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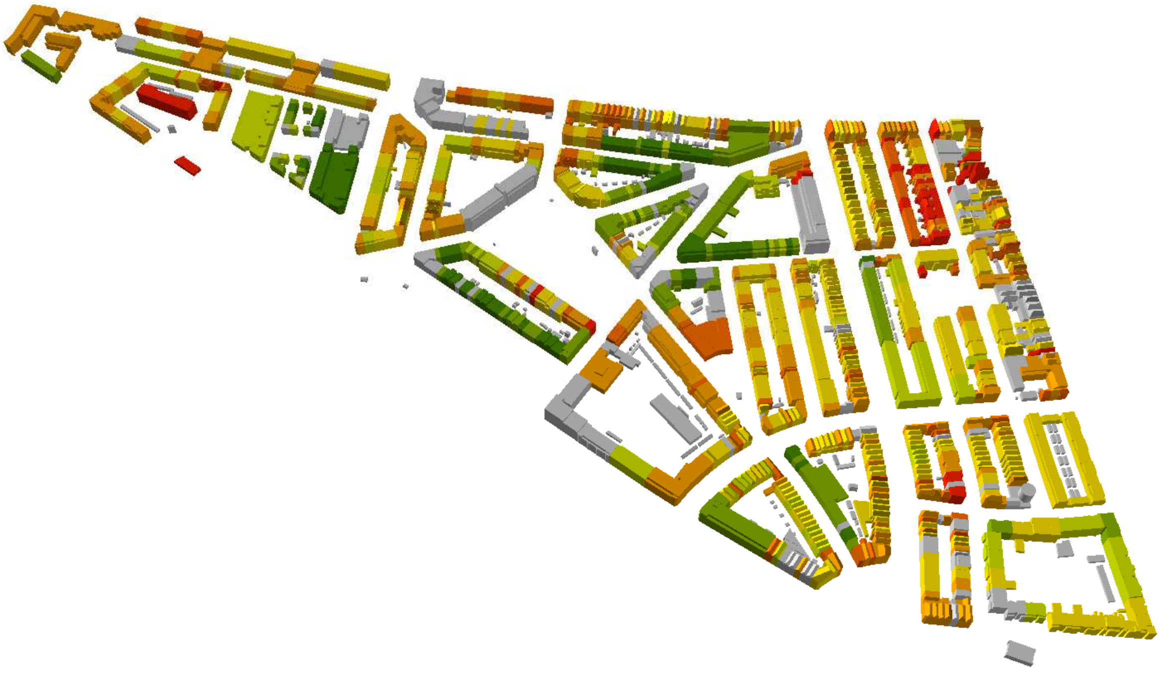
Hochschule für Technik

FEB

Technical documentation

Urban energy analysis of the city district Rotterdam – Bospolder, based on a CityGML 3D city model



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Abstract:

This urban energy analysis was realized in the context of the INTERREG project MUSIC, in collaboration with the City of Rotterdam.

The full potential of the CityGML 3D city model of Rotterdam - Bospolder has been exploited in this urban energy analysis, enhanced with the rich building attribute database of the City of Rotterdam. For each building (residential, non-residential and with mixed-usage), a thermal model has been created and then simulated with the standard monthly energy balance method.

The realism of the simulated building heating demands has been verified by a comparison with the actual gas consumptions and with a statistical energy analysis led by the University of Luxemburg. The overall results are coherent, showing an average specific heat energy demand around 140 kWh/m².yr in Bospolder district (total heating demand of 40 TWh/a).

From this energy diagnostics of the Bospolder buildings stock, a global refurbishment scenario, based on realistic insulation and energy efficiency upgrading measures, has been simulated and energy saving potentials have been calculated for each building. Total heating saving potential for the whole district reaches 59%.

Despite certain issues concerning the data quality of the model, the 3D-city-model-based energy analysis has been proven reliable in this context, offering many possibilities to drive an optimized long-term energy strategy in the Rotterdam - Bospolder district.
After this study on a “test district”, which allowed to calibrate the tools and control the reliability of the results, the next phase could be an extension of this energy analysis to the whole City of Rotterdam.

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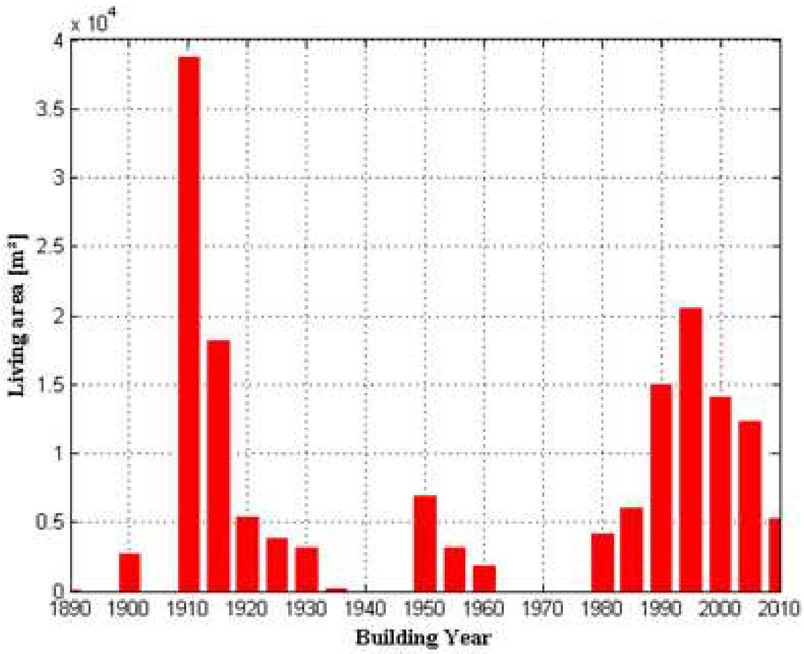
1 Overview of the city district Rotterdam – Bospolder

The district Bospolder is situated in Rotterdam West, on the northern side of the river Nieuwe Maas. Built at the beginning of the 20th century, this mainly residential district whose total living area approximates 300.000 m², knows a significant densification since two decades.

Fig. 1: Aerial view of the city district Rotterdam Bospolder

Source: Google earth.

Fig. 2: Building phases of Bospolder district between 1890 and now

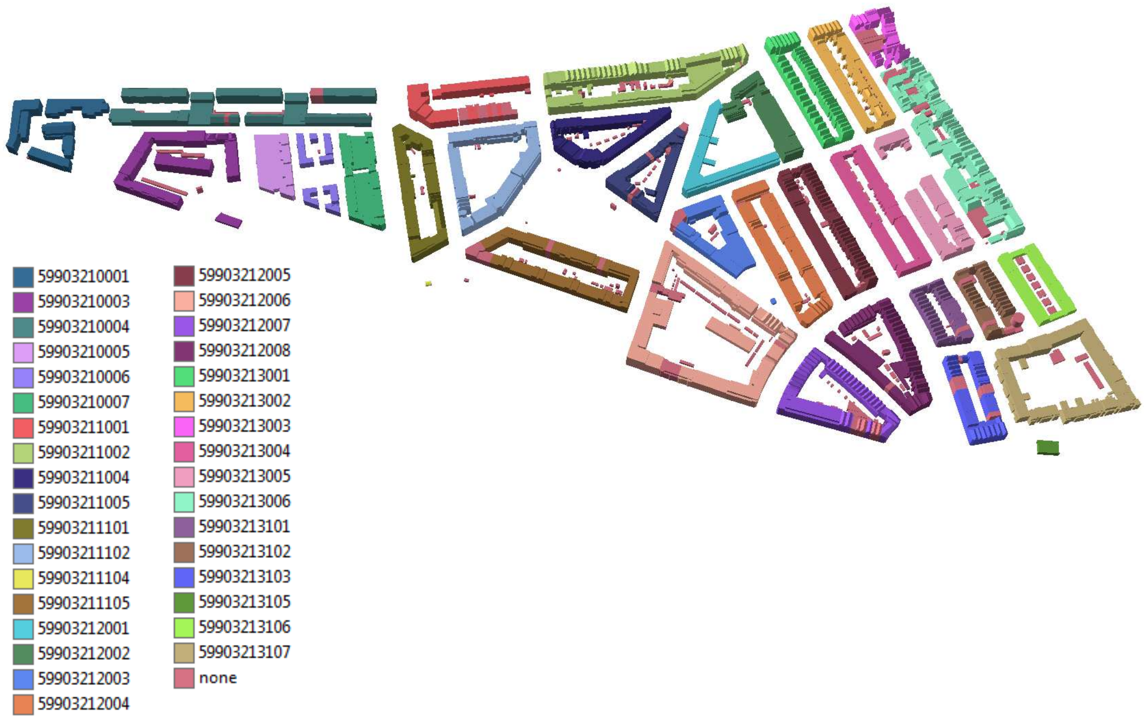


Source: HFT-Stuttgart, based on data of the city Rotterdam

The district Rotterdam - Bospolder has been divided by the Municipality of Rotterdam in 42 administrative neighborhood units (so-called BAG),among which 32 contain heated buildings

(residential or non-residential). These neighborhood units allow in this study for a detailed analysis of the simulation results.
Another district partition, smaller than these Neighborhood units, has been punctually used in this study: the zip code (PPC6).

Fig. 3: Neighborhood (Blok) partition of Bospolder district



2 Presentation of the 3D-city-model-based energy analysis and its workflow

2.1 Overview

The 3D-city-model-based energy analysis used in this study addresses any buildings (residential, mixed and non-residential) of any urban areas in the world, insofar a CityGML 3D city model and some necessary building parameter inputs are available.

This 3D-city-model-based energy analysis calculates the heat demand, final energy and CO_2 emission of each building of a district.
Because of the calculation method, which is a physical model based on the standardized monthly energy balance (ISO 13790), the results take into account the local weather (air and sky temperatures, solar irradiances for the different orientations), the real building geometry and possibly the actual building physics and refurbishment state (if these information data are not available, benchmarking values from building typology libraries are used instead).

In addition to heat demand diagnostics, which serves in particular as a calibration phase, this process offers opportunities to simulate extreme meteorological year, or detailed energy scenarios and see their impact in term of energy savings.
Refurbishment investment costs can be also calculated, taking into account the targeted building energy efficiency, the actual building state, and the building element areas from the 3D city model.
The resulting energy and economic indicators, visualized in a virtual three-dimensional district, can assist energy planners and municipal managers in the definition of refurbishment priorities, as well as the coordination of a long-term urban energy strategy.

3D-city-model-based energy analysis could also directly address the building owners or tenants and allow them to calculate their energy savings potential and the investment costs of a required refurbishment. Whatever the application, 3D city models have the potential to facilitate and support a holistic city energy strategy and thereby, become a keystone of the energy transition.

2.2 Required input data

For a 3D-city-model-based energy analysis, each available data sets regarding the building envelope, building efficiency and building use are useful and can be integrated in the calculation process, refining the urban thermal model and improving the result accuracy.

Some minimum input data and files are necessary to start a 3D-city-model-based energy analysis:

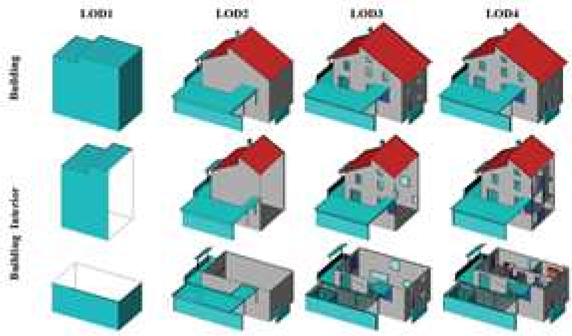
- a CityGML 3D city model
- a precise and realistic building construction library
- the building usage and building year (or age class) of each buildings
- In case of final energy calculation: the heat systems of each building

2.2.1 CityGML 3D city model

The OGC Standard CityGML is an open, multifunctional model that can be used for geospatial transactions, data storage, and database modeling (Groeger et al., 2012). It provides a basis for 3D geospatial visualization, analyzing, simulation and exploration tools, and therefore offers the possibilities for numerous and varied spatial analyses such as noise mapping, urban wind flow studies, photovoltaic potential, district network connections and extensions, heating demand calculations, simulation of refurbishment scenarios, and the integration of new buildings into an urban surrounding.

A considerable advantage of CityGML in comparison to other 3D city model formats is its spatio-semantic model, which specifies object modeling in different levels of detail. Due to this, it is an excellent database for heating demand analysis of existing buildings stock, since the level of building parameter availability/quality can be reflected in the Levels of Detail of CityGML (see Figure 4).
The most simple geometric representation of a building for a heating demand evaluation consists of a simple rectangular block. This block model consists of the “Level of Detail 1” (LoD1) of CityGML. The Level of Detail 2 (LoD2) adds the roof form to the building level, Level of Detail 3 (LoD3) adds in the positioning of the façade windows, and Level of Detail 4 (LoD4) incorporates the modeling of the indoor space.

Fig. 4: The four Levels of Detail of CityGML



Source: Karlsruhe Institute of Technology (Groeger et al., 2012, page 72)

3D city model can be generated, either by stereo air photo, digital cadaster combined with building information (height, roof type), or laser scanning. In particular, the latter technique allows for an automatic generation of a CityGML model of whole cities in a short time. By 2013, the complete buildings stock of Germany will be modeled with CityGML – LoD1. Some regions like Saxony have already completed their 3D city model with LoD2 (Baltrusch et al. 2011).

Given the diverse qualities of the 3D city models, a validation and healing module named “CityDoctor” has been developed in the HFT Stuttgart, which allows for the control and enhancement of the geometrical quality of the 3D model by closing polygons and volumes or separating buildings with common adjacent walls (Wagner et al., 2011). Nevertheless, the 3D city model to be analysed must present already clear building structures.

In the case of Rotterdam, a 3D city model is available in LoD2. However, due to some deficits in the model, the CityDoctor healing was extended by new healing algorithms. As described in chapter 3.

2.2.2 Building construction library

Such building construction libraries are essential to address districts with several hundred or thousands of buildings. They link building typologies (defined by building types and age classes) to building efficiency benchmarking parameters. These libraries can exist at a national level (e.g. Project Tabula, 2012), for certain regions (e.g. the states of Bavaria, 2006, and Schleswig Holstein, 2012, in Germany), or for specific city quarters with exemplary monitoring projects (e.g. Karlsruhe Rintheim, 2013). Generally, the more locally and accurately these building libraries are defined, the higher the accuracy of the on-site construction characteristics.

2.2.3 Building usage and age

They are the minimum required building attribute data, necessary to pick up the right benchmarking parameters from the building libraries. The refurbishment year or refurbishment state, although not necessary to start the energy analysis, are valuable data, impacting strongly the accuracy of the heat demand and energy savings results.

2.2.4 Building heat system

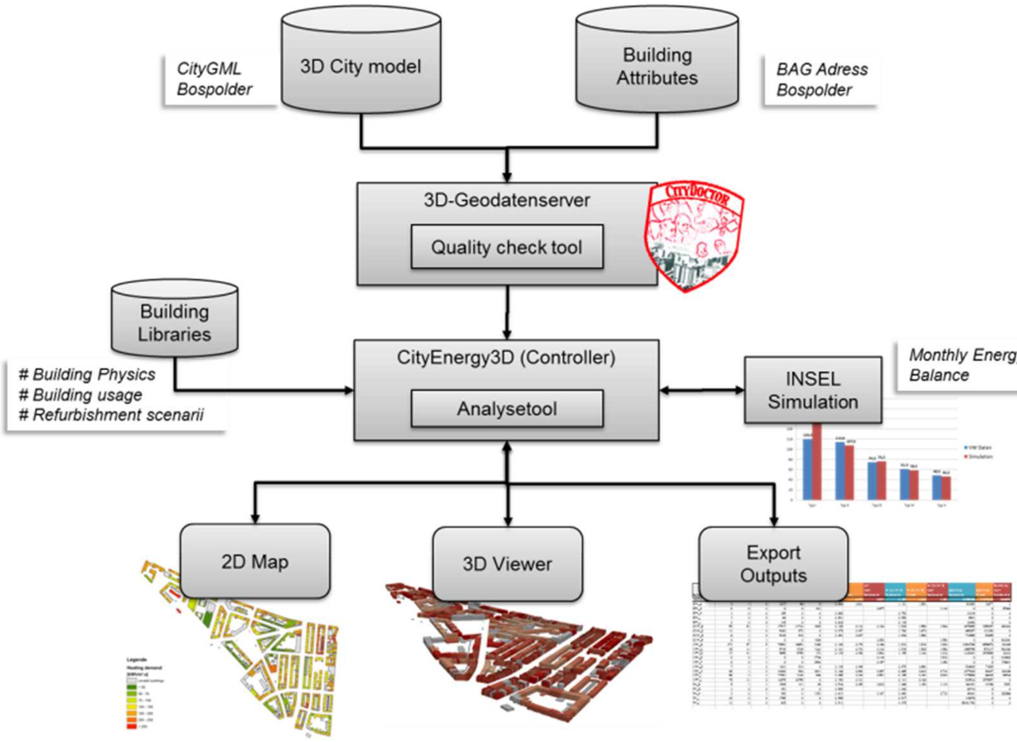
The information data relative to the heat systems (combustible type and system efficiency), although not necessary for the heat demand calculation process, are required as soon as the final energy consumption must be calculated. This is the case for instance for the calculation of the CO_2 emissions or primary energy, or for the validation of the simulation results with some measured gas consumptions. In this last case, the measured gas consumption data must be corrected with the yearly climate factor and correctly distributed to the corresponding buildings.

2.3 Workflow

The workflow of the 3D-city-model-based energy analysis is presently performed by numerous separated modules and softwares.

In the near future, all these modules will be gathered on a unique simulation platform, which will be directly accessible and usable by the different stakeholders of energy urban planning. This development is the goal of the new 3-years project SimStadt (www.simstadt.eu).

Fig. 5: Workflow of the energy analysis based on 3D city model



Source: HFT- Stuttgart

First, the healing module “CityDoctor” checks and corrects the CityGML-based 3D city model to make its quality in compliance with the rest of the energy analysis.

Then, the specific Java-based software SimStadtPreProc, developed at the Hochschule für Technik Stuttgart, undertakes its geometrical analysis by extracting relevant information like volumes, envelope surfaces and orientation, adjacent walls etc.
A systematic and automatic data pre-processing allows for the calculation of the relevant thermal input data for different Levels of Detail and data availabilities.
As the building thermal properties, such as heat loss coefficients (U values), are rarely known and the collection of this information is time-consuming, some implemented algorithms can be used to assess them by means of benchmarking parameters from the building construction libraries. Depending on the availability of additional information, these values can be updated, particularly in regard to refurbishment measures.

Regarding the heating demand calculation itself, the quasi-static monthly energy balance (standardized in the ISO 13790), implemented in the software Insel 8, has been chosen in this process. Its limited input requirements are compatible with a 3D city model, while its robust and reasonably accurate algorithm is used worldwide by energy standard organizations. Moreover, the computing time of this heating demand calculation is well suited to generate and compare long-term urban energy scenarios for districts with thousands of buildings.
From the standard ISO 13790, some simplifications and adaptations have been made. For example, every building is modeled with a single thermal zone, since their internal structure is not detailed for CityGML model LoD1 or LoD2. In the special case of multi-usage building, set-point temperatures, internal gains and air change rates are averaged according to the respective used area.

Additionally to the heating demand diagnostics of the existing building stocks, some refurbishment scenarios can be defined per building in different ways:

- defined by an energy standard goal
- defined by specific refurbishment measures
- defined by new envelope efficiencies (e.g. U-Values of the building elements, airtightness, thermal bridges)

By comparing the simulation results of these refurbishment scenarios with the actual state, Energy saving potentials can be calculated.

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3 Analysis of the available input data and their qualities

3.1 3D CityGML city model of Rotterdam

In order to make use of the 3D city model of Rotterdam for an energy demand simulation, the existing model needs to be enhanced. As a result of a model validation, it turned out that the model does not provide a solid geometry per building. As a consequence, it was not possible to calculate the building volume. In order to enhance the model geometry, a new healing algorithm was developed that detects holes in the building geometry and automatically inserts missing polygons to fill these holes. The resulting 3D model is suitable for the energy demand simulation for most of the buildings.

The algorithm has been developed as an add-on to our CityDoctor software tool. The software including the add-ons was delivered to the City of Rotterdam.

3.1.1 Validation results

The 3D City Model of Rotterdam was analyzed using the CityDoctor Validation Software. The model contains several systematical errors:

- Invalid building ID
- Polygon orientation
- Missing wall surfaces
- Several topological errors

The systematical errors are explained in this subchapter using a simple example, the building shown in Figure 6 with ID {4A7684E5-542F-4011-A74D-DF5ED87F0D4E} from the Bospolder data set.

The building ID is invalid according to the CityGML conventions: The gml:id has to be a XML name. By definition, a XML name has to start with an alphabetic character, underline character (_) or colon (:). The ID must not start with the character '{', however, this is easy to fix.

All polygons of a building have to be defined by a sequence of points in counterclockwise order. The order of the points defines the orientation of the polygon. This is essential for example to calculate the visibility and solar gains of a facade. In the given model, the point sequence was given sometimes in clockwise order, leading to a wrongly oriented polygon, as shown in Figure 7.

The walls of a building that separates it from other buildings are missing in the model, see Figure 8. As a consequence, the building geometry is not a solid, and the volume of the building cannot be calculated.

Fig. 6: Building {4A7684E5-542F-4011-A74D-DF5ED87F0D4E}

Fig. 7: Wrong orientation of polygons

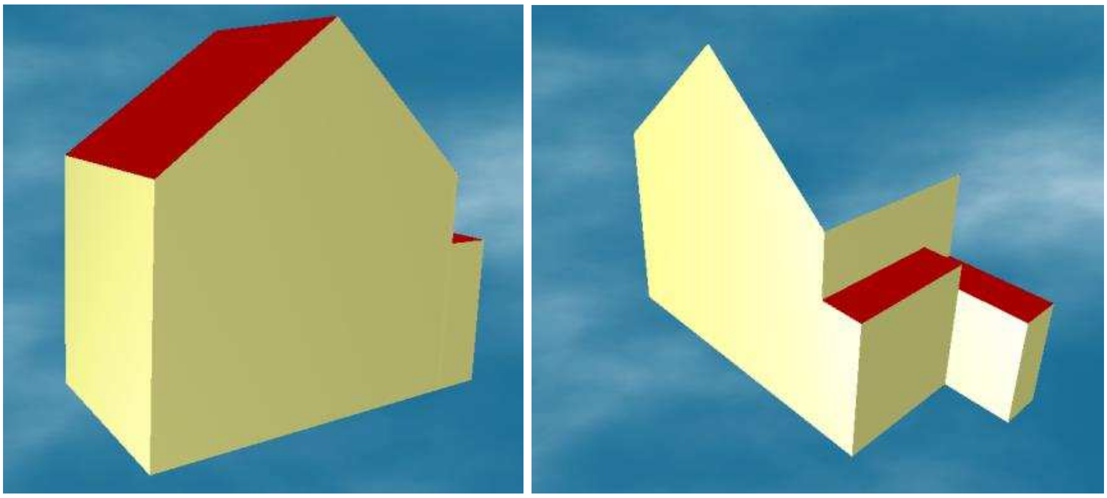


Fig. 8: Missing polygons

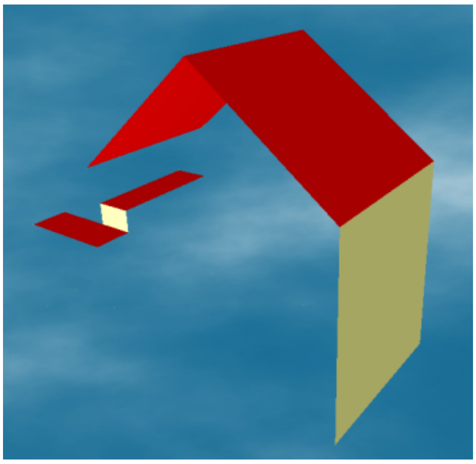
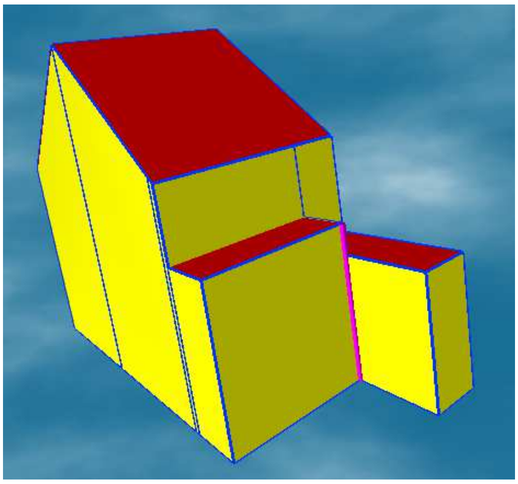
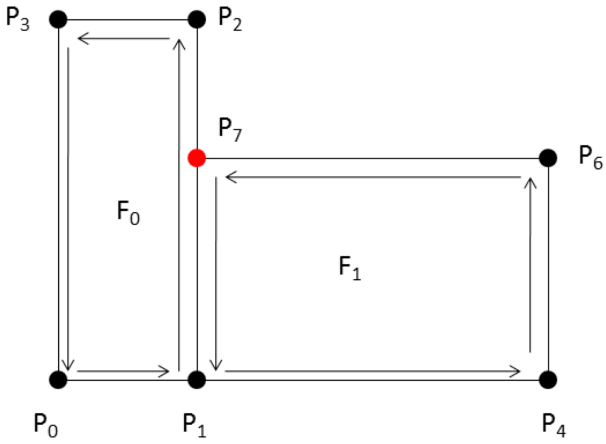


Fig. 9: Topological error

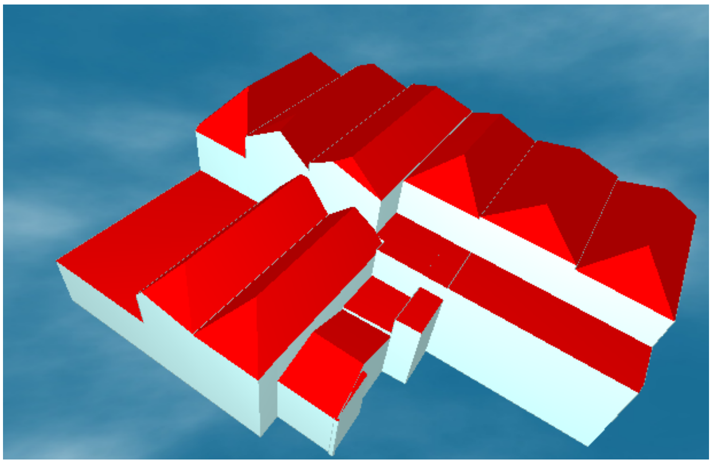




Polygon F0 is defined by (P1, P2, P3, P0, P1), Polygon F1 as (P1, P4, P6, P7, P1). However, in a topologically correct solid (2-manifold) geometry, each edge shares exactly two polygons. In this example. edge (P1, P2) and edge (P1, P7) bound only one polygon. In a correct model, F0 has to be defined as (P1, P7, P2, P3, P0, P1).

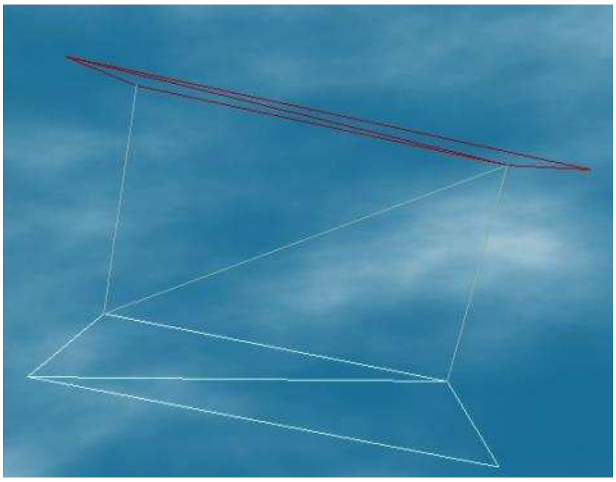
In addition, several buildings contain substantial geometric and semantic errors. Some examples are shown in the following figures.

Fig. 10: Building complex modeled as one building only.



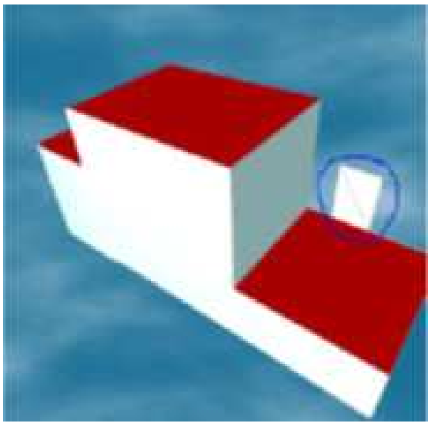
It should be at least split into building parts.

Fig. 11: Building geometry consisting of 3 polygons only.



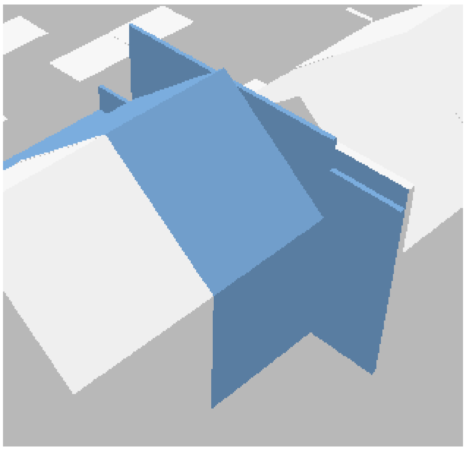
In this example, the building geometry consists of 3 polygons only. It is impossible to build a solid with less than 4 polygons (tetraeder) in general.

Fig. 12: Dangling polygon.



Sometimes dangling polygons appear. They usually belong to the neighboring building.

Fig. 13: Building integrating wall geometry



In this case, the building consists of the building geometry and partially of the wall geometry. This should be split into two separate CityObjects in CityGML.

As an example, the validation of the Hoogvliet Zuid CityGML model is summarized here. With the CityDoctor Validation and Healing, such a summary can be generated for each of the given CityGML files. The file contains 10828 building. 10332 (96%) of these buildings have errors. Figure 14 shows the distribution of boundary surfaces. The amount of ground surfaces equals the number of buildings, as expected. The number of roof surfaces doubles the number of buildings, which is an indicator that many buildings have saddle roofs. Most of the boundary surfaces are wall surfaces, as expected.

Fig. 14: Hoogvliet Zuid: distrubution of boundary surfaces

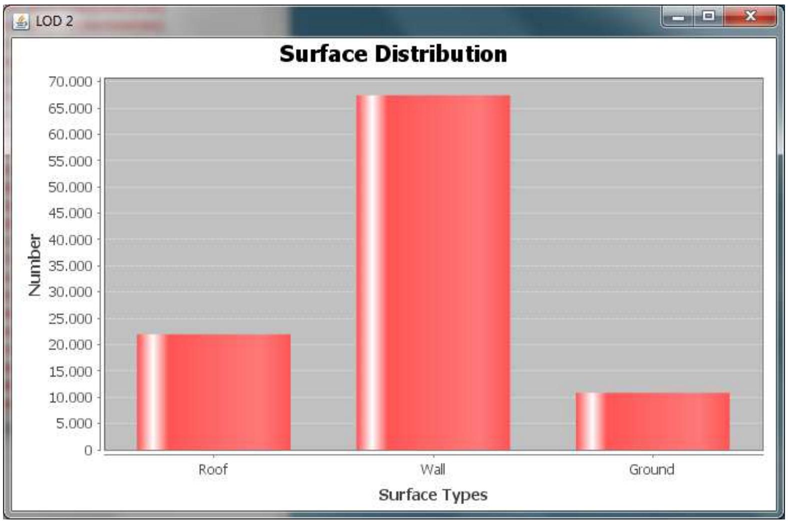


Fig. 15: Hoogvliet Zuid: distribution of errors

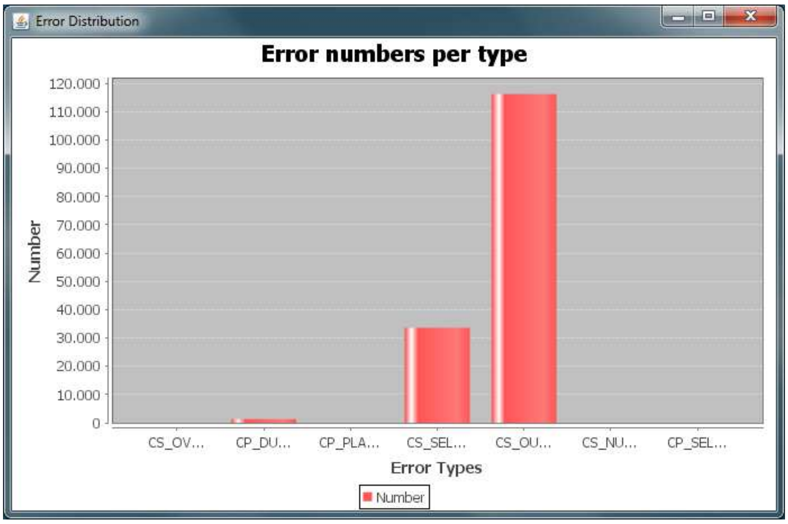
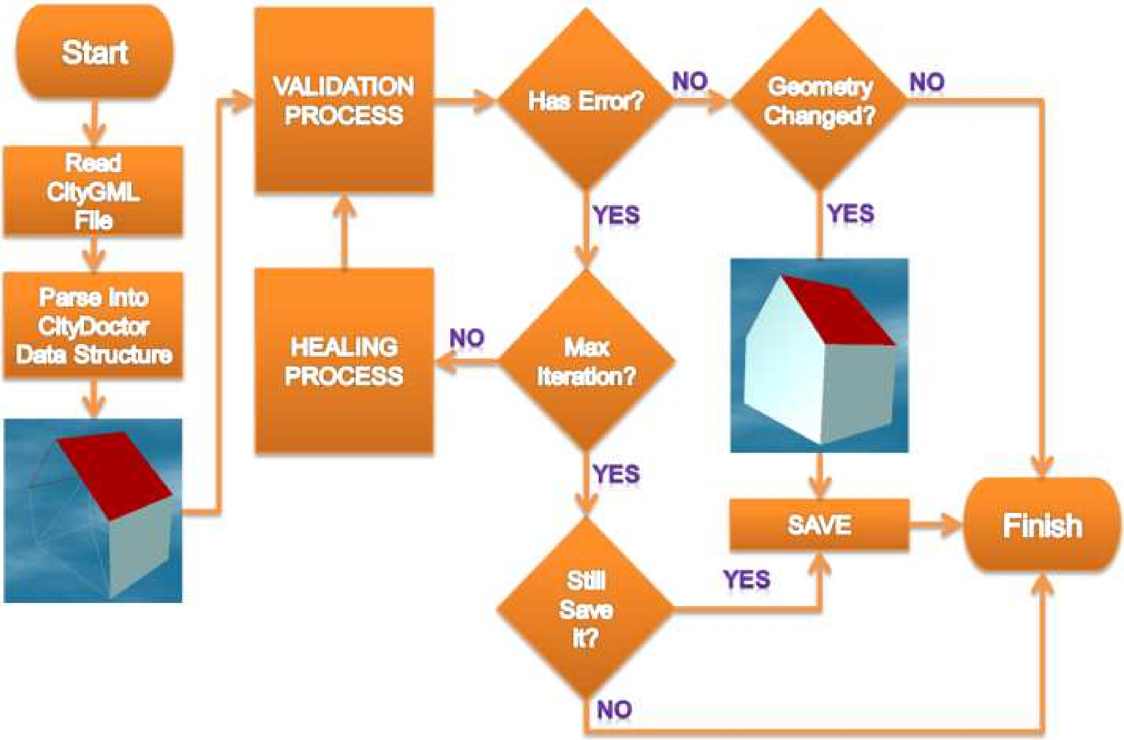


Figure 15 shows the error distribution of the Hoogvliet Zuid model before healing. A lot of CS_OUTEREDGE errors appear in the model, due to missing polygons. As explained above, an edge has to share two polygons in a 2-manifold solid geometry. If an edge bounds one polygon only, a CS_OUTEREDGE error is reported. The second most common error is a self-intersection due to the topological errors. From time to time other errors such as double use of the same point in the same polygon appear.

3.1.2 Impact of the 3d city model healing process

For each error detected during the validation process a specific error object contains all necessary parameters for healing. Our approach assumes that all errors should be healed hierarchically, according to the dependency of the respective checks. An iterative approach assures that after an error is healed, the geometry is checked repeatedly for new errors which might have been introduced during the last healing step. This enables to manipulate the original model in a controlled and reproducible way.

Fig. 16: Healing workflow



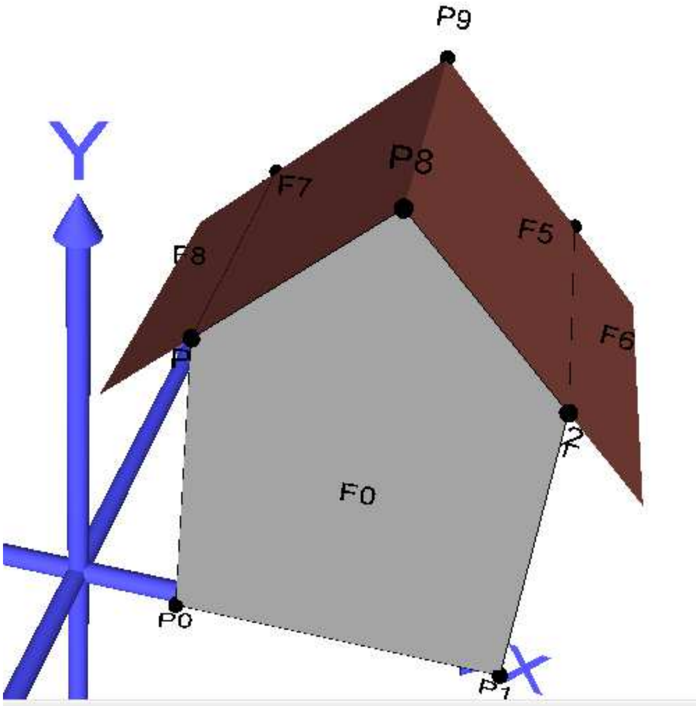
For the cases where problems can't be solved by the healing algorithms after a user-defined maximum number of iterations, an error object is returned. Healing is done in two phases. Firstly all the polygons are healed and then if polygons pass the validation process, solid-errors are healed. In Figure 15 the healing process is illustrated.

The validation and healing approach is precisely described in 2 recent publications: Wagner et al., 2013, and Alam et al. 2013

A specific healing operator was developed for the Rotterdam model, able to heal non-planar holes with orthogonal polygons. This situation appears quite often in the Rotterdam model.

However, some errors such as dangling faces and the above mentioned semantic errors could not be healed. Dangling faces are valid in CityGML Multisurface geometry and wanted in some models. See for example the following building with overlapping roof. This is a dangling surface, but a valid CityGML model uses to keep the roof area as close to reality as possible. In the given example in Figure 12, dandling face is not wanted, however, this is very difficult to decide by an algorithm.

Fig. 17: Valid CityGML model with dangling surfaces



It should be modeled as 1 Solid and 2 MultiSurface geometries, but this is rarely supported, usually it is modeled as one MultiSurface geometry, which is valid in CityGML as well.

In the Hoogvliet Zuid model, 8474 building models have been healed (82%). In case of the Bospolder model 916 out of 1174 buildings have been healed (78%).

To be able to support batch processing, a batch version has been developed in addition to the interactive CityDoctor software with graphical user interface.

A user documentation for the CityDoctor Healing Software, Rotterdam edition, is supplied in the annex 5.

3.2 Attribute building/dwelling databases

The city of Rotterdam provided us two building databases for the district Bospolder:

- A building address database
- A residential dwelling database

Since calculations are conducted at the building level in the 3D-city-model-based energy analysis, and since the residential dwelling database does not apply to the total building stock of Bospolder district, the first database has been the main source of building attribute data for the energy analysis.

The following table presents the datasets listed for each building address in the building address database.

Fig. 18: List of parameters in the building address databse

Parameter name	English description
gebouwnummer	Building address ID
GUID	CityGML Building object ID
Blokcode	Neighborhood unit iD
openbare_ruimte	Neighborhood name
PPC6	Zip code
bouwjaar	Building year
laagste_bouwlaag	Storeys number under ground
hoogste_bouwlaag	Storeys number above ground
gebruik1	Main building usage
gebruik2	Secondary building usage
x_coord	Geographical coordinate X
y_coord	Geographical coordinate Y

Source: City of Rotterdam

In the perspective of the energy analysis, each element of this database (3729 building addresses) must be connected with the building object of the CityGML 3D city model of Bospolder (924 CityGML building objects).

Here, the difficulty lies in the fact that some CityGML building object can be related with several building addresses (up to 60) with different parameters:

- 226 CityGML building objects are related to building addresses with different main building usage
- 160 CityGML building objects are related to building addresses with different geographical coordinates
- 48 CityGML building objects are related to building addresses with different zip code PPC6
- 29 CityGML building objects are related to building addresses with different storeys numbers
- And 3 CityGML building objects are related to building addresses with different building years

In all these cases, an arbitrary choice must be done for the selection of the building attribute to be attached to the CityGML building.
For each CityGML building object, as in the building address database, 2 building usages maximum have been considered, hierarchized in a main and, if specified, a secondary building usage. Without any data concerning the respective floor area occupied for the different building usages, the specified secondary usage has been systematically considered as occupying the whole ground floor.
In the case where several building addresses related to a unique CityGML building object present “concurrent” building usages, the priority has been given to the residential usage. This latter has been retained as main building usage, while one of the other main building usages has been retained as secondary building usage of the whole CityGML building object.
For the other parameters, the CityGML building object retains the majority building addresses parameter.

Besides, 266 CityGML building objects are not related with any building addresses. They are in majority garages, or other unused buildings (then without heat demand). Nevertheless, some are obviously residential row houses. These ones unfortunately won't be part of the urban energy analysis, since they don't have the minimum necessary building attributes for it (building year and building usage).

Fig. 19: Buildings of Bospolder district without any building attributes (in red)

Source: HFT - Stuttgart

3.3 Building libraries

Building libraries are essential to address districts with several hundreds or thousands of buildings. The building construction libraries (or building typology libraries) detail benchmarking values of building physics and thermal parameters for different building typologies generally classified by age and type. Beside the building construction libraries, the building usage libraries detail occupation-dependent data (internal gains, heating temperature set-points and schedule) per building usage.

Generally, the more locally and accurately these building libraries are defined, the higher is the accuracy of the on-site characteristics.

3.3.1 Voorbeeldwoningen 2011

A national building typology library for Netherland has been developed in 2011: Voorbeeldwoningen 2011.
The building typology classification is composed of 5 building age class:

- < 1946

- 1946 - 1964
- 1965 - 1974
- 1975 - 1991
- 1992 - 2005

… and 5 building types:

- Detached single-family house
- Double single-family house
- Row house
- Maisonette
- Apartments (detailed in 3 sub-configurations)

For each combination {building age class; building type}, a list of actual U-Values (see Annex 1) and a recommended refurbishment package with new U-Values and related investment costs are detailed.

Fig. 20: Description of the building typology detached single-family house, built before 1964 “Voorbeeldwoningen 2011”

Source: brochure “Voorbeeldwoningen 2011”

A deeper analysis of this library shows many limits and approximations: the whole residential building types and ages are summarized in only 5 different datasets of U-Values (no individualization according to building types), without any details concerning the wall/roof/basement construction layers and thickness. Moreover, the refurbishment package do not take into account the building state before refurbishment, since all the U-Values after refurbishment are identical, corresponding to the latest building age class 1992 – 2005.

Following these limits, the consideration of another building construction library has been decided. The German national building typology library, although older and not "local", is much more accurate and realistic, and then would lead to less approximation.

3.3.2 Deutsche Gebäudetypologie (2003)

Between 1989 and 1993 (with updates since), the *Institute für Wohnen und Umwelt* (IWU) led a detailed survey on the whole German residential building stocks (hundreds of buildings audited), to develop a classification of 36 German building typologies according to building age and building type.

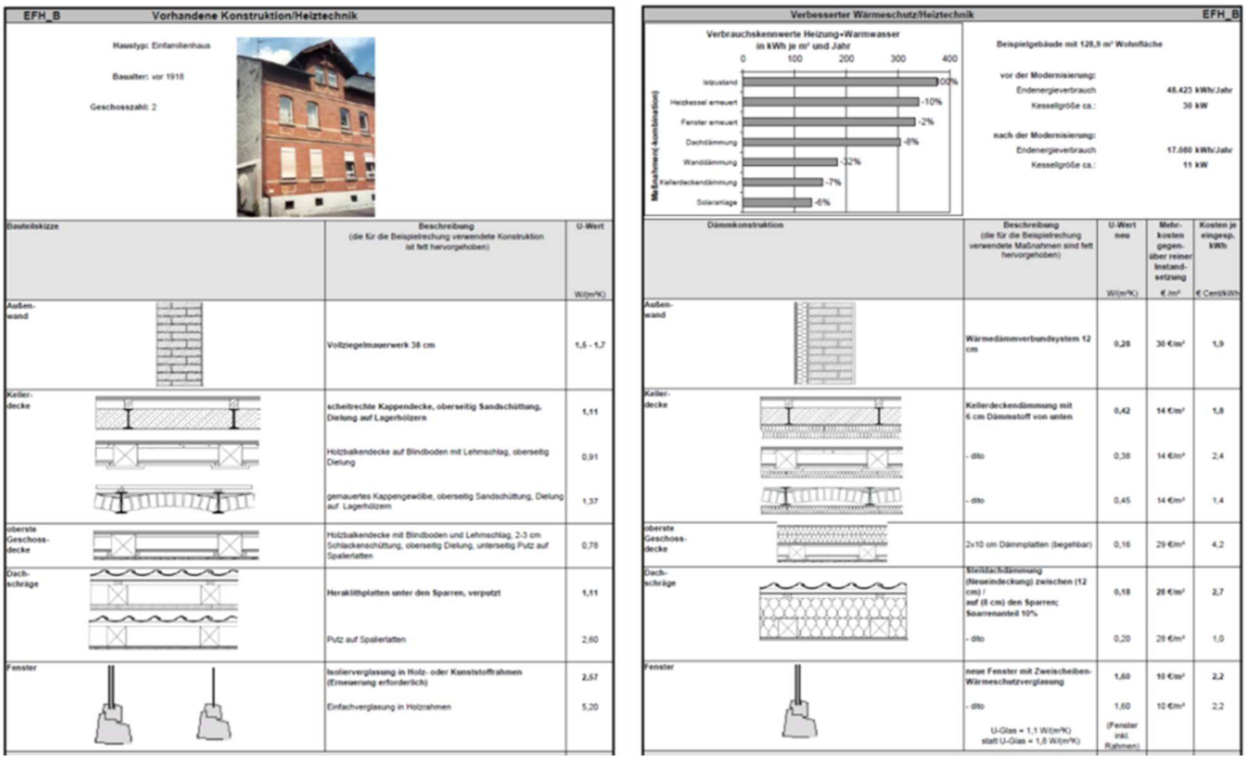
Fig. 21: Building typologies of IWU according to building age and type

Source: Deutsche Gebäudetypologie - Systematik und Datensätze

For each of these building typologies, a building archetype has been detailed, including its actual building physics (construction material and layer thickness) and associated thermal properties (U-Values).

In 2003, recommended refurbishment measures individualized for each building typology have been added to the building library (IWU, 2003), including the new U-values after refurbishment, the average associated energy savings and investment costs, as shown in the figure 22.

Fig. 22: Description of the actual state and recommended refurbishment measures for the building typology "EFH_B" (single-family house before 1919).



Source: Institut Wohnen und Umwelt, 2003

Beside these national building typologies, some cities, regions and Bundesländer have also developed similar building typologies classifications. The building typology library of the German Land Schleswig-Holstein, realized recently in 2012, could have been an alternative for Rotterdam.

3.3.3 Building usage library

The building address database of the City Rotterdam contains information data about the building usages (Gebruik) of the different buildings.

This information is very important in the perspective of the building thermal simulation, since it determines the different hypotheses concerning internal gains (depending on the occupancy per m² and electrical devices), heating set-point temperatures and schedules, domestic hot water demand, air change rate as well as window-to-wall ratio.

Previously to the building simulation, a building usage library specific to the different building usage categories defined by the City of Rotterdam has been created, including standard parameters detailed in the norm DIN V 18599-10 (see Annex 4).
The window-to-wall ratios of the different building usages come from on-site experiences of the Hochschule für Technik Stuttgart.

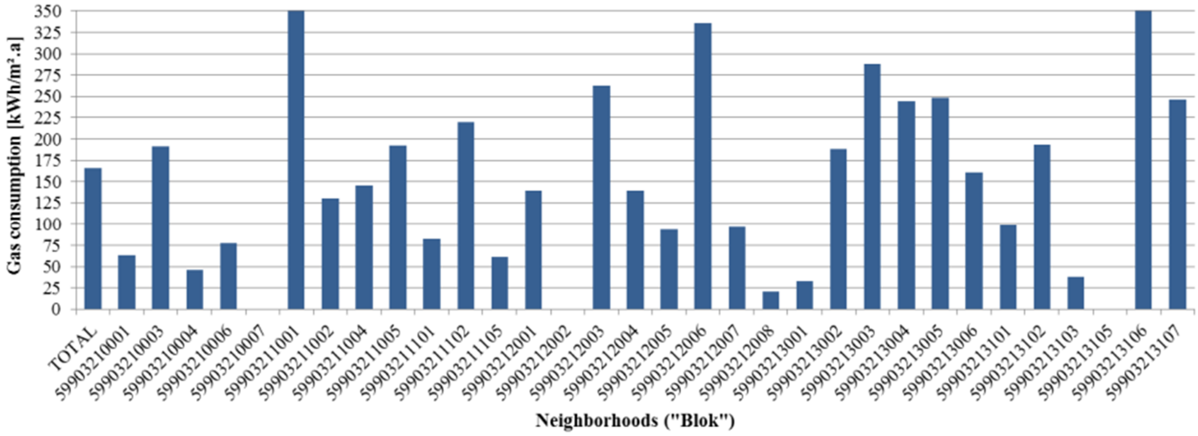
3.4 Gas consumption data

Contrary to statistical/ benchmarking energy analysis methods, the 3D city model based energy analysis does not require any consumption data as input data.
Nevertheless, when they are supplied at a “high-resolution” level (optimum: building level), they are an interesting means to check the accuracy of the simulation model, and then calibrate it.

The City of Rotterdam provided 2 gas consumptions data base: the yearly gas consumptions summed per neighborhood units and per zip code units (PPC6) in Bospolder.
Unfortunately, some contextual information data, essential to analyze the consumption data, are missing: heating and DHW production systems per building, cooking system (gas/electrical), centralized heating systems connecting several building to the same central plant etc.

As shown in the Figure 23, the gas consumption data per Neighborhood, normalized with the heated floor area calculated from the 3D city model, give often unrealistic results: some gas consumption lies below 30 kWh/m².a, whereas some others exceed 350 (even up to 1130 kWh/m².a!).

Fig. 23: Specific gas consumption in kWh/m².yr, in the different Neighborhood of Bospolder



In the gas consumption data base at Zip-code level, some Zip-code units containing CityGML (residential) building objects present no consumption according to the gas consumption data, and vice-versa: some Zip-code units with gas consumption data non-null doesn’t have any building according with the CityGML 3D City model.

A possible cause would be a difference between the gas consumption partition and the Neighborhood/Zip-code units as defined in the building databases and 3D city model.

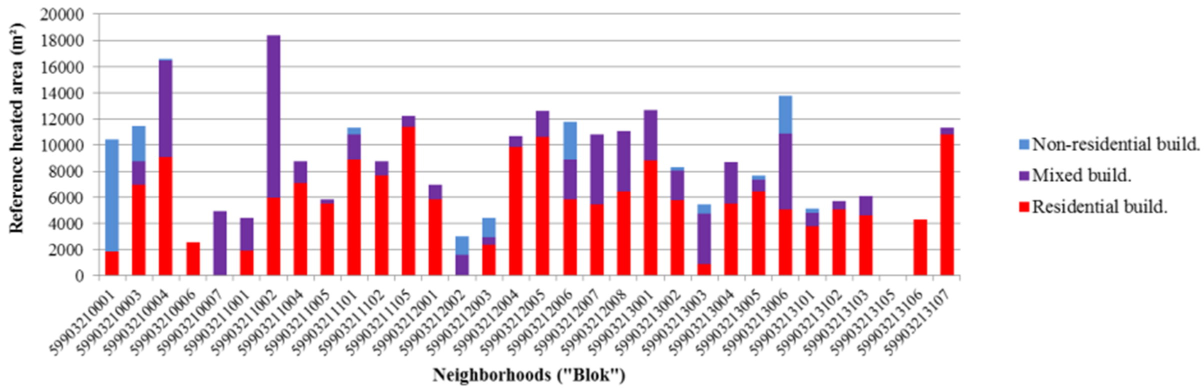
4 Energy calculation results – present state

4.1 Reference heated floor area

The reference heated floor has been calculated for all buildings (including non-residential) of the CityGML 3D city model, according to the standard method DIN V 18599.

In the following figure, heated floor area is detailed for non-residential, mixed, and residential buildings, summed up per Bospolder Neighborhood.

Fig. 24: Reference heated area – Bospolder



Most of the following results are normalized by this reference heated floor area (specific heating demand or specific CO2 emission), allowing to assess the building energy efficiencies.

4.2 Heating demand and heat density

The heating demands of all buildings of the CityGML 3D city model of Bospolder have been calculated, as described in the part 2.3.

Heating demand calculation results are presented in the two following graphs, first as a mapping of Bospolder, then as a statistical diagram.

Fig. 25: Specific heating demand mapping - Bospolder

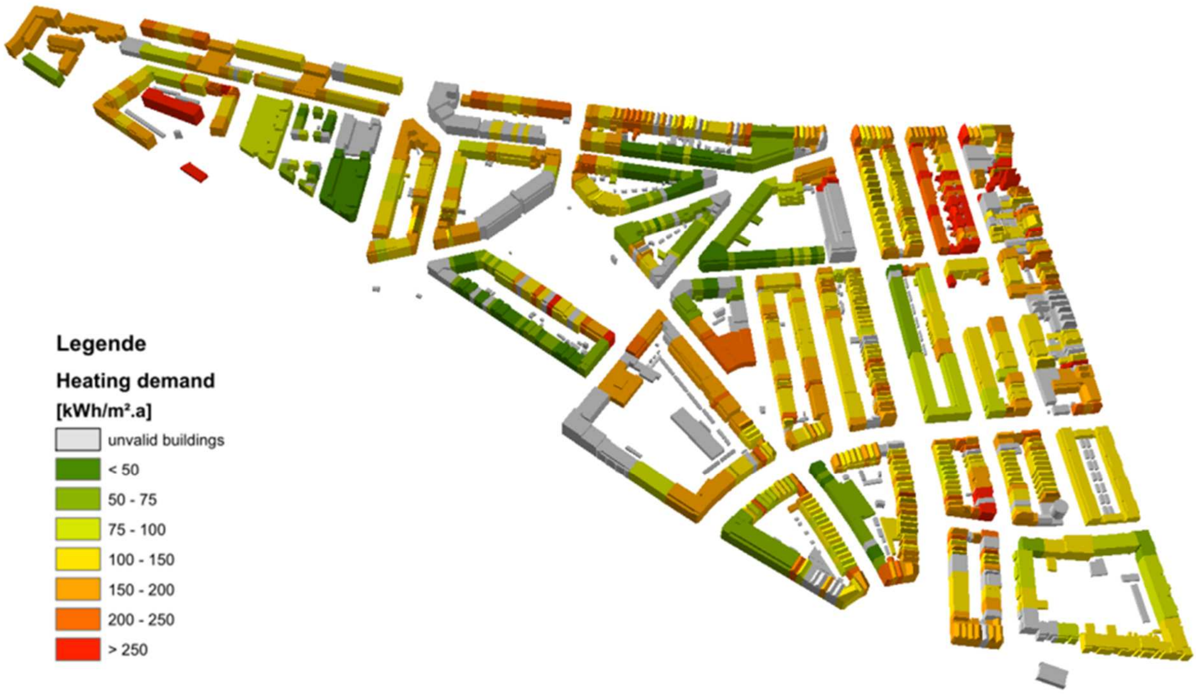
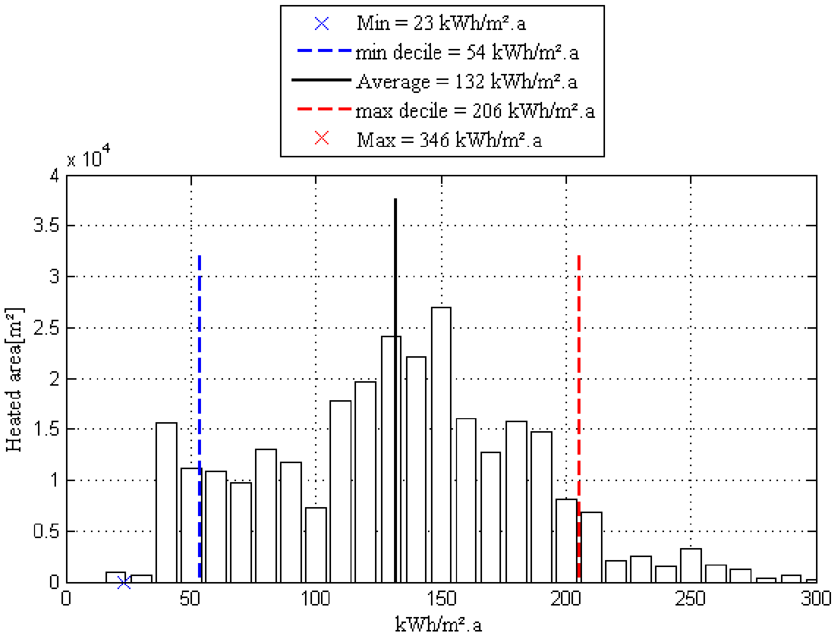


Fig. 26: Specific heating demand diagram - Bospolder



The specific heating demand in Bospolder is quite heterogeneous, spread out between 23 kWh/m².yr and more than 300 kWh/m².yr. Average specific heating demand reaches 132 kWh/m².yr.

These heating demands have been summed up by building typologies. The average values, represented on the figure 27, show several general trends: As expected, the older is the building typology, the higher is its heating demand, except for the ten years after the WWII where the urgent need of new buildings may have cause the construction of low-efficient buildings.

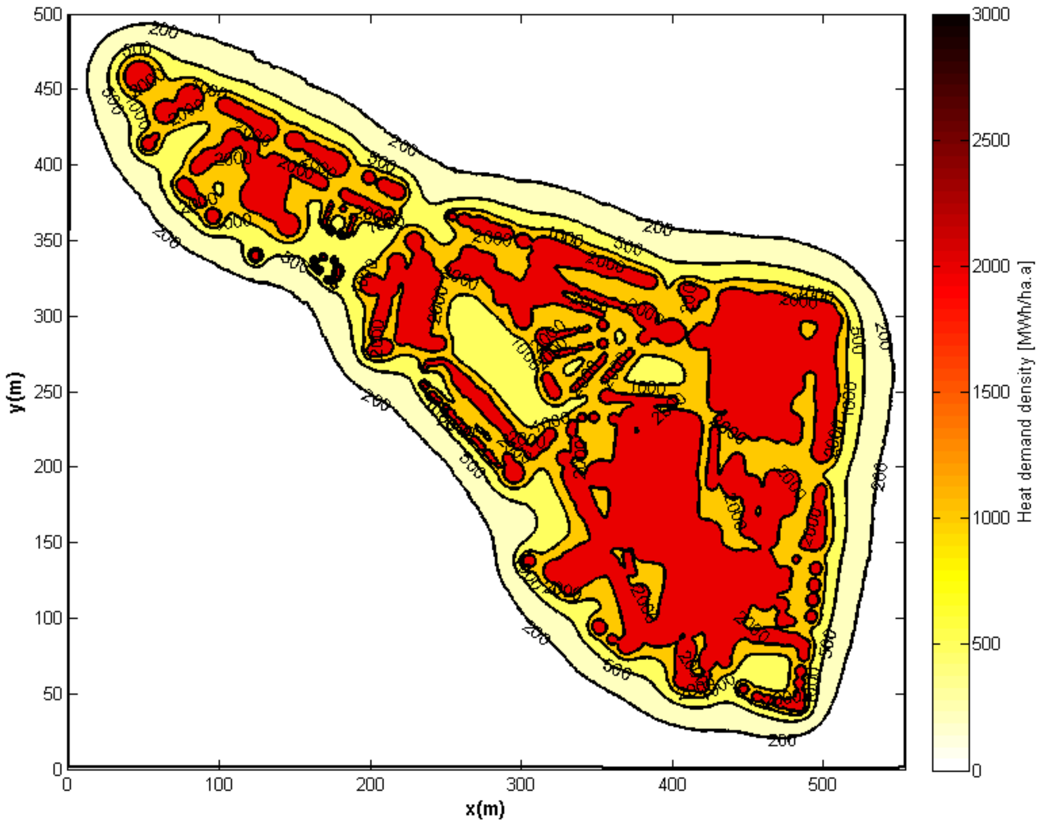
Another main trend: the bigger is the building, the lower generally is its heating demand normalized per heated area, due to a more favorable compactness index.

Fig. 27: Specific heating demand per building typology - Bospolder

	EFH	RH	MFH	GMH
vor 1918	143,3	155,5	148,7	147,9
1919-1948			158,9	126,5
1949-1957		187,8	174,8	126,2
1958-1968				
1969-1978				
1979-1983			106,9	
1984-1994	108,4	133,5	92,5	
1995-2001		65,8	53,2	
nach 2002			47,6	

The total heat demand is the sum of the heating demand and domestic hot water (DHW) demand. Its density, represented on the following figure, may be useful for HVAC facility companies, to draw (profitable) District Heating Networks in the zones where the heat demand of the customers is the highest.

Fig. 28: Heat demand density – Bospolder



4.3 CO_2eq emission

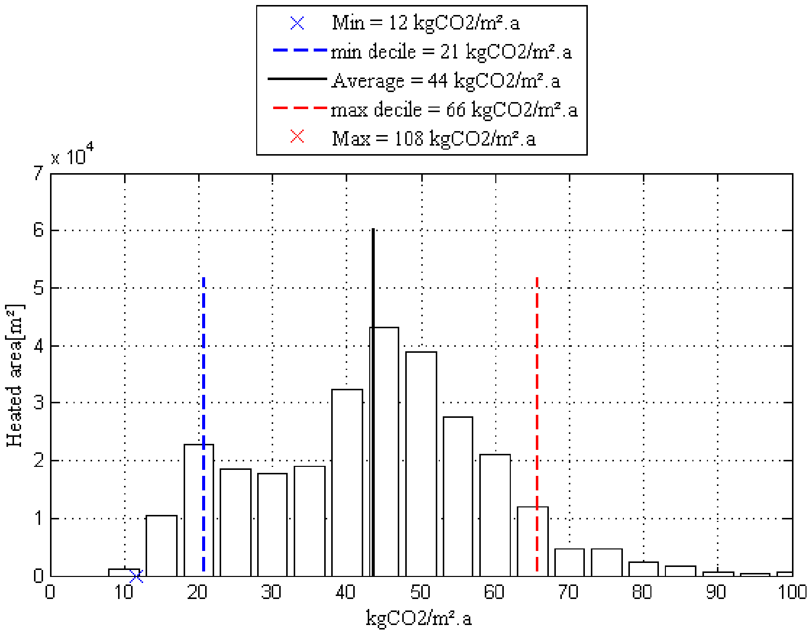
The CO_2 equivalent emission considered in this study refers to the heating and domestic hot water consumptions. “equivalent” means that the impact of all greenhouse gas (CO_2, methane, nitrus oxide) are considered in this amount. As an example, burning 1 kWh gas causes 253 grams CO_2eq.

To calculate CO_2eq emissions, the fuel and efficiency of heating and DHW systems must be known. Unfortunately, no database of HVAC systems in Bospolder was available.
As suggested by the City of Rotterdam, we considered that all buildings have a gas boiler. We assumed that their seasonal efficiency reach in average 85%, not depending on the construction year since original heating systems have generally been changed with more efficient new ones

CO_2eq emission calculation results are presented in the two following graphs, first as a mapping of Bospolder, then as a statistical diagram.

Fig. 29: Specific CO_2eq emission mapping - Bospolder

Fig. 30: Specific CO_2eq emission diagram – Bospolder



Following the heating demand trend, CO_2 emission per m² in Bospolder is also quite heterogeneous, spread out between 12 kgCO_2/m².yr up to 108 kgCO_2/m².yr. Average CO_2 emission reaches 44 kgCO_2/m².yr.

4.4 Verification of the simulated heat demand values

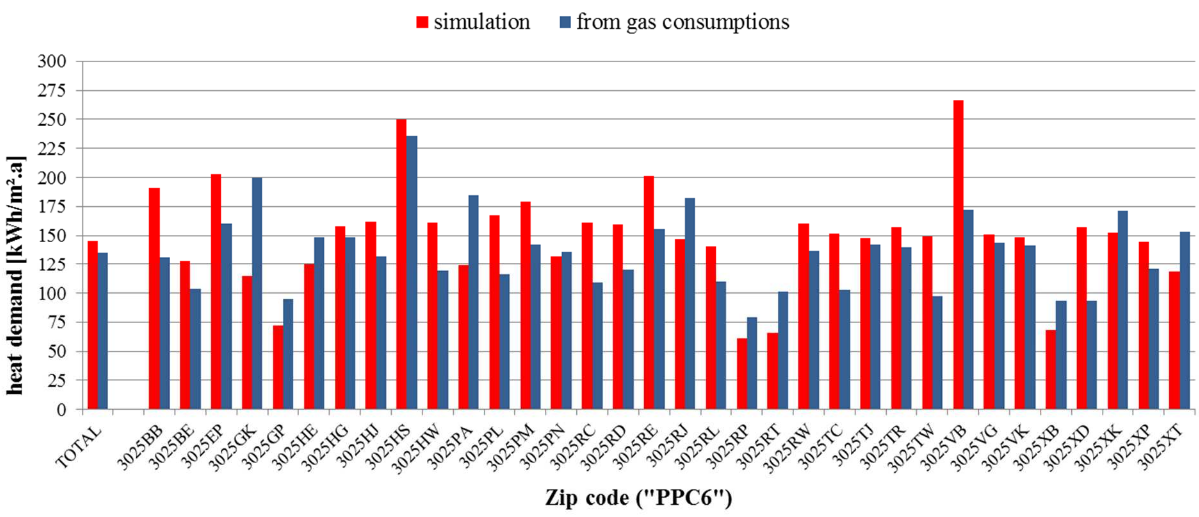
4.4.1 Comparison with actual heat demands assessed from gas consumptions

Despite the open questions exposed in part 3.4 concerning the use of gas consumption data, we intent in this paragraph to assess the “actual” heat demand from the gas consumptions and to compare it with the simulated heat demand presented in the last paragraph, in order to have an idea of the coherence of the different data.
Therefore, results presented in this paragraph must be considered with an extreme prudence.

To calculate the “actual” heat demand from the gas consumptions, we assumed that all buildings have a gas boiler, with an average seasonal efficiency of 85%, and that gas is used only for space heating and domestic hot water usage.

As detailed in the part 3.4, gas consumption data per neighborhood unit are barely exploitable, presenting unrealistic yearly specific gas consumption (per square meter). In comparison, gas consumption data grouped per Zip-code look more realistic.
Since the probability is sizeable that non-residential buildings don’t have gas-fired heating systems, only the neighborhood units whose residential building part is predominant (arbitrary criteria: more than 2/3 of the total used area) have been considered for this comparison. Moreover, we excluded Zip code units with invalid CityGML building objects or less than 5 CityGML building objects.
Results are presented in the graph below.

Fig. 31: Comparison specific heat demands Simulation / Gas consumptions – Bospolder’s zip codes



Except for some singular cases (Zip code 3025GK, 3025VB and 3025XD), the relative errors remains in the range +/-30%, while the total deviation reaches here 9%. This comparison at udistrict level is then reasonably coherent

Again, these results must be taken with an extrem prudence, since the zip-code and neighborhood partitions in the 3D city model and in the gas consumption data file seem not identical.

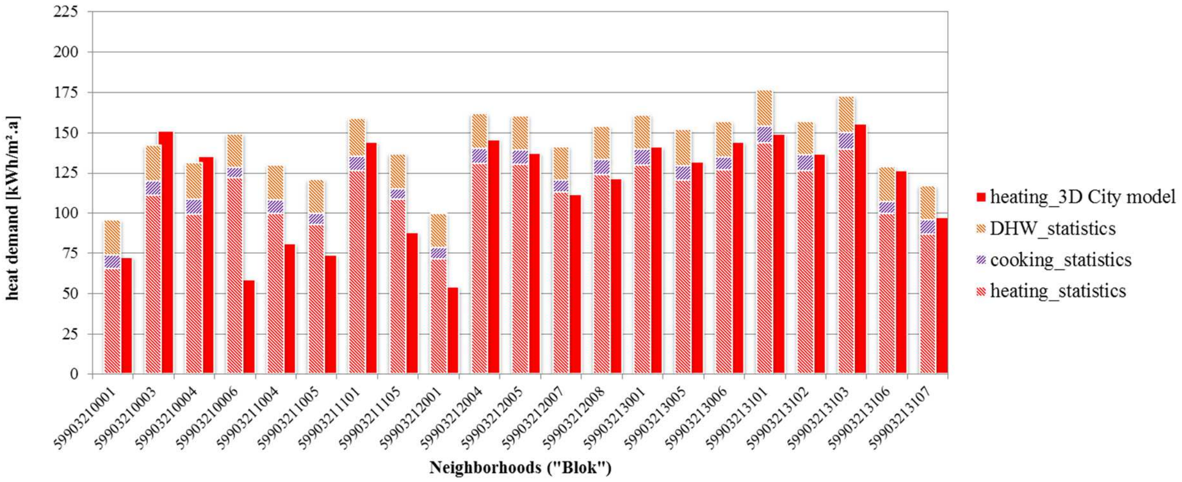
4.4.2 Comparison with the statistical energy analysis method

Interesting also is the comparison between the results of this 3D city model based energy analysis and those of the statistic energy analysis realised by the University Henri Tudor of Luxemburg for residential buildings.

This statistic energy analysis is based on local gas consumption values of some residential buildings, which are then extrapolated at district scale. To deduce the heating demand from these gas consumption values, they assume that the domestic hot water (DHW) and the cooking are satisfied with a gas-fired systems for all dwellings. Following the dutch standard NEN 7120:2011, gas consumption for cooking is assumed to reach 65 m³/year per dwelling (without consideration of the floor surface or number of people), corresponding to an average of 8.7 kWh/m².a, while the considered specific DHW demand for each dwelling reaches 18.9 kWh/m².a.

The gas boilers yearly efficiency hypothesis varies from 75% to 90%, depending on the type of dwelling and period of construction as specified in the brochure "Voorbeeraldwoning 2010". The results of both method are compared in the graph below for the Bospolder neighborhoods where residential buildings are predominant. Except for few neighborhoods (in particular Blok 59903210006), both heating demand results are reasonably coherent, with a standard deviation of 23%. Highest differences seem to take place in new urban area, where the statistic energy analysis give higher space heating demand than the 3D city model based energy analysis.

Fig. 32: Comparison specific heating demands of 2 energy analysis methods - Bospolder's neighborhoods



5 Calculation of energy saving potentials

5.1 Refurbishment scenario definition

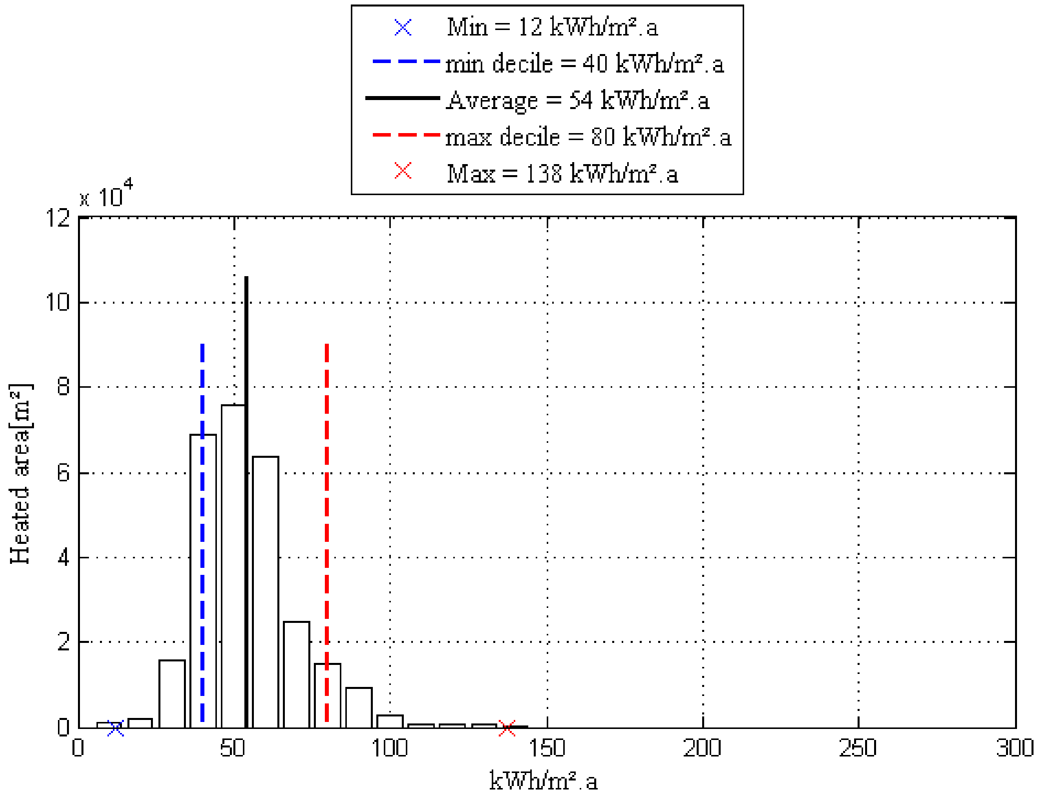
After having calculated the heating demand of the existing buildings stock in the chapter 4, the energy saving potential is assessed in this new chapter.

For it, a realistic and personalized energy refurbishment scenario of the Bospolder building stock is considered. It consists of specific refurbishment measures, individualized per building typologies, recommended by the Institut für Wohnen und Umwelt in its report *"Energieeinsparung durch Verbesserung des Wärmeschutzes und Modernisierung der Heizungsanalge für 31 Musterhäsuer der Gebäudetypologie"* (see paragraph 3.3.2).
For instance, building built before 1919, generally with stone facades, will be refurbished with an inside insulation (6 - 8cm), while post WWII buildings will get a dicker outside insulation.

Heating demand calculation results after refurbishment are presented in the two following graphs, first as a mapping of Bospolder, then as a statistical diagram.

Fig. 33: Specific heating demand mapping – Bospolder scenario refurbishment

Fig. 34: Specific heating demand diagram – Bospolder scenario refurbishment



In this refurbishment scenario, the specific heating demand in Bospolder is quite homogeneous, mainly situated between 40 and 80 kWh/m².yr. Average heating demand reaches 54 kWh/m².yr.

5.2 Heating saving potentials

By comparing the heating demand before and after refurbishment, we deduce the heating energy savings.

The average heating energy saving potential in Bospolder district reaches **59%**, from 0% for the building recently built with already high energy standard, up to 85% for non-insulated multifamily houses built in the 50's.

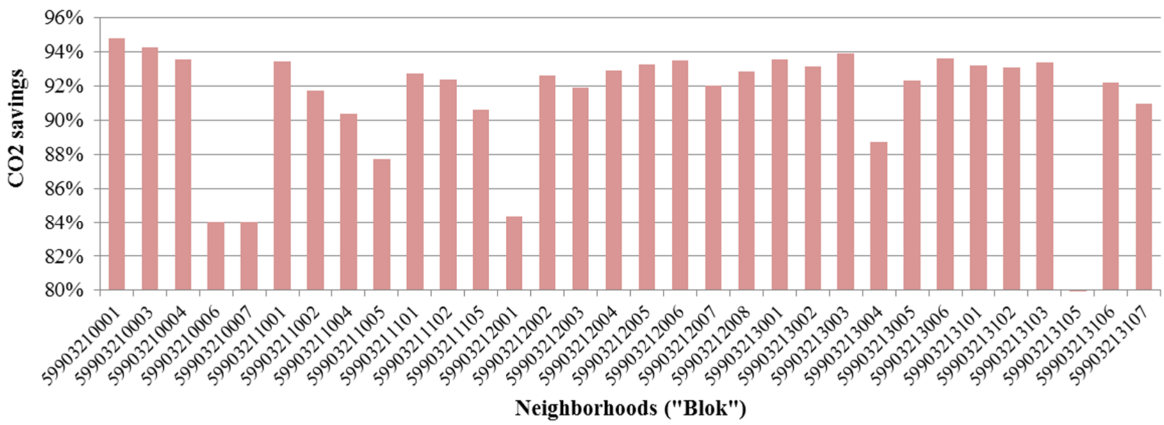
Fig. 35: Heating savings potential mapping – Bospolder scenario refurbishment

5.3 CO_2-saving potentials

Similarly to heating energy saving potentials, CO_2-saving potentials can be calculated in Bospolder district. As in the paragraph 4.3, only CO_2 equivalent emission referring to the heating and domestic hot water consumptions are considered in this calculation.

The DHW demand is assumed constant before and after the refurbishment.
Concerning the heat systems, a global connection of all the existing buildings to the district heating network of Rotterdam would lead to a CO_2 reduction of 84% according to the City of Rotterdam (corresponding to a CO_2 factor of the district heating of 48 g /kWh). By refurbishing simultaneously the buildings and then decreasing their heat demand, the total CO_2 reduction for the buildings stock of Bospolder would reach 92.6%, and even up to 95% reduction in some "Blok".

Fig. 36: CO_2 emission saving potential mapping – Bospolder scenario refurbishment



6 Conclusion & perspectives

The full potential of the CityGML 3D city model of Rotterdam - Bospolder has been exploited in this urban energy analysis. This allowed for the calculation for each building of its exact geometrical parameters required for the energy analysis: its used/living area, its heated volume, its façade area distinguishing the outside and adjacent walls and their orientations.

The building attribute database delivered by the City of Rotterdam, detailing in particular the building year and building usages of all the buildings stock of Bospolder district, has been an important data sources for the realization of the urban energy analysis. It allowed for the determination of the thermal parameters of the building envelope, based on a detailed building construction library, as well as the occupancy parameters (air change rate, set-point temperatures, occupancy schedule etc…). A thermal model of each building (residential, non-residential and with mixed usages) has been created and then simulated with the standard monthly energy balance method, a physical calculation using in particular the on-site meteorological values (monthly mean ambient temperatures and solar radiations for the different façade/roof orientations) as inputs.

The realism of the simulated heating demands has been verified by a comparison with the actual gas consumptions and with a statistical energy analysis led by the University of Luxemburg. Although a comparison building per building was not possible due to data privacy reasons, the comparison at a zip-code level (PPC6) has shown reasonably coherent results.

From this energy diagnostics of the Bospolder buildings stock, a global refurbishment scenario, based on realistic insulation and energy efficiency upgrading measures, has been simulated and energy saving potentials were calculated for each building. Total heating savings for the whole district reached 59%. Beside this proposed refurbishment scenario, the 3D-city-model-based energy analysis allows for the simulation of other customizable refurbishment scenarios, either by defining target energy standards or implementing virtual refurbishment measures per building/building typologies. An optimized urban energy strategy can be planned in this way, which is not possible for example with statistical methods based on (benchmarking) consumption values.

Nevertheless, this study of Bospolder district has faced some limits.
Despite the use of the healing module "CityDoctor" and its automatic correction functions, newly developed in the Hochschule für Technik, some time-consuming manual post-treatments have been required to repair numerous typological mistakes. Even after this correction phase, some buildings remain incurable and then un-exploitable for the urban energy analysis. A typologically and geometrically exact 3D city model is a pre-requirement for an accurate urban energy analysis. By using the full potential of the CityDoctor module (delivered with this report) to heal the rest of the 3D city model of Rotterdam, the municipality could prepare and highly shorten the future work delegated to a research center/engineering company for the energy analysis of the whole City of Rotterdam.

Besides, the building address database of the city Rotterdam, although very detailed (especially concerning the user profiles), misses some information data specific to the actual energy/refurbishment state of the buildings (year of refurbishment, insulation measures, heat systems etc.). These information data participate substantially to the model accuracy when it comes to calculate the actual heating demand and the energy saving potential per building.

Generally, the improvement of the data quality is decisive for a reliable urban energy analysis. Collecting data for a whole district is a considerable challenge for a city. Different solutions exist or are currently being investigated: on the one hand, automatic data collection methods using image preprocessing algorithms are being developed to determine for example window-to-wall ratio or outside insulations. On the other hand, a share of the data collection effort thanks to a crowd-sourcing approach can be an interesting alternative, with the use for example of web-based services addressing to each citizen.

However, the results presented in this report have been proved reasonably coherent, and can be directly used by the energy planners and city managers to drive the energy transition in the region of Rotterdam, starting from the city district Bospolder.

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Annex 1: Building typology library Voorbeeldwoningen 2011 – U-Values actual state

Dwelling Type	Vrijstaande woning (EFH)					2 onder 1 kap woning			
Building Age Class	... - 1945	1946 - 1964	1965 - 1974	1975 - 1991	1992 - 2005	... - 1964	1965 - 1974	1975 - 1991	1992 - 2005
Code	EFH_B	EFH_C	EFH_D	EFH_E	EFH_F				
U-Wall	1.61	1.61	1.45	0.64	0.36	1.61	1.45	0.64	0.36
U-Flat Roof / Top ceiling					0.36	1.54	0.89	0.64	0.36
U-Slote Roof	1.54	1.54	0.89	0.64	0.36	1.54	0.89	0.64	0.36
U-Groundfloor	1.72	1.72	2.33	1.28	0.36	1.72	2.33	0.64	0.36
U-Heat Bridge	0.1	0.1	0.1	0.1	0.05	0.1	0.1	0.1	0.05
Main Uvalue Window	2.8	2.8	2.8	2.8	1.6	2.8	2.8	2.8	2.8
gvalue Window	0.75	0.75	0.75	0.75	0.65	0.75	0.75	0.75	0.65
nair (vol/h)	0.6	0.6	0.6	0.5	0.5	0.6	0.6	0.5	0.5
Average Storey Height	3	2.6	2.6	2.6	2.6	3	2.6	2.6	2.6
Average Window frame fraction	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3

Dwelling Type	Rijwoning (RH)					Maisonnettewoning				
Building Age Class	... - 1945	1946 - 1964	1965 - 1974	1975 - 1991	1992 - 2005	... - 1945	1946 - 1964	1965 - 1974	1975 - 1991	1992 - 2005
Code	RH_B	RH_C	RH_D	RH_E	RH_F	MFH_B	MFH_C	MFH_D	MFH_E	MFH_F
U-Wall	2.22	1.61	1.45	0.64	0.36	2.22	2.22	1.45	0.64	0.36
U-Flat Roof / Top ceiling	2.08				0.36					
U-Slote Roof	2.08	1.54	0.89	0.64		2.08	2.08	0.89	0.64	0.36
U-Groundfloor	2.44	1.72	2.33	1.28	0.36	2.44	2.44	2.33	0.64	0.36
U-Heat Bridge	0.1	0.1	0.1	0.1	0.05	0.1	0.1	0.1	0.1	0.05
Main Uvalue Window	2.8	2.8	2.8	2.8	1.6	2.8	2.8	2.8	2.8	1.6
gvalue Window	0.75	0.75	0.75	0.75	0.65	0.75	0.75	0.75	0.75	0.65
nair (vol/h)	0.6	0.6	0.6	0.5	0.5	0.6	0.6	0.6	0.5	0.5
Average Storey Height	3	2.6	2.6	2.6	2.6	3	2.6	2.6	2.6	2.6
Average Window frame fraction	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3

Dwelling Type	Galerijwoning				Portiekwoning				
Building Age Class	... - 1964	1965 - 1974	1975 - 1991	1992 - 2005	... - 1945	1946 - 1964	1965 - 1974	1975 - 1991	1992 - 2005
Code					GMH_B	GMH_C	GMH_D	GMH_E	GMH_F
U-Wall	1.61	1.45	0.64	0.36	2.22	1.61	1.45	0.64	0.36
U-Flat Roof / Top ceiling	1.54	0.89	0.64	0.36	2.08	1.54	0.89	0.64	0.36
U-Slote Roof									
U-Groundfloor	1.72	2.33	0.64	0.36	2.44	1.72	2.33	0.64	0.36
U-Heat Bridge	0.1	0.1	0.1	0.05	0.1	0.1	0.1	0.1	0.05
Main Uvalue Window	2.8	2.8	2.8	1.6	2.8	2.8	2.8	2.8	1.6
gvalue Window	0.75	0.75	0.75	0.65	0.75	0.75	0.75	0.75	0.65
nair (vol/h)	0.6	0.6	0.5	0.5	0.6	0.6	0.6	0.5	0.5
Average Storey Height	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6
Average Window frame fraction	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3

Dwelling Type	(Overig) flatwoning			
Building Age Class	... - 1964	1965 - 1974	1975 - 1991	1992 - 2005
Code				
U-Wall	1.61	1.45	0.64	0.36
U-Flat Roof / Top ceiling	1.54	0.89	0.64	0.36
U-Slote Roof				
U-Groundfloor	1.72	2.33	1.28	0.36
U-Heat Bridge	0.1	0.1	0.1	0.05
Main Uvalue Window	2.8	2.8	2.8	1.6
gvalue Window	0.75	0.75	0.75	0.65
nair (vol/h)	0.6	0.6	0.5	0.5
Average Storey Height	2.6	2.6	2.6	2.6
Average Window frame fraction	0.3	0.3	0.3	0.3

Annex 2: Building typology library IWU 2005 – U-Values actual state

Dwelling Type	Single Family House (EFH)								
Building Age Class	vor 1918	1919-1948	1949-1957	1958-1968	1969-1978	1979-1983	1984-1994	1995-2001	nach 2002
Code	EFH_B	EFH_C	EFH_D	EFH_E	EFH_F	EFH_G	EFH_H	EFH_I	EFH_J
U-Wall	1.7	1.7	0.93	1.44	1.21	0.8	0.68	0.5	0.28
U-Flat Roof / Top ceiling	0.78	0.78	0.78	0.78	0.63	0.44	0.3	0.22	0.13
U-Slote Roof	1.11	1.11	1.11	0.92	0.63	0.43	0.3	0.22	0.13
U-Groundfloor	1.11	1.11	1.01	0.97	0.85	0.81	0.55	0.34	0.13
U-Heat Bridge	0.1	0.1	0.1	0.1	0.1	0.1	0.05	0.05	0.05
Main Uvalue Window	2.57	2.57	2.57	2.9	2.57	2.57	2.1	1.6	1.27
gvalue Window	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.63	0.6
nair (vol/h)	0.6	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5
Average Storey Height	2.6	2.75	2.36	2.52	2.6	2.5	2.5	2.5	2.5
Average Window frame fraction	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3

Dwelling Type	Row House (RH)								
Building Age Class	vor 1918	1919-1948	1949-1957	1958-1968	1969-1978	1979-1983	1984-1994	1995-2001	nach 2002
Code	RH_B	RH_C	RH_D	RH_E	RH_F	RH_G	RH_H	RH_I	RH_J
U-Wall	1.7	1.39	1.39	1.44	0.8	0.68	0.77	0.49	0.24
U-Flat Roof / Top ceiling	0.78	0.78	0.78	0.78	0.52	0.41	0.3	0.22	0.14
U-Slote Roof	1.8	**1.11**	**1.41**	**1.11**	**0.77**	**0.43**	**0.3**	0.22	0.14
U-Groundfloor	0.9	1.6	1.01	0.97	0.97	0.67	0.55	0.32	0.29
U-Heat Bridge	0.1	0.1	0.1	0.1	0.1	0.1	0.05	0.05	0.05
Main Uvalue Window	2.57	2.8	2.9	2.57	2.57	2.57	2.57	1.6	1.27
gvalue Window	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.63	0.63
nair (vol/h)	0.6	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5
Average Storey Height	2.9	2.6	2.55	2.51	2.5	2.5	2.5	2.53	2.53
Average Window frame fraction	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3

Dwelling Type	Multi-Family House (MFH)								
Building Age Class	vor 1918	1919-1948	1949-1957	1958-1968	1969-1978	1979-1983	1984-1994	1995-2001	nach 2002
Code	MFH_B	MFH_C	MFH_D	MFH_E	MFH_F	MFH_G	MFH_H	MFH_I	MFH_J
U-Wall	1.7	1.7	1.44	1.21	0.74	0.8	0.66	0.35	0.28
U-Flat Roof / Top ceiling	0.78	0.78	0.78	1.37	1.37	0.44	0.3	0.22	0.2
U-Slote Roof	2.6	1.4	1.11	1.11	0.77	0.43	0.3	0.22	0.2
U-Groundfloor	1.37	1.11	1.65	0.97	0.97	0.67	0.55	0.34	0.34
U-Heat Bridge	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.05	0.05
Main Uvalue Window	2.57	2.8	2.8	2.57	2.8	2.57	2.57	1.6	1.27
gvalue Window	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.63	0.63
nair (vol/h)	0.6	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5
Average Storey Height	3	2.8	2.65	2.61	2.51	2.75	2.7	2.7	2.7
Average Window frame fraction	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3

Dwelling Type	Big Multi-Family House (GMH)					High Towers (HH)	
Building Age Class	vor 1918	1919-1948	1949-1957	1958-1968	1969-1978	1958-1968	1969-1978
Code	GMH_B	GMH_C	GMH_D	GMH_E	GMH_F	HH_E	HH_F
U-Wall	1.45	1.45	1.21	1.3	1.36	1.11	0.82
U-Flat Roof / Top ceiling	2.6	2.6	2.08	0.82	0.82	0.68	0.35
U-Slote Roof	0.78	0.78	1.11	0.77	0.66		
U-Groundfloor	1.37	1.11	1.55	0.85	0.97	0.97	0.71
U-Heat Bridge	0.1	0.1	0.1	0.1	0.1	0.15	0.15
Main Uvalue Window	2.9	2.57	2.57	2.57	2.57	3.3	2.8
gvalue Window	0.76	0.76	0.76	0.76	0.76	0.76	0.7
nair (vol/h)	0.6	0.6	0.6	0.6	0.5	0.5	0.5
Average Storey Height	2.8	2.9	2.75	2.5	2.55	2.5	2.55
Average Window frame fraction	0.3	0.3	0.3	0.3	0.3	0.3	0.3

Annex 3: Building typology library IWU 2005 – U-Values after refurbishment

Dwelling Type	Single Family House (EFH)								
Building Age Class	vor 1918	1919-1948	1949-1957	1958-1968	1969-1978	1979-1983	1984-1994	1995-2001	nach 2002
Code	EFH_B	EFH_C	EFH_D	EFH_E	EFH_F	EFH_G	EFH_H	EFH_I	EFH_J
U-Wall	0.28	0.28	0.25	0.27	0.26	0.24	0.22		
U-Flat Roof / Top ceiling	0.16	0.16	0.16	0.18	0.2	0.14	0.17		
U-Slote Roof	0.18	0.18	0.18	0.18	0.18	0.15	0.13		
U-Groundfloor	0.42	0.42	0.4	0.4	0.37	0.37	0.3		
U-Heat Bridge	0.03	0.03	0.03	0.03	0.03	0.03	0.03		
Main Uvalue Window	1.6	1.6	1.6	1.6	1.6	1.6	1.6		
gvalue Window	0.63	0.63	0.63	0.63	0.63	0.63	0.63		
nair (vol/h)	0.5	0.5	0.5	0.5	0.5	0.5	0.5		

Dwelling Type	Row House (RH)								
Building Age Class	vor 1918	1919-1948	1949-1957	1958-1968	1969-1978	1979-1983	1984-1994	1995-2001	nach 2002
Code	RH_B	RH_C	RH_D	RH_E	RH_F	RH_G	RH_H	RH_I	RH_J
U-Wall	0.28	0.27	0.24	0.27	0.24	0.25	0.23		
U-Flat Roof / Top ceiling	0.16	0.23	0.16	0.16	0.14	0.14	0.12		
U-Slote Roof	0.2	0.18	0.19	0.18	0.18	0.15	0.13		
U-Groundfloor	0.38	0.47	0.4	0.4	0.4	0.33	0.33		
U-Heat Bridge	0.03	0.03	0.03	0.03	0.03	0.03	0.03		
Main Uvalue Window	1.6	1.6	1.6	1.6	1.6	1.6	1.6		
gvalue Window	0.63	0.63	0.63	0.63	0.63	0.63	0.63		
nair (vol/h)	0.5	0.5	0.5	0.5	0.5	0.5	0.5		

Dwelling Type	Multi-Family House (MFH)								
Building Age Class	vor 1918	1919-1948	1949-1957	1958-1968	1969-1978	1979-1983	1984-1994	1995-2001	nach 2002
Code	MFH_B	MFH_C	MFH_D	MFH_E	MFH_F	MFH_G	MFH_H	MFH_I	MFH_J
U-Wall	0.46	0.28	0.27	0.26	0.23	0.24	0.22		
U-Flat Roof / Top ceiling	0.16	0.16	0.16	0.17	0.17	0.14	0.17		
U-Slote Roof	0.2	0.19	0.18	0.18	0.18	0.15	0.13		
U-Groundfloor	0.48	0.42	0.47	0.4	0.4	0.33	0.3		
U-Heat Bridge	0.03	0.03	0.03	0.03	0.03	0.03	0.03		
Main Uvalue Window	1.6	1.6	1.6	1.6	1.6	1.6	1.6		
gvalue Window	0.63	0.63	0.63	0.63	0.63	0.63	0.63		
nair (vol/h)	0.5	0.5	0.5	0.5	0.5	0.5	0.5		

Dwelling Type	Big Multi-Family House (GMH)					High Towers (HH)	
Building Age Class	vor 1918	1919-1948	1949-1957	1958-1968	1969-1978	1958-1968	1969-1978
Code	GMH_B	GMH_C	GMH_D	GMH_E	GMH_F	HH_E	HH_F
U-Wall	0.46	0.27	0.26	0.27	0.27	0.26	0.24
U-Flat Roof / Top ceiling	0.16	0.16	0.29	0.16	0.16	0.15	0.16
U-Slote Roof	0.2	0.2	0.18	0.17	0.17		
U-Groundfloor	0.48	0.42	0.47	0.37	0.4	0.4	0.34
U-Heat Bridge	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Main Uvalue Window	1.6	1.6	1.6	1.6	1.6	1.6	1.6
gvalue Window	0.63	0.63	0.63	0.63	0.63	0.63	0.63
nair (vol/h)	0.5	0.5	0.5	0.5	0.5	0.5	0.5

Annex 4: Building usage library

Building Usage	Building Usage Code	Heating Set-point-temperature [°C]	Intern Gains [W/m²]	Nair	Window/Wall Ratio	Occupancy [m²/pers]	DHW demand [kWh/m².a]	Ratio atb: indirect heated area / Tot area	Annual operating day	Daily heating system operating hours	Sources
Residential	1	19	3.4	0.5	0.2	30	16	0.2	300	17	DIN V 18599-10, Table 3
Mixed function	2	21	2.9	1	0.4	20	8	0.15	250	13	DIN V 18599-10, Table 4
Jail	3	19	4.2	0.5	0.05	10	16	0.15	365	17	DIN V 18599-10, Table 4
Health care	4	21	5.5	1.28	0.3	15	193	0.15	365	24	DIN V 18599-10, Table 4
Industry	5	16	7.8	1	0.1	20	19	0.15	250	11	DIN V 18599-10, Table 4
Office	6	21	2.1	2	0.6	10	8	0.15	250	13	DIN V 18599-10, Table 4
Accomodation	7	21	4.2	0.96	0.2	10	164	0.15	365	24	DIN V 18599-10, Table 4
Education	8	21	5	2	0.3	3	0	0.15	200	10	DIN V 18599-10, Table 4
Sport	9	16	2.1	0.96	0.1	20	45	0.15	300	17	DIN V 18599-10, Table 4
Retail	10	21	4.7	1.28	0.6	5	0	0.15	300	14	DIN V 18599-10, Table 4
Other	11	21	3.4	1	0.2	20	0	0.15	300	13	DIN V 18599-10, Table 4

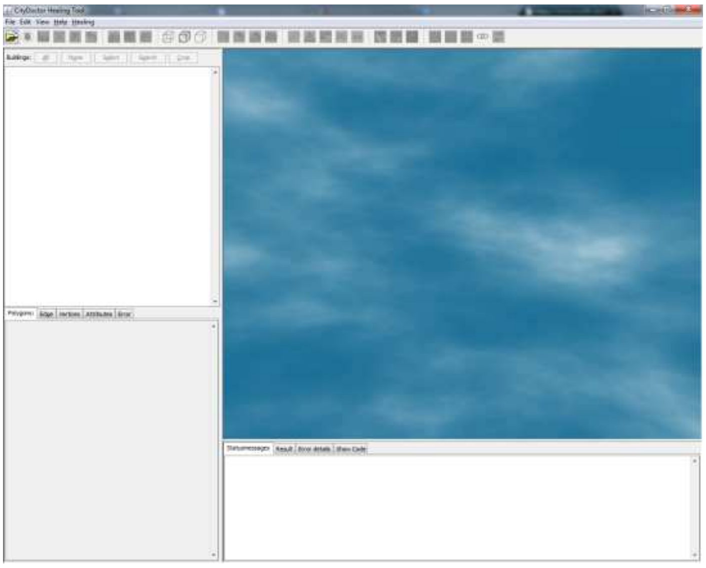
Annex 5: City Doctor Healing User Guide

Running CityDoctor Healing Tool (with GUI) from the jar

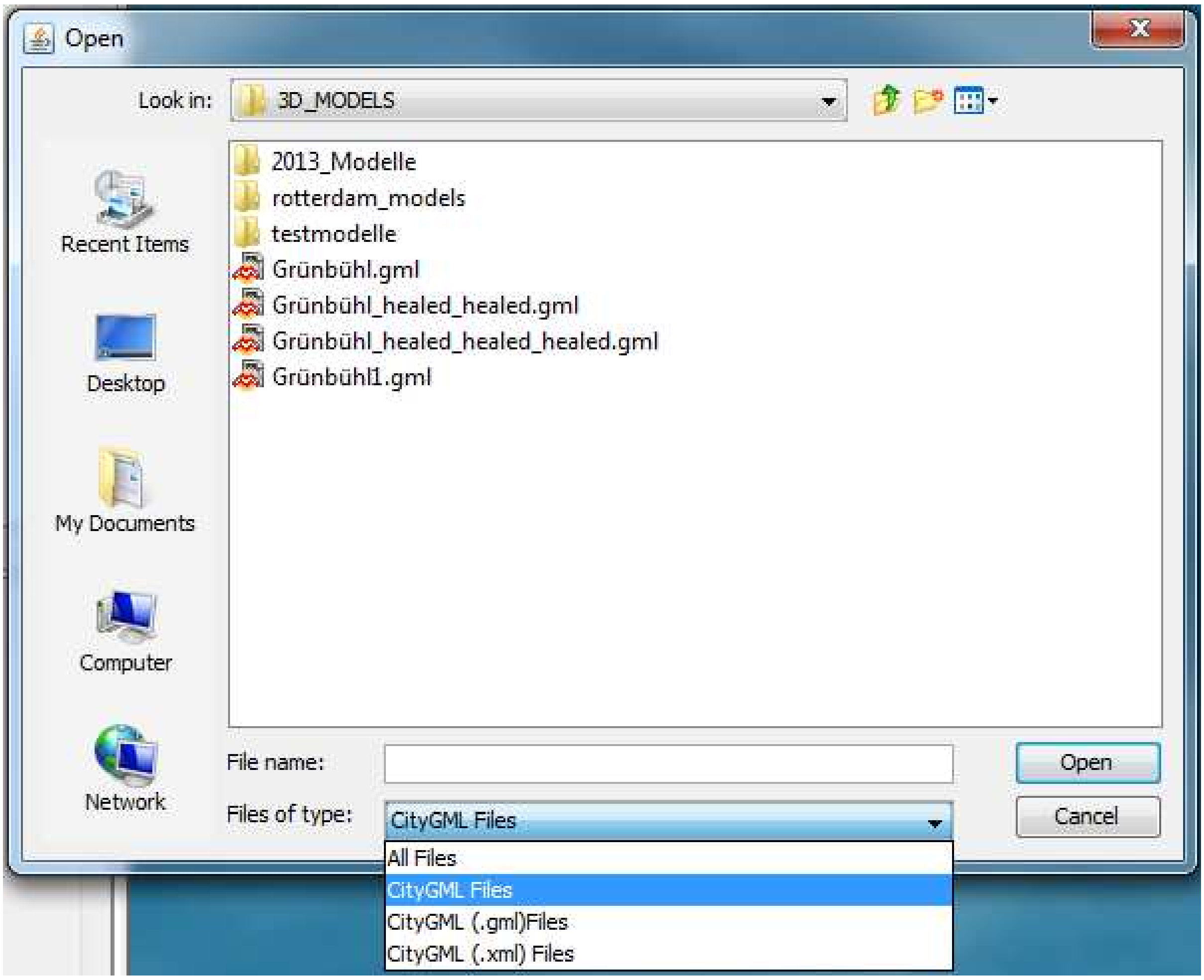
Make sure that you have Java 1.7 on your system and that it is included in your PATH variable. Execute the batch file according to the OS from the directory where you unpacked the zip-file. The batch file contains a command where the memory assigned for this application can be manipulated (command must be entered on a single line):

```
java
"-Dfile.encoding=UTF-8"
-Xms512m [Note: Here can be memory be assigned to avoid heap space error]
-Xmx512m [e.g. –Xms4096m –Xmx4096m ]
-Djava.library.path=.\lib;<.\lib\dll_32 | .\lib\dll_64>
-cp
.;
.\citydoctorHealing.jar;
.\lib\citydoctor.jar;
.\lib\activation.jar;
.\lib\CityGML4j.jar;
.\lib\gluegen-rt.jar;
.\lib\gluegen-rt-natives-windows-amd64.jar;
.\lib\itext-xtra-5.1.3.jar;
.\lib\itextpdf-5.1.3.jar;
.\lib\Jama-1.0.2.jar;
.\lib\jaxb-api.jar;
.\lib\jaxb-impl.jar;
.\lib\jaxb-xjc.jar;
.\lib\jce-jdk13-147.jar;
.\lib\jcommon-1.0.17.jar;
.\lib\jdom.jar;
.\lib\jfreechart-1.0.14.jar;
.\lib\jh.jar;
.\lib\jhall.jar;
.\lib\jhbasic.jar;
.\lib\jogl-all-natives-windows-amd64.jar;
.\lib\jogl-all.jar;
.\lib\jsearch.jar;
.\lib\jsr173_1.0_api.jar;
.\lib\QSCity3D_Help.jar;
.\lib\sjsxp.jar;
.\lib\stringsearch.jar
de.hft.stuttgart.citydoctor.CityDoctorHealingStream
```

Running the batch file will launch the application and following GUI will show up:

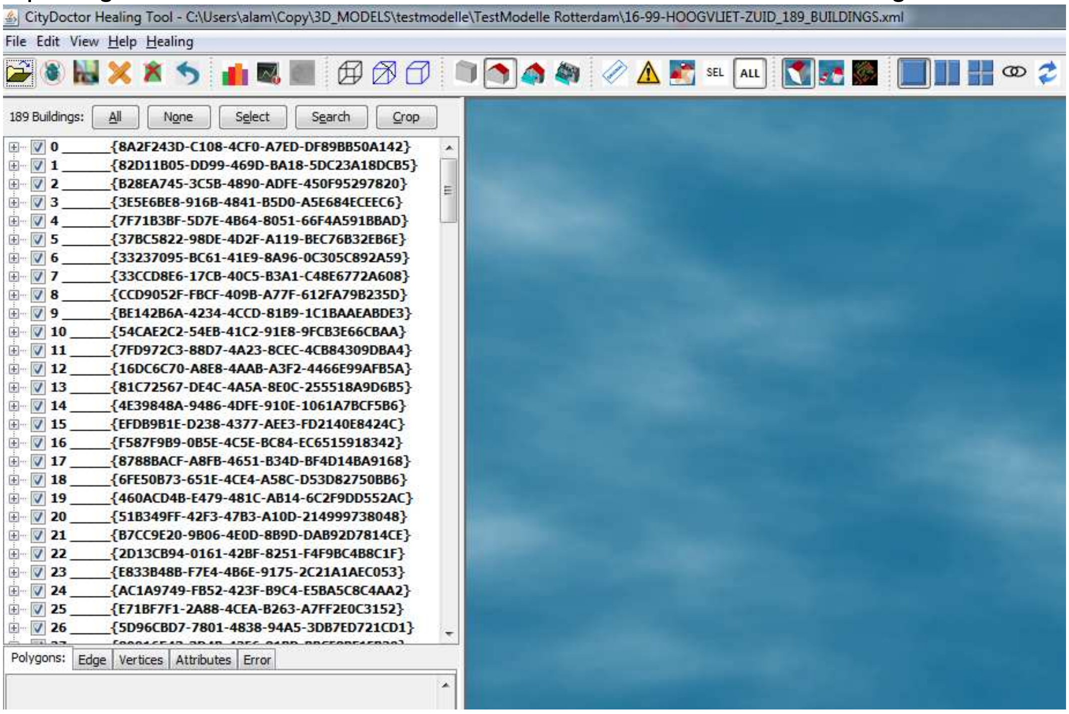


- To load a model press  Button or select
- Then

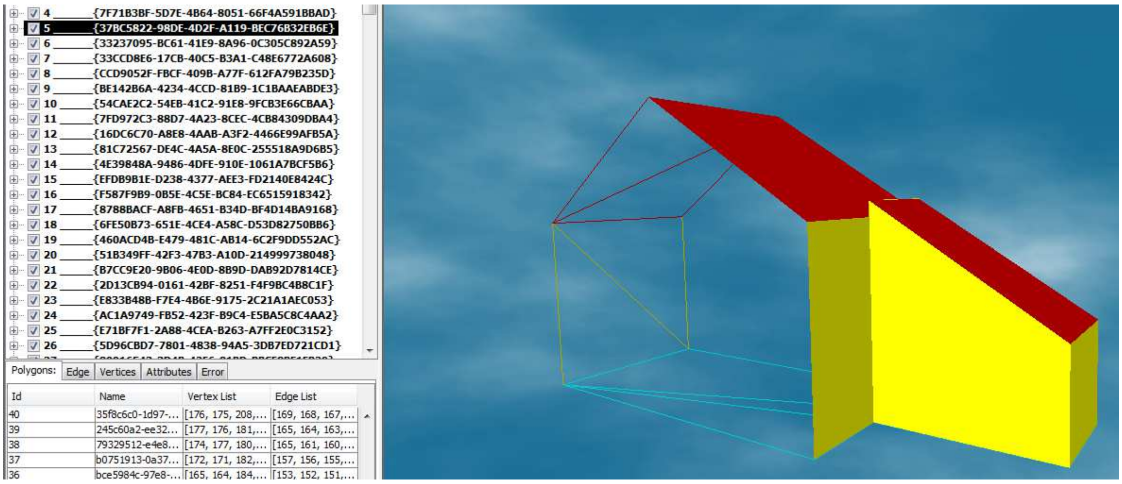


will appear. Goto the location and select the file. This location is saved in the properties file when the application is closed, so that each time you don't have to browse all the way back to here.

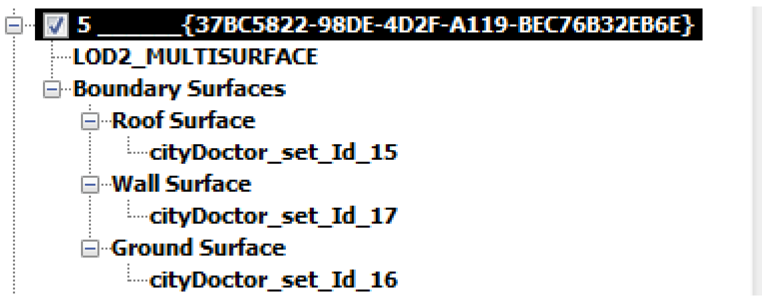
- Opening the file will activate almost all the buttons and fill the Building List



Selecting a building will show the whole building in the viewer and populate the tables in the bottom left tabbed pane.



A building node consists of several parts:



If a geometry is modelled with boundary surfaces then the geometry is stored in the LOD(1-4)SOLID/MULTISURFACE and Boundary surfaces only stores a references to the polygons they holds together (no duplication).

When a node is clicked the polygon, edge, vertices, attributes and error table fills up with respective data.

Polygon table consists of col 1: CD id, col2: CityGML id, col3: [CD ids of vertices in the pointlist], col4: : [CD ids of edges in the edgelist]:

Polygons: | Edge | Vertices | Attributes | Error

Id	Name	Vertex List	Edge List
32	citydoctor_auto...	[95, 66, 61, 95]	[127, 126, 125]
31	citydoctor_auto...	[81, 66, 86, 81]	[124, 123, 122]
30	citydoctor_auto...	[71, 66, 76, 71]	[121, 120, 119]
29	citydoctor_auto...	[81, 76, 66, 81]	[122, 120, 116]

Edge Table consists of col1: CD id of edge, col2: CD id of an end of the edge, col3: CD id of another end of the edge, col4: CD ids of polygons bound to the edge.

Polygons: | Edge | Vertices | Attributes | Error

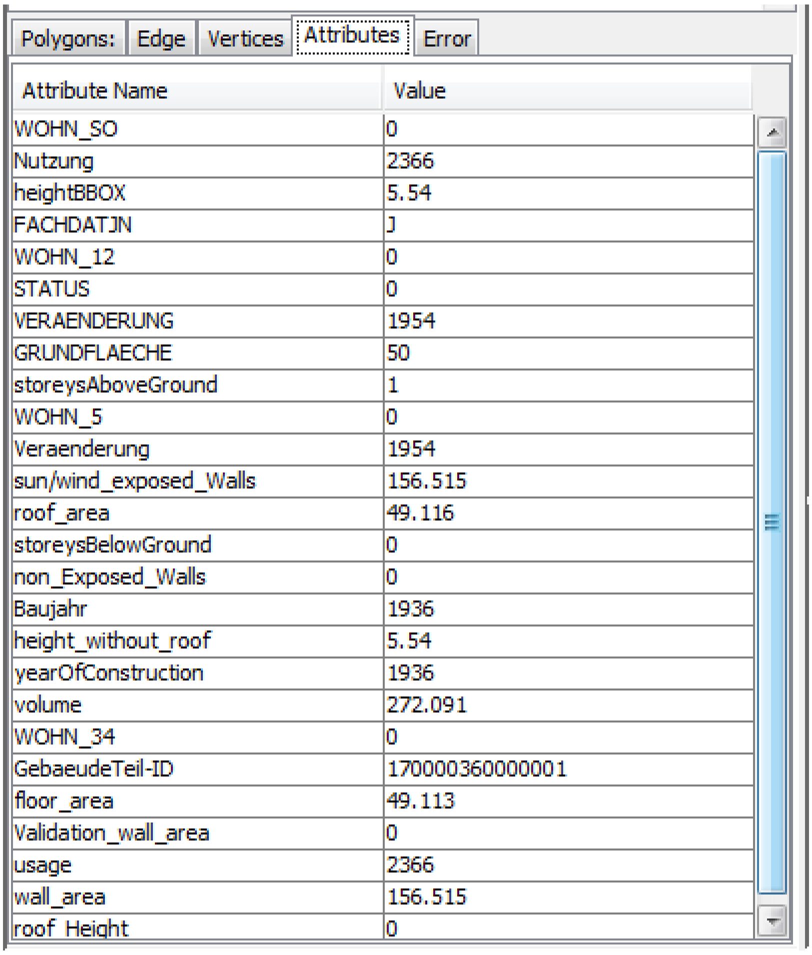
Id	Start Point	End Point	Bounds
127	61	95	[32, 26]
126	66	61	[32, 11]
125	95	66	[32, 28]
124	86	81	[31, 15]

Vertex Table consists of col1: CD id of vertex and col2,3,4: X,Y,Z

Polygons: | Edge | Vertices | Attributes | Error

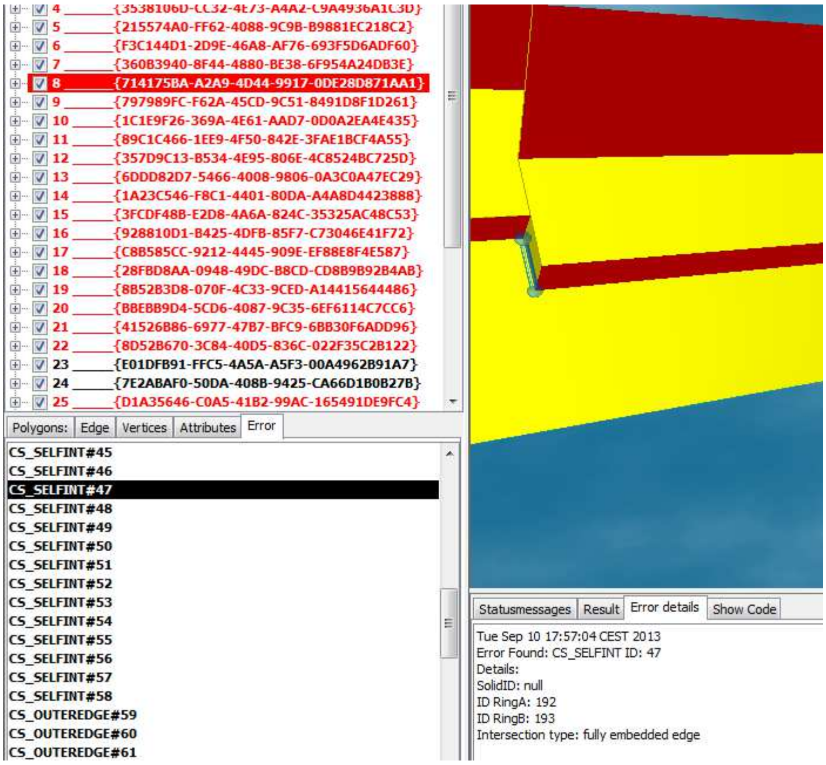
Id	X	Y	Z
45	3510803.55	5404696.63	366.37
44	3510802.72	5404696.56	366.37
43	3510802.14	5404702.75	366.37
90	3510807.47	5404696.95	360.83

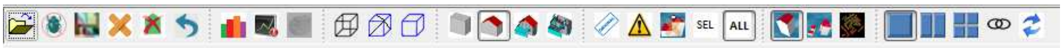
Attribute Table consists of: col1: name of attribute, col2: value of that attribute



Attribute Name	Value
WOHN_SO	0
Nutzung	2366
heightBBOX	5.54
FACHDATJN	J
WOHN_12	0
STATUS	0
VERAENDERUNG	1954
GRUNDFLAECHE	50
storeysAboveGround	1
WOHN_5	0
Veraenderung	1954
sun/wind_exposed_Walls	156.515
roof_area	49.116
storeysBelowGround	0
non_Exposed_Walls	0
Baujahr	1936
height_without_roof	5.54
yearOfConstruction	1936
volume	272.091
WOHN_34	0
GebaeudeTeil-ID	170000360000001
floor_area	49.113
Validation_wall_area	0
usage	2366
wall_area	156.515
roof_Height	0

Error Table consists of the error objects produced by the validation process. Selecting an error shows its detail information in the Error Details tab at the bottom right tabbed pan. And more details about visualization of the error can be found in the wiki.





Default bar: (from left)

Open button: Launch open dialogue window.
Validation button: Launch validation window.
Save button: Launch save dialogue window.
Heal button: Start healing process
Delete Polygon button: delete a polygon
Undo button: Undo all changes.

Statistics bar:

Model Statistics: Measure model statictics
Error Statistics: Measure error statictics
Healing Statistics: Measure healing statictics

Mode bar:

Wireframe mode: show building in wireframe mode without filling polygons.
Triangulated mode: highlightes the triangulation of a polygon
Edge Highlight mode: highlightes the edges of a polygon

LOD bar:

LOD1 button: show LOD1 model
LOD2 button: show LOD2 model
LOD3 button: show LOD3 model
LOD4 button: show LOD4 model

Filter bar:

Show **Original** button: shows only the original buildings which has no error or not been healed in the building list.

Show **Error** button: shows only the buildings which has error in the building list.

Show **Healed** button: shows only the buildings which has been healed in the building list.

Show **Selected** button: shows only the selected buildings in the building list.

Show **All** button: shows all the buildings in the building list.

Building Mode bar:

Single building mode: shows one building at a time. The selected building from the building list shows up here.

Selected building mode: shows several building with checkbox selected in the viewer. Selecting a selected building from the list will highlight the building in the viewer.

All building mode: shows all the buildings in the viewer. Selecting a building from the list will highlight the building in the viewer.

Window mode bar:

Single window mode: Shows the viewer in one single section.

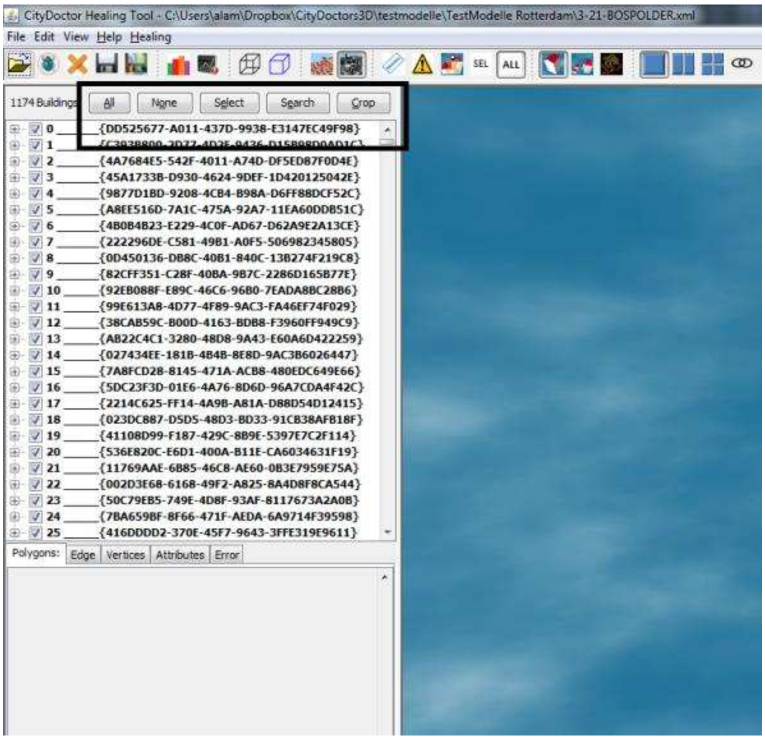
Double window mode: Shows the viewer in two sections. In one section the original building can be viewed and in another the healed building.

Quad window mode: Shows the viewer in four sections, In one section the original building can be viewed and in another the healed building. Next two are reserved for alternatives but at this moment it shows the heald building.

Sync windows: sysnconize the movements and parameters within the viewers.

Refresh window: refresh the viewer when UI is not updated according to the model. But not working at this moment, restoring the window solves this issue.

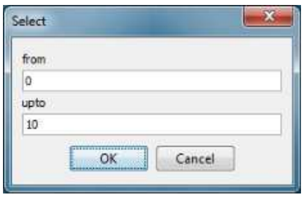
Selecting buildings from the building list:

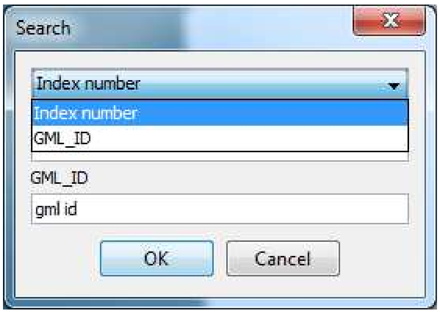


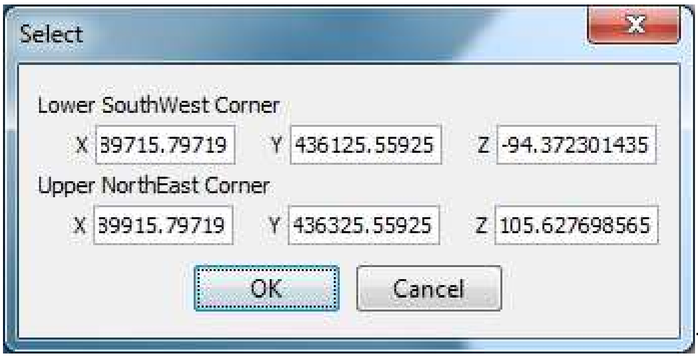
2 ______{4A7684E5-542F-4011-A74D-DF5ED87F0D4E}

In the list of buildings 2 represent the **index number** or id given by the CDH tool. And the gmlid of the building {4A7684E5-542F-4011-A74D-DF5ED87F0D4E} is given next to it after a bit of space______.

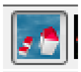
There are 5 buttons for selecting buildings from the list:

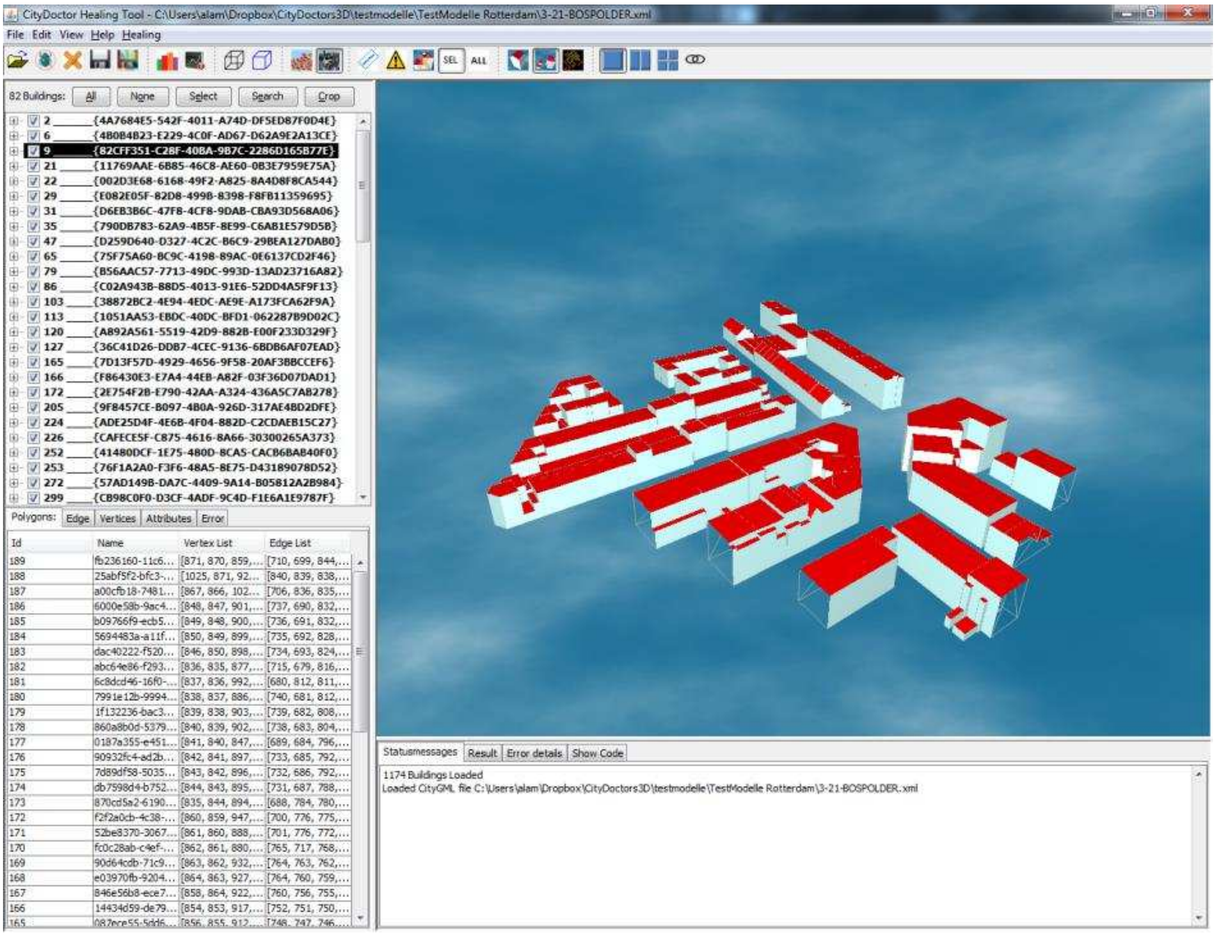
- All: select all buildings
- None: clear all selection
- Select: A window will pop up like this.  Select buildings according to the range of **index number** specified

- Search:  There are two options to select a building either by index number or gmlid.

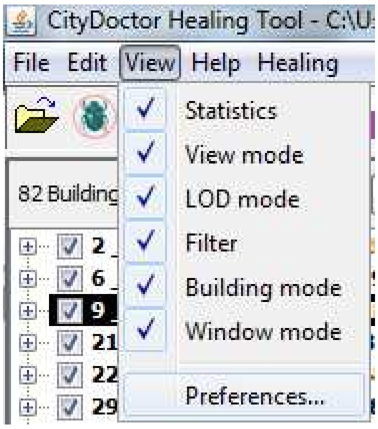
- Crop: 

This window will pop up. It will select buildings within a bounding box. The default values are +-100 meter from the center of the building selected in the list. These values can be set according to need of user. Then by selecting 

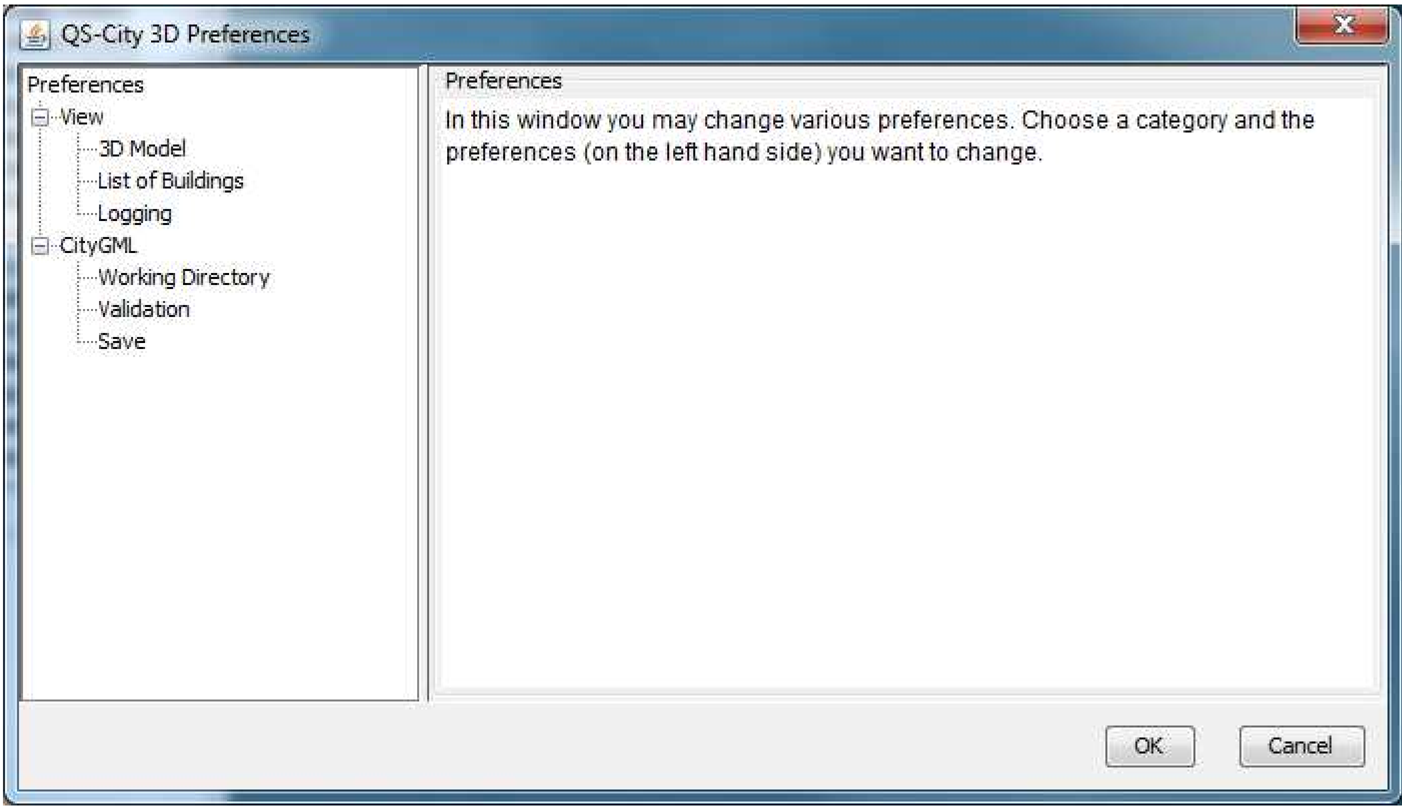
button will fill the list only with the selected buildings and  will show the selected buildings together in the viewer.



Tool bars can be switched on and off from the view menu:

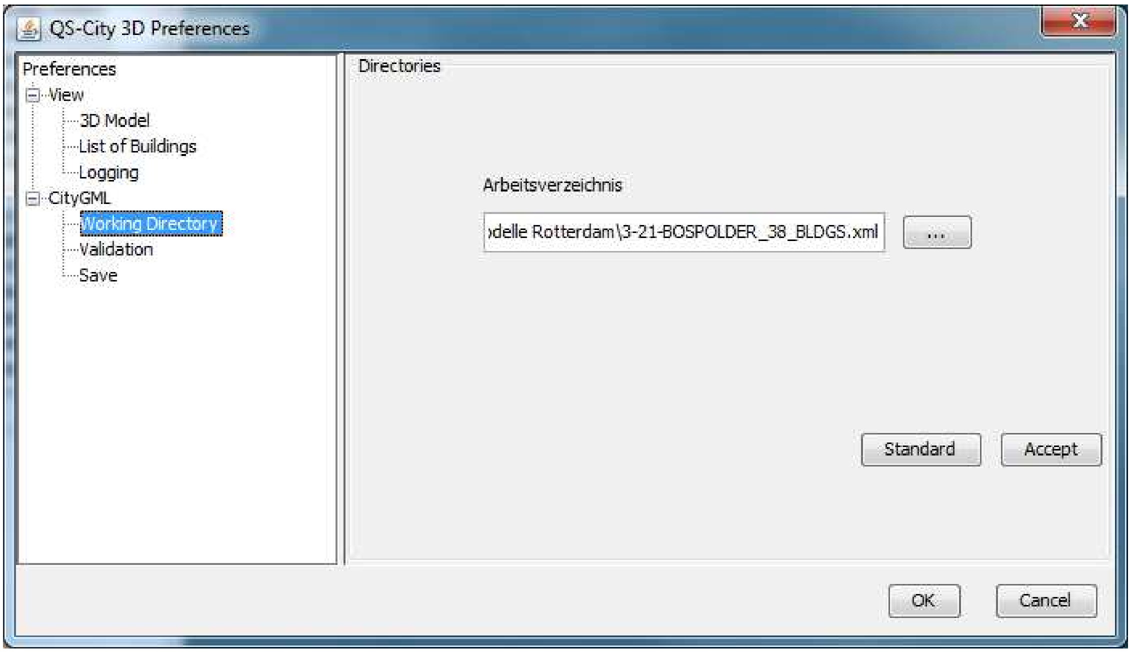


There is a preference option in the view menu bar.

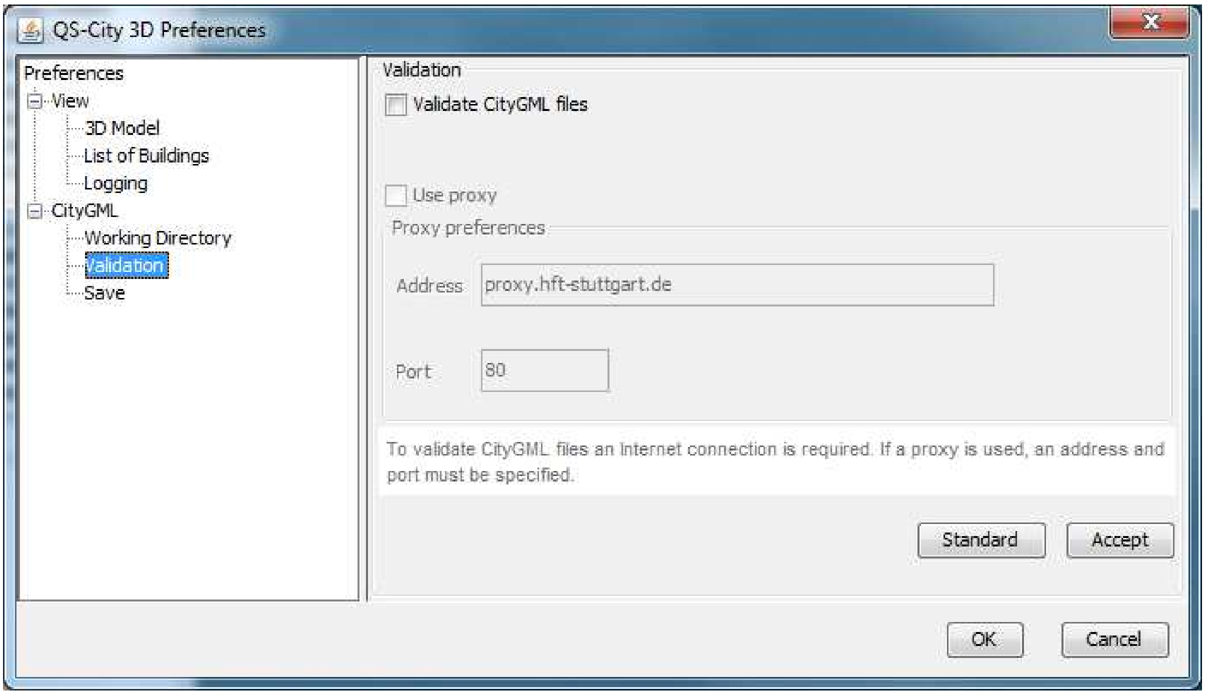


3D model preference have option to choose model colors.

Working directory (this can be set here, default is nothing, which opens my document path):

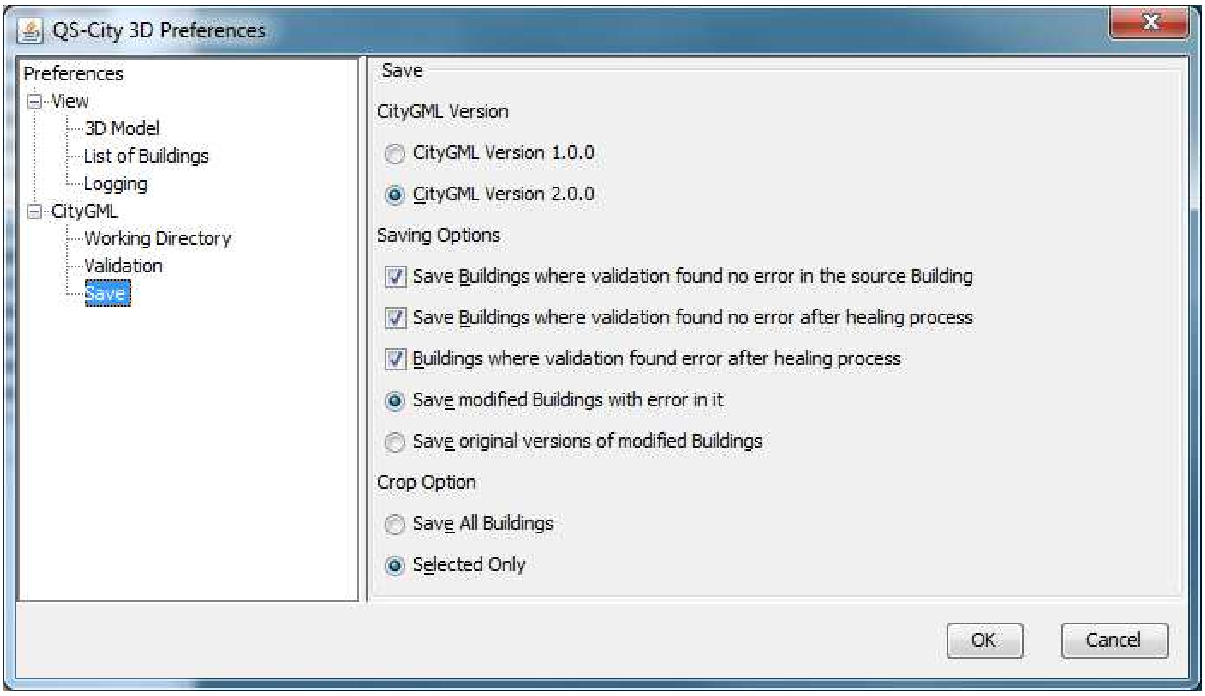


There is a check box where the validation according to CityGML schema can be activated. And a proxy settings can be given.

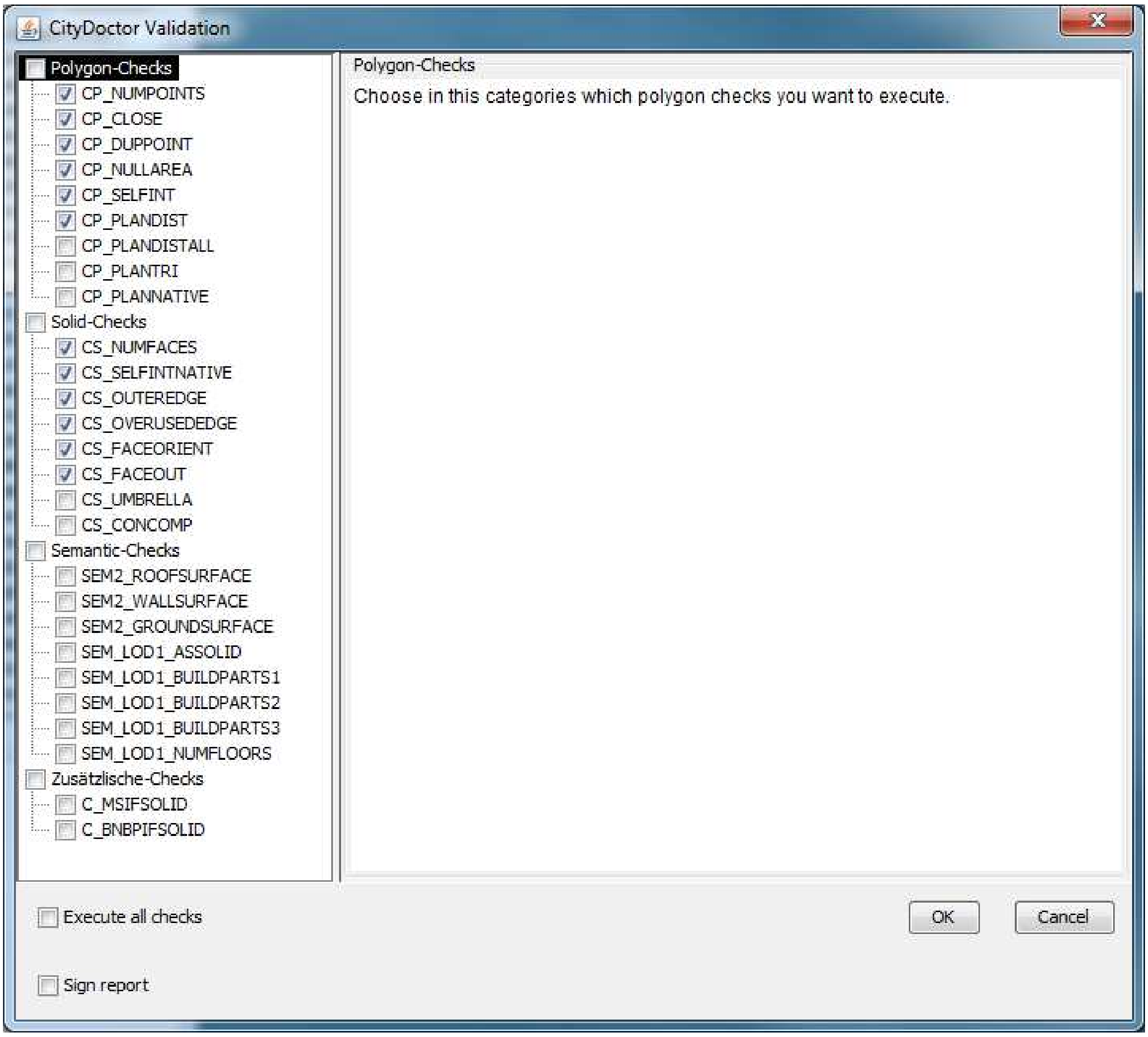


A file can be saved in CityGML version 1 or 2.

It can also be specified which buildings to save and which to ignore, whether it should save only the cropped part or the whole model.



Validating a model:



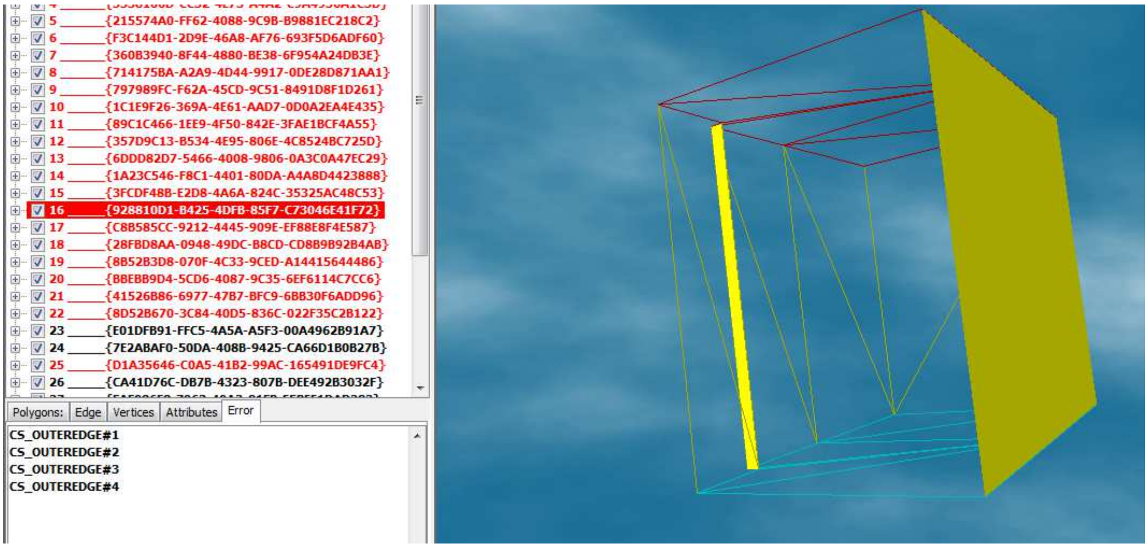
To validate a model one has to press the validate button and this validation window will show up.

There are checkboxes before each checks. If the user wants to check an error that check must be active here. There is a dependency among the checks:

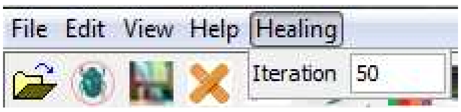
Check ID		A	B	C	D	E	F	G	H	I	J	K	L
CP_NUMPOINTS	A	–	–	–	–	–	–	–	–	–	–	–	–
CP_CLOSE	B	–	–	–	–	–	–	–	–	–	–	–	–
CP_DUPPOINT	C	X	X										
CP_SELFINT	D	X	X	X	–	–	–	–	–	–	–	–	–
CP_PLAN*	E	X	X	X	–	–	–	–	–	–	–	–	–
CS_NUMFACES	L	X	X	X	X								
CS_SELFINT	F	X	X	X	X	X	–	–	–	–	–	–	X
CS_2POLYPEREDGE	G	X	X	X									
CS_FACEORIENT	H	X	X	X	–	–	–	X	–	–	–	–	–
CS_FACEOUT	I	X	X	X	–	X	X	X	X	–	–	–	–
CS_CONCOMP	J	X	X	X				X					
CS_UMBRELLA	K	X	X	X	–	–	–	X	–	–	–	–	–

Each check node opens a brief description about it in the panel next to it.

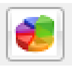
Healing a model:

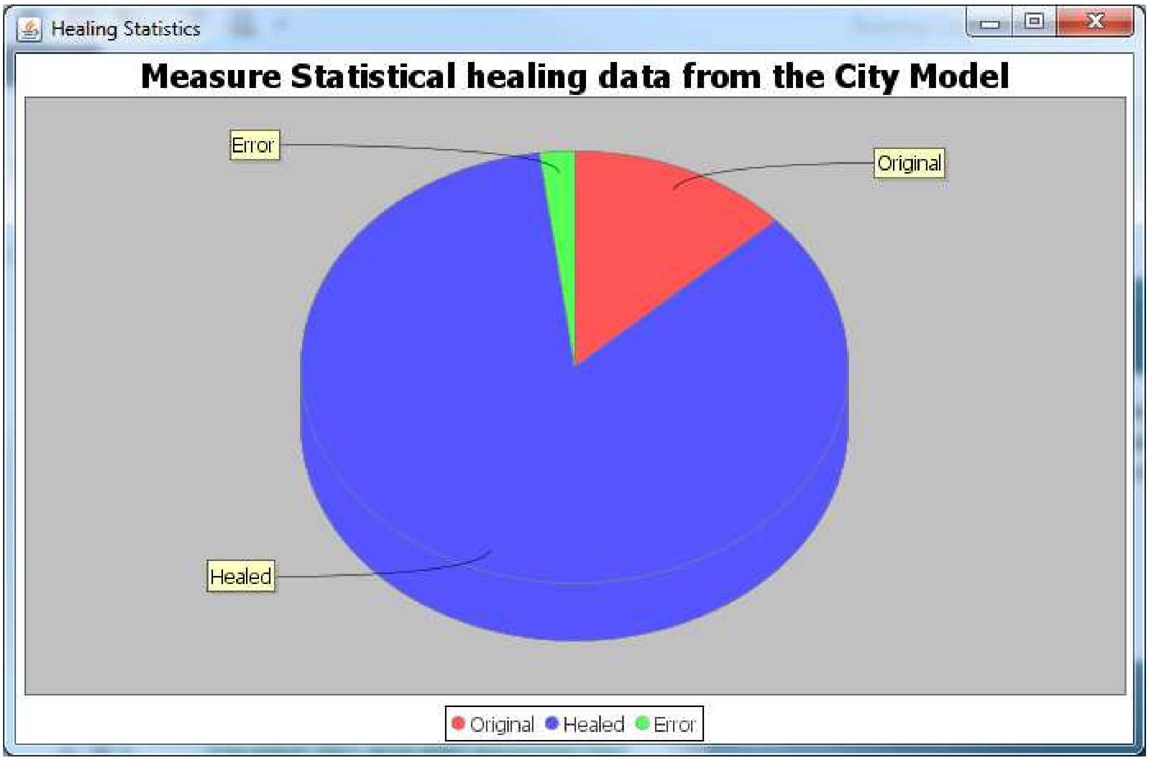


To heal a model it must be validated first. Then healing iteration is set. Healing is an iterative process. After the healing process starts it identifies which error it has and calls that healing function, after executing that healing the building is validated again and if it has no error then the healing process for that building ends but if it has error then that error is healed and the process continues. There are some cases where it might get into an endless loop or a very large loop. To avoid those case this iteration has been assigned so that it will call the healing process maximum until the iteration.

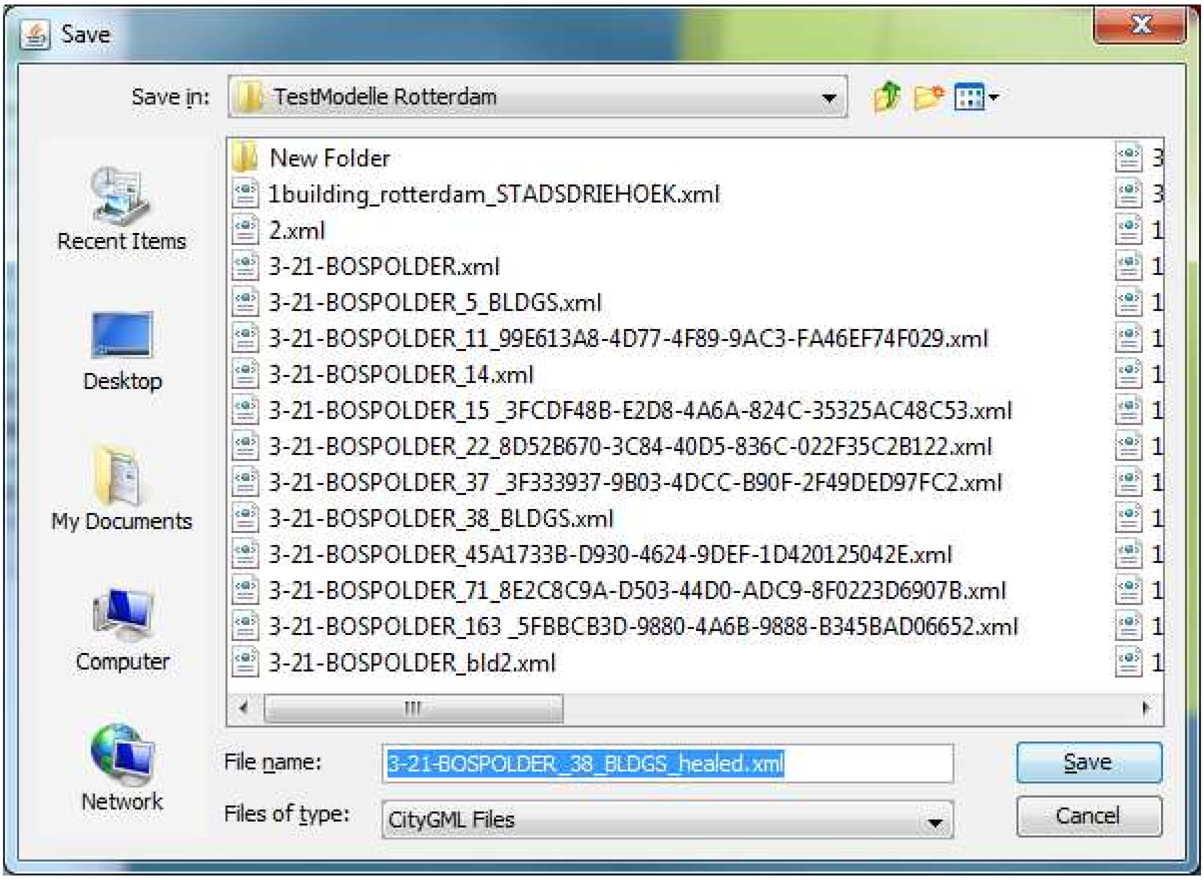


After the healing process is finished the building list changes the color according to the status of healing.

Then the  button is activated and pressing the healing statistics button pops up this statistics.



Save the healed model:



Just press the save button and the save dialogue will appear and the healed model can be saved.

Running CityDoctor HealingTool from the command line

Make sure that you have Java 1.7 on your system and that it is included in your PATH variable. Execute the following command in the directory where you unpacked the zip-file (command must be entered on a single line):

```
java
"-Dfile.encoding=UTF-8"
-Xms512m
-Xmx512m
-Djava.library.path=.\lib;<.\lib\dll_32 | .\lib\dll_64>
-cp
    .;
    .\citydoctorHealing.jar;
    .\lib\citydoctor.jar;
    .\lib\activation.jar;
    .\lib\CityGML4j.jar;
    .\lib\gluegen-rt.jar;
    .\lib\gluegen-rt-natives-windows-amd64.jar;
    .\lib\itext-xtra-5.1.3.jar;
    .\lib\itextpdf-5.1.3.jar;
    .\lib\Jama-1.0.2.jar;
    .\lib\jaxb-api.jar;
    .\lib\jaxb-impl.jar;
    .\lib\jaxb-xjc.jar;
    .\lib\jce-jdk13-147.jar;
    .\lib\jcommon-1.0.17.jar;
    .\lib\jdom.jar;
    .\lib\jfreechart-1.0.14.jar;
    .\lib\jh.jar;
    .\lib\jhall.jar;
    .\lib\jhbasic.jar;
    .\lib\jogl-all-natives-windows-amd64.jar;
    .\lib\jogl-all.jar;
    .\lib\jsearch.jar;
    .\lib\jsr173_1.0_api.jar;
    .\lib\QSCity3D_Help.jar;
    .\lib\sjsxp.jar;
    .\lib\stringsearch.jar
de.hft.stuttgart.citydoctor.CityDoctorHealingStream
    -iterations=10
    -checksToDo=<list of checks>
    -checkParams=Double_delta_0.5,Double_delta_45;String_test_Aha,Double_delta_2
    -sourceFile=<inputFileName>
    -outFile=<outputFileName >
    -CityGMLversion=<v1_0 | v2_0>
```

Params:

- *iterations*
  sets the maximum number of iterations of the healing process
- *checksToDo*
  comma separated list of all checks to be performed for geometric validation of the file.
  Available checks:
  de.hft.stuttgart.citydoctor.check.CP_NUMPOINTS,
  de.hft.stuttgart.citydoctor.check.CP_CLOSE,
  de.hft.stuttgart.citydoctor.check.CP_DUPPOINT,
  de.hft.stuttgart.citydoctor.check.CP_NULLAREA,
  de.hft.stuttgart.citydoctor.check.CP_SELFINT,
  de.hft.stuttgart.citydoctor.check.CP_PLANDIST,
  de.hft.stuttgart.citydoctor.check.CS_NUMFACES,
  de.hft.stuttgart.citydoctor.check.CS_SELFINTNATIVE,
  de.hft.stuttgart.citydoctor.check.CS_OUTEREDGE,
  de.hft.stuttgart.citydoctor.check.CS_OVERUSEDEDGE,
  de.hft.stuttgart.citydoctor.check.CS_FACEORIENT,
  de.hft.stuttgart.citydoctor.check.CS_FACEOUT,
  de.hft.stuttgart.citydoctor.check.CS_UMBRELLA,
  de.hft.stuttgart.citydoctor.check.CS_CONCOMP,
- *checkParams*
  parameters for some checks, e.g. tolerance values (not implemented yet)
- *sourceFile*
  path to the XML file containing the city model to be validated and healed
- *outFile*
  path to the output file containing the healed city model
- CityGMLversion
  Version of CityGML encoding: CityGML 1.0 or CityGML 2.0

  CityDoctor HealingTool runs all checks which are defined by *checksToDo* before applying healing methods on detected errors. In an iterative process this is repeated until no more errors are found in the current building or the maximum number of *iterations* is reached. 10 iterations are usually sufficient.
  To achieve best results, all checks should be selected in the same order as in the list above.

Example:

```
java "-Dfile.encoding=UTF-8" -Xms512m -Xmx512m -Djava.library.path=.\lib;.\lib\dll_32 -cp .;.\citydoctorHealing.jar;.\lib\citydoctor.jar;.\lib\activation.jar;.\lib\CityGML4j.jar;.\lib\gluegen-rt.jar;.\lib\gluegen-rt-natives-windows-i586.jar;.\lib\itext-xtra-5.1.3.jar;.\lib\itextpdf-5.1.3.jar;.\lib\Jama-1.0.2.jar;.\lib\jaxb-api.jar;.\lib\jaxb-impl.jar;.\lib\jaxb-xjc.jar;.\lib\jce-jdk13-147.jar;.\lib\jcommon-1.0.17.jar;.\lib\jdom.jar;.\lib\jfreechart-1.0.14.jar;.\lib\jh.jar;.\lib\jhall.jar;.\lib\jhbasic.jar;.\lib\jogl
```

```
-all-natives-windows-i586.jar;.\lib\jogl-
all.jar;.\lib\jsearch.jar;.\lib\jsr173_1.0_api.jar;.\lib\QSCity3D_He
lp.jar;.\lib\sjsxp.jar;.\lib\stringsearch.jar
de.hft.stuttgart.citydoctor.CityDoctorHealingStream -iterations=10 -
check-
sToDo=de.hft.stuttgart.citydoctor.check.CP_NUMPOINTS,de.hft.stuttgar
t.citydoctor.check.CP_CLOSE,de.hft.stuttgart.citydoctor.check.CP_DUP
POINT,de.hft.stuttgart.citydoctor.check.CP_NULLAREA,de.hft.stuttgart
.citydoctor.check.CP_SELF-
INT,de.hft.stuttgart.citydoctor.check.CP_PLANDIST,de.hft.stuttgart.c
itydoctor.check.CS_SELFINTNA-
TIVE,de.hft.stuttgart.citydoctor.check.CS_OUT-
EREDGE,de.hft.stuttgart.citydoctor.check.CS_OVER-
USEDEDGE,de.hft.stuttgart.citydoctor.check.CS_FACEORIENT,de.hft.stut
tgart.citydoctor.check.CS_FACEOUT -checkParams=Double_delta_0.5,Dou-
ble_delta_45;String_test_Aha,Double_delta_2 -sourceFile=3-21-BOSPOL-
DER.xml   -outFile=./healed/3-21-BOSPOLDER_healed.xml   -CityGMLver-
sion=v2_0
```