features were available in the provided data sets for the test area of Amazonenhaven, which means that many new features might be identified if different area is selected. Presently the semantics and attributes available in the data sets differ quite significantly from the semantics of the Dutch information models. The discussions with the specialists revealed that the classes of the Dutch IM should be enriched with more attributes and in some cases with more semantics. In this respect further investigations are needed in two directions: 1) a specification of needed features and 2) an approach for semantic mapping between the available data sets (maintained outside the Port of Rotterdam) and conceptual data model of Port of Rotterdam. This project has investigated only data sets needed for two cases studies and covering specific test area. A further research is needed to collect information which semantics and attributes are of interest for all departments and all types of activities within the Port. It is expected that many BIM objects need to be semantically defined. Within this project an extension of IFC model for quays was developed and proposed to standardization organization BuildingSMART.

This project has proposed a unique data structure for maintenance of data, which make use of existing standards (GIS and BIM). The data structure provides management of features, which means semantics, geometry and topology (when needed).

The most important characteristic of a feature is semantics. We propose the use of existing semantically reach models such as the national IMxxx and the international CityGML and IFC. As mentioned previously many of the concepts needed for the Post of Rotterdam are already available in these models. I n case the existing concepts are insufficient or unavailable, new ones will be defined (as for quays) or the existing ones will be extended (as the examples used for utilities). This approach ensures concepts are re-used and will allow knowledge-based approaches for search and integration of data to be applied (e.g. the semantic demonstrator). Such use of standardized vocabularies in GIS and BIM will contribute to avoiding misunderstanding and duplication of information. The generic model of Port of Rotterdam should be seen as a collection of concepts or a conceptual data model or top-level ontology with strict vocabulary, definitions and attributes. Data sets obtained from external organizations will be mapped to this internal Port of Rotterdam model for further. It will be also used between the different departments.
The second important component of a feature is geometry. The intended geometry is three-dimensional. However many of the provided data sets were two-dimensional. For the demonstrators many of 3D geometries were created manually. Although increasing number of 3D data are becoming available (also considering the effort of Geonovum towards extending all IMxxx into 3D), many data sets will remain 2D. Further research is needed to investigate how 2D features can automatically be integrated with 3D geometries. Several options could be investigated, such as draping over 3D features (e.g. cadastral boundaries over 2.5 terrain features), creating 3D symbols (e.g. threes) or 3D reconstruction.

Topology between the features could be of interest only in exceptional cases. The identified and tested spatial analysis (cross and section) do not require maintenance of topology. It might be beneficial for utility networks, but further investigations are needed to estimate the efforts needed to create and maintain it. All features, however, has to be valid. This would require validation procedures which often are based on topological operations. But in this case the topology is only applied and no topological data structure is needed.

The project has clearly shown that there are many different options to integrated semantically reach 3D data (BIM and GIS). In this project we have developed and experimented with three of them, but we are aware that other possibilities could be investigated. We have applied:

- Translation of BIM semantics and geometries to GIS (to apply 3D operation cross and section)
- Translation from GIS to BIM (quays use case)
- Kept the two models with their semantics and geometry parallel to each other. The third approach was used to develop the demonstrators. The integrated model was then visualized in one visualization environment, based on game engine.

The tree approaches have their advantages and disadvantages. The first two translation-based approaches allow re-use of commercially available well-known software such as ArcGIS. However, the translation of geometry or semantics could face numerous issues. For example, the geometries might be too complex to simplify, or the semantics might be not be available in the host model. For example all features represented with cylinders and cones in the quay BIM model had to be represented as meshes (patches) to be accepted in the ArcGIS. The third approach might appear most beneficial, as it allows maintenance of most complex cases. The BIM model can be seen as a next (higher resolution) LOD after the GIS LODs.
This project also demonstrated that a 3D model allows not only search and integrated visualisation of information, but also geometric operations such as 'cross' and 'section' to be performed on all data sets. Innovative operations were developed, which ensure the semantics of the clipped features is inherited from the parent. The geometry is kept valid and closed. The project had demonstrated that sufficient 3D rendering engines are currently available for visualisation and query of 3D data. Prototypes with WebGL and the game engine Flare3D illustrate the power of 3D visualisation, query an interaction. Depending on the user, the functionality of the visualisation system can vary from simple visualisation to query and even editing of data.

This project did not investigate in depth the data formats to be used in data sharing and exchange. The data format are currently mostly shape files, but increased attention should be paid on GML decoding, which most suitable for representing semantically reach schemas. Further research is needed to clarify whether

The integration of BIM and GIS raises semantics, geometry and topological issues. Among the three, semantics is most critical. There are many semantics developments within BIM and GIS, but they are within the domains and not across domains. The project has clearly revealed that one top-level ontology is required, which can support the data exchange between models. The top-level semantics should be formally described, using ontologies to allow machine-based mappings.

This project has made clear that data integration issues are best visible by large companies that deal with many data set, numerous partners and companies. Typically, the standards and file formats are developed either by domain specialist or software developers. In both cases the specialists restrict themselves to the area of interest. Therefore, large companies as the Port of Rotterdam should take a pro-active role and initiate a broader discussion on data integration between domains toward explaining the complexity of integration and analysis, and providing appropriate case studies.

The proposed solutions need to be further tested within a business case, which should demonstrate the benefit of the proposed solutions for the work processes of the Port of Rotterdam.

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Appendix 1 Mapping between available shape files and Information Models

Features is Shape files	Features in Information Models	Information Models
Voetpad	OpenbareRuimte	BAG
Buskom	OpenbareRuimte	BAG
City_GML	Pand	BAG
Opstal	Pand	BAG
Hoofdgebouw	Pand	BAG
Bijgebouw	Pand	BAG
Ondergrond	DBKVlak	NEN
Uitbouw_Maaiveld	BuildingPart	NEN
Havenkraan	CityFurniture	NEN
Haveninrichting	CityFurniture	NEN
Overige_Verharding	AuxiliaryTrafficArea	NEN
	Railway	NEN
Parkeerplaats	TrafficArea	NEN
Tunnel	TunnelPart	NEN
Onbebouwd	FunctioneelGebied	IMGeo
Vaste_Bak	Kunstwerkdeel	IMGeo
Silo	Kunstwerkdeel	IMGEo
Fundering Silo	Kunstwerkdeel	IMGeo
Gras	SolitaryVegetationObject	IMGeo
Overig_Groen	SolitaryVegetationObject	IMGeo
Bosplantsoen	SolitaryVegetationObject	IMGeo
Struik	SolitaryVegetationObject	IMGeo
Haag	SolitaryVegetationObject	IMGeo
Wegberm	SolitaryVegetationObject	IMGeo
Leidingstrook	Buisleiding	IMKL
Kgeul	Leidingelement	IMKL
Bedrijventerrein_nieuw	Activiteitperceel	IMLB
Bedrijventerrein	Activiteitperceel	IMLB
Civiele_kunstwerken_vlakken	Kunstwerk	IMWA
Kademuur	Kunstwerk	IMWA
Kademuur_nieuw_bolders	Kunstwerk	IMWA
Kademuur_nieuw	Kunstwerk	IMWA
Kademuur_CityGML	Kunstwerk	IMWA
Muur	Kunstwerk	IMWA
Waterloop	Water	IMWA
Vaargeul_in_water	Waterbodem	IMWA
Getijdenwater_nieuw	Waterdeel	IMWA
Getijdenwater	Waterdeel	IMWA
Greppel	Water	NEN
Pad	Weg	IMWE
Rijbaan	Weg	IMWE
Rijwielpad	Wegdeel	IMWE
Spoorbaan_Trein	Spoorbaandeel	TOP10NL

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