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# CREATION OF A CITYGML-BASED 3D CITY MODEL TESTBED FOR ENERGY-RELATED APPLICATIONS

C. León-Sánchez*, G. Agugiaro, J. Stoter

[1] 3D Geoinformation group, Delft University of Technology, Faculty of Architecture and the Built Environment, The Netherlands - (c.a.leonsanchez, g.agugiaro, j.e.stoter)@tudelft.nl

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**KEY WORDS:** 3DCM, CityGML, UBEM, UEM, Testbed

**ABSTRACT:**

This document introduces the process for the creation of a testbed for energy applications based on a semantic 3D city model for the municipality of Rijssen-Holten in The Netherlands. The creation of this dataset requires the consolidation from multiple data sources as well as a lot of manual work so the authors can warranty as much as possible the quality of the dataset so in can be used in several use cases. The data is stored following the OGC standard CityGML v2.0 and contain the geometrical and semantical information of CityObjects from the thematic modules Building, Vegetation and Relief. This data set consolidates the open weather data from the closest weather station to the study area located in Heino in the Netherlands. We discuss the decisions taken during the manual data collection process and we present some use cases that have already consume the dataset at the time of writing this document.

## 1. INTRODUCTION

The development of techniques to simulate and analyse at several scales the Urban Building Energy Modelling (UBEM) require a flexible approach based on the variety buildings (size, geometry, economic destination, physics, etc.) and other relevant urban objects, which is often hindered by the lack of access to openly available data e.g., energy consumption of buildings. For that reason, the building stock and a detailed modelling of buildings play a major role to achieve this goal.

This paper presents the work for the creation of a testbed for energy applications in the municipality of Rijssen-Holten (circa 38.000 inhabitants, corresponding to circa 23.000 buildings), located in the eastern part of The Netherlands based on a semantic 3D city model (3DCM). Figure 1 provides a location context for the municipality; in orange is the continental border of The Netherlands, in red colour is the delimitation of Rijssen-Holten.

The purpose of this testbed is to have a better characterisation of the building stock by coping with the current lack of data such as the building's function(s) or their number of storeys, so it can be used in urban energy modelling simulation tools.

Additionally, we want to provide an open dataset for testing heterogeneous Urban Energy Modelling (UEM) tools with a reference dataset which is sufficiently rich of attributes, semantics, geometries, etc., so that it avoids the typical complex initial part of data integration/cleaning/etc., before running the actual application.

## 2. DATA COLLECTION AND PREPARATION

In this section we describe the input datasets and methods we use to acquire the data.

* Corresponding author


**Figure 1.** Rijssen-Holten, thick red line, location in the Netherlands

### 2.1 Buildings

In 2021, the 3D Geoinformation Group at TU Delft published a country-wide 3DCM dataset, called 3DBAG v.2.0, containing all buildings in the Netherlands in three different levels of detail (LoD1.2, LoD1.3 and LoD2.2) (Peters et al., 2022). It combines two main datasets, the Addresses and Buildings Key Registry (Basisregistraties Adressen en Gebouwen, BAG), the database where Dutch municipalities store the information on local addresses and buildings managed by the Land Registry Office Dutch (kadaster, 2022); the AHN (Actueel Hoogtebestand Nederland) which is the digital height map of the Netherlands that contains detailed and precise height data (point clouds LiDAR) with an average of 8 points per square meter. The dataset was previously pre-processed in terms of geometries, as described in (León-Sánchez et al., 2021).

For the testbed, we decided to use the LoD2.2 so the geometries that compose the building's envelope can be semantically differentiated i.e., in GroundSurface, WallSurface and RoofSurface, etc. Buildings with more than one part are hierarchically organised using CityGML classes Building and BuildingPart. The former one contains the general semantic information for the whole building, while the later contains the detailed data as well as the geometries. Buildings (Parts) contain the address objects according to the BAG. Coplanar surfaces from the same object (Building or Building Part) and thematic definition are merged to reduce the number of surfaces.

The available attributes for the buildings are:

- The building ID (known as the Pand from the BAG)
- Class of the building
- Function(s): defined by means of the BAG gebruiksdoel values (in Dutch: usage function)
- Number of floors above and below terrain (if this information is available)
- GroundSurface area, in $m^2$
- Gross volume (i.e. enclosed by the LoD2 thematic surfaces), in $m^3$
- Information regarding their topology (e.g. free-standing or adjacent to other buildings), expressed by means of the number of adjacent buildings
- In case of adjacent building (parts); a list of IDs of the corresponding building (parts). For party walls (Agugiaro et al., 2022), geometries are split in surfaces between shared and not shared.

For all thematic surfaces, attributes are extracted from the geometries and are:

- Azimuth angle, in decimal degrees, measured counter-clockwise from North
- Orientation, expressed as one of N, NE, E, SE, S, SW, W, NW values
- Inclination (tilt) angle, in decimal degrees, measured from the horizontal plane upwards
- Normal vector to the thematic surface, expressed by means of its 3 components (nx, ny, nz)
- Area of the thematic surface, in $m^2$

After the geometrical computations and adjustments, we join the 3DCM with two datasets. First with the BAG database to quantify the number of cadastre units per building (Verblijfsobjects) as well as to extract the buildings' function(s); second with a survey done by the municipality of Rijssen-Holten that includes the number of storeys per building (parts).

From the dataset joins, only 60% of buildings obtained function information, in the case of the number of storeys, only around 50% of buildings were surveyed. Table 1 and figure 2 show the basic aggregation values of the building stock in Rijssen-Holten based on the input datasets.

| Item | Buildings | |
|---|---|---|
| Buildings | 23.395 | |
| only in LoD0 | 886 | 4% |
| modelled in LoD2 | 22.509 | 96% |

**Table 1.** Input building stock in Rijssen-Holten

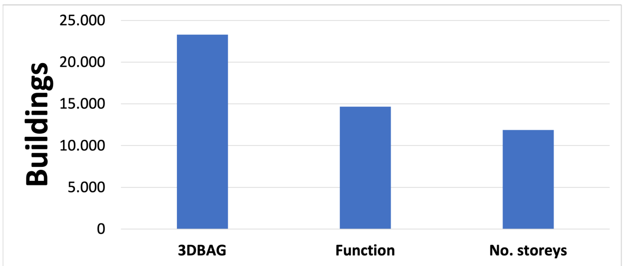



**Figure 2.** Summary of the initial three input datasets

### 2.2 Manual data collection

The initial databases joins (figure 2) and the lack of alternative sources of data provide the main reason to do a manual collection in the study area. For this, we decided to use Google Street View (Google, 2022) and Mapillary (Mapillary, 2022) in case of no imagery from google. Those platforms offer street level based imagery. Figures 3 and 4 show a sample of the same location at the municipality of Rijssen around the *EPSG:4326* coordinates $\varphi = 52°18'40.1'' \ \lambda = 6°31'42.0''$ for both datasets.


**Figure 3.** Rijssen Google Street View sample


**Figure 4.** Rijssen Mapillary sample

**2.2.1 Number of storeys** The building reconstruction method of the 3DBAG does not further split or divide each *Building* or *BuildingPart* we collect only the value of the highest number of storeys of a building, both for above and below the ground. Figure 5 shows an example of a residential building in Rijssen, our method collects the highest number of storeys based on figure 5(a); the survey done by the municipality of Rijssen-Holten split the buildings as shown in figure 5(b) so it is necessary to aggregate the data per building.

Table 2 shows the distribution of buildings in the study area by the number of storeys above ground. For the number of storeys bellow ground, the testbed contains the information of 43% of the building (parts); 9.578 building (parts) do not have basement or storeys bellow ground, 69 have one storey and 1 has two storeys bellow ground. For this information, we decide to collect the data for only those building (parts) that it is possible to see it. For that reason, the underground parking place at the city center of Rijssen does not contain data for this attribute since the underground part of the construction is not modelled and we don't know the correct number of storeys.

(a) A (b) B

Figure 5. Example of number of storeys (2) of a building

| Number of Storeys | No. Buildings | |
|---|---|---|
| 1 | 9.821 | 43,00% |
| 2 | 4.011 | 18,00% |
| 3 | 8.729 | 39,00% |
| 4 | 35 | 0,15% |
| 5 | 4 | 0,02% |
| 6 | 3 | 0,01% |
| 7 | 1 | 0,00% |

Table 2. Building's distribution by number of storeys above ground

**2.2.2 Building Function** For this attribute, we use as well the the street level imagery datasets. Buildings are classified according the classification defined by the Dutch Kadaster. For those building (parts) which the facade do not provide enough information to classify the building (part), we use the surrounding building (parts) as a context.

That is the case of some lodging building (parts) *Bungalowpark* (holiday park in English) or *Vakantiehuis* (Vacation house in English) that look like a residential building, figure 6 shows an example of a *logiesfunctie* (lodging function in Dutch) building.


Figure 6. Example of a lodging building

## 2.3 Energy label

The *EP-Online* is the official database of the Netherlands in which energy consultants can register the energy labels as well as the energy performance indicators of dwellings (Rijksoverheid, 2022). This open access dataset was published at 13th July 2017 and it is updated daily and consolidated monthly.

| Building class | no. Buildings | |
|---|---|---|
| Residential | 12.439 | 55% |
| Unknown | 5.381 | 24% |
| Non-residential (single function) | 4.054 | 18% |
| Mixed-use | 577 | 3% |
| Non-residential (multi function) | 153 | 1% |

Table 3. Building's distribution by class

Since the 1st January 2015, it is mandatory to provide a registered energy label when selling or renting out a property (Rijksoverheid, 2022). The consolidated database at 1st June 2022 contains 4.824.861 dwellings of which 99, 3% can be spatially located based on their unique id (verblijfsobject identificatie in Dutch). In the case of Rijssen-Holten, it contains the data of 7.120 dwellings that correspond to 5.586 unique buildings 24% of the stock of the municipality.

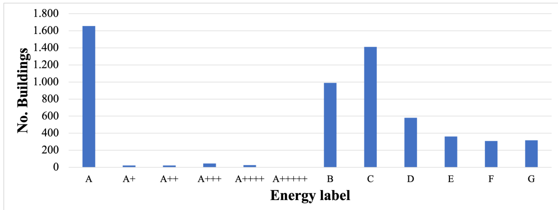



Figure 7. Buildings per energy label class in Rijssen-Holten

## 2.4 Building Type

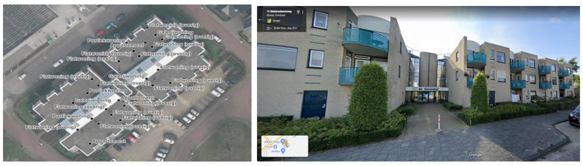
The classification of the building stock is done following the TABULA project typologies (EPISCOPE Project, 2017). Since the project defined from a common concept that was farther developed into national building typologies, the testbed contains two attributes European and the Netherlands classification schemes.

The European scheme is classified into: Single Family House (SFH), Terraced House (TH), Multi Family House (MFH), Apartment Block (AB). The Netherlands scheme is more detailed and as a consequence more complex to classify, table 4 shows the translation of the Dutch types.

| English | Dutch |
|---|---|
| Detached house | Vrijstaande woning |
| Semi-detached | Twee-onder-één-kap,<br>Twee-onder-een-kap,<br>rijwoning hoek |
| Porch | Portiekwoning |
| Terraced house in between | Rijwoning tussen |
| Terraced house corner | Rijwoning hoek |
| Maisonette | Maisonnette |
| Gallery building | Galerijwoning |
| Terraced house (other) | Flatwoning (overig) |
| Apartment | Appartement |
| Carvan | Woonwagen |
| Houseboat with existing berth | Woonboot bestaande ligplaats |
| Houseboat with new berth | Woonboot nieuwe ligplaats |
| Shared house | Woongebouw met niet-zelfstandige<br>woonruimte |
| Lodging | Logieswoning |

Table 4. Netherlands classification of the building stock

We define basic rules to automatise as much as possible the classification process i.e., building (parts) without adjacent ones are classified as *Detached house*. The *EP-Online* (Rijksoverheid, 2022) dataset contains an attribute with the building type according to the Netherlands classification scheme. In this case, we find that the classification is based on the dwelling perspective and the criteria varies so a building with several dwellings that have a energy label could have multiple values for building type. To solve this clarity issue, we manually review each building and select the appropriate one according its design.



(a) Energy label dataset (b) Google Street View

**Figure 8.** Example of a multi familiar residential building with several classification types

Figure 8 shows an example of a residential building with four (4) different values for the building type attribute according to the energy label dataset. The assigned values are: Apartment, Terraced house (other), Gallery building and Porch. All classes agree in the fact that is a multi familiar building with several dwellings. In our opinion, it should not be classified a s *Gallery* since the dwelings' front door are not located on a shared "gallery"; we agree with of classifying it as a *Porch* due to the main entrance visible in figure 8(b); nevertheless, the remaining assigned types are also possible and the assignation criteria is fuzzy. For this building we manually classify it as *Porch*

A BAG address correspond to one kadaster unit (verblijfsobject). Table 5 provides an insight of the distribution of buildings in Rijssen-Holten. A Single-family house is defined by two main characteristics, no adjacency to other building (parts) and is associated to only one address. A Semi-detached house consist of building (parts) that share (at least partially) a boundary surface from another building (part) or to make it more explicit, to have a different Building id; each of the touching building (parts) has only one address associated.

A Terraced house is composed for those building (parts) that have more than one adjacent building (parts) and additionally, each building ID might have associated up to ten addresses. A commercial is a building which its function is not residential. A Multi-family house is a building (part) that is associated to several address. An apartment block is a building that is associated to several address, this classification is done by the manual inspection of those that complain to the main rule and their design is like falls into the tower style (tall building with a not too big footprint).

| **TABULA Building (Parts) Type** | **no. Buildings** | |
|---|---|---|
| Single-family house | 9.048 | 40,03% |
| Semi-detached house | 7.805 | 34,53% |
| Terraced house | 4.191 | 18,54% |
| Commercial | 1.390 | 6,15% |
| Multi-family house | 167 | 0,74% |
| Apartment block | 3 | 0,01% |

**Table 5.** Buildings' distribution by TABULA Type

Table 6 provides an insight of the building stock classified considering the TABULA project specification f or T he Netherlands. The classes with the two highest number of buildings *Vrijstaande Woning* and *Twee-onder-een-kapwoning* are defined following the following conditions. The former are those building (parts) that have no adjacency to other building (parts), the later are those building (parts) that have one adjacency building (part). For the other classes, we do a manual collection using the already mentioned street level imagery platforms as well as the energy label ()Rijksoverheid2021 dataset.

| **TABULA NL Building (Parts) Type** | **No. Buildings** | |
|---|---|---|
| Vrijstaande Woning | 10.504 | 46,00% |
| Twee-onder-een-kapwoning | 5.239 | 23,00% |
| Tussenwoning | 3.737 | 17,00% |
| Hoekwoning | 3.002 | 13,00% |
| Flatwoning | 95 | 0,42% |
| Portiekwoning | 12 | 0,05% |
| Galerijwoning | 7 | 0,03% |
| Maisonnettewoning | 5 | 0,02% |
| Appartementencomplex | 3 | 0,01% |

**Table 6.** Buildings' distribution by The Netherlands Type

### 2.5 Weather data

Since Rijssen-Holten does not have open weather data available, we consolidate the data of closest weather station, which is located at Heino in the Dutch province of Overrijssel (figure 9). The two datasources are:

1. climate.onebuilding.org (Lawrie and Crawley, 2019), which is a repository of free climate data for building performance simulation. The shared data in this website are Typical Meteorological Years (TMY) published by a variety of organizations. The prime format is *EPW* but the climate location contains:
    - EPW (EnergyPlus Weather Format)
    - CLM (ESP-r weather format)
    - WEA (Daysim weather format)
    - PVSyst (PV Solar weather design format)
    - DDY (ASHRAE Design Conditions or "file" design conditions in EnergyPlus format)
    - RAIN (hourly precipitation in $m/hr$, where available)
    - STAT (expanded EnergyPlus weather statistics)
2. The Dutch PV portal climatological year data (PVMD, 2022), which is based on measurements made available by the Koninklijk Nederlands Meteorologisch Instituut (KNMI). This dataset contains the averaged measurements over 31 years with the first measurement correspondig to the $1^{st}$ of January 1991. This dataset contains the following data:
    - Irradiance: average global horizontal irradiance (GHI) $[W/m^2]$.
    - T_ambient: average ambient temperature measured at 1.5 m above the ground.
    - T_ground: average ground temperature at 10 cm above the ground.
    - Wind: average wind speed at 10 m above the ground.
    - Cloud: cloud coverage in eighths of the visible sky area where 0 is clear-sky and 8 is a completely obscured sky.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- Pressure: air pressure at the measurement station in Pascal.
- Rainfall: rainfall at the measurement station in mm/hr.
- Diffuse: diffuse horizontal irradiance in $W/m^2$ calculated from GHI.
- Direct: direct horizontal irradiance in $W/m^2$ calculated from GHI. The more commonly used direct normal irradiance (DNI) can be calculated by dividing 'Direct' by the factor sin(Elevation) (the sine of the Sun elevation).
- Elevation: sun elevation in degrees above the horizon.
- Azimuth: sun azimuth in degrees relative to north.

The late four values are calculated with a scientific model (unfortunately this informatino is not provided ) and not measured directly (PVMD, 2022).

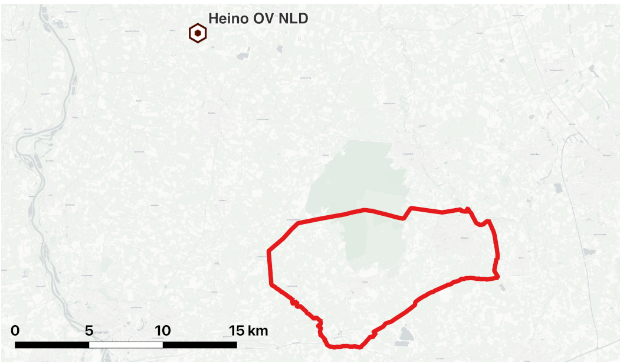



**Figure 9.** Location of the weather station at Heino, the boundary of Rijssen-Holten is coloured in red

### 2.6 DTM

For the Digital Terrain Model (DTM), we use the as the input data the AHN3 raster-based Digital Elevation Mdel (DEM) (AHN, 2019). The input data is triangulated with a height tolerance of $20cm$ to reduce the number of triangules in the output data. The resulting Triangulated Irregular Network (TIN) is a rectangle of a dimension of $x = 20.245m$ and $y = 12.245m$ for a total area of $30.863, 5ha$ divded into Tiles of $250m \times 250m$; 81 tiles for the x axis and 61 tiles for the y axis for a total of 4.941 Tiles. Figure 10 presents the TIN (black triangles) of the municipality of Rijssen-Holten (red colour boundary) over a openstreetmap background.

### 2.7 Vegetation

(Voortman, 2021) states the methodology implemented by the municipality of Rijssen-Holten for the identification of the vegetation areas in their jurisdiction using the AHN3 point cloud dataset (AHN, 2019). We use Voortman work as the starting point for our trees modelling approach.

Voortman's calculation is done using FME and removes all points from the ANH3 point cloud that were not both vegetation and their height difference compared to the ground level is higher than 2m so small shrubs and hedges are not included; The remaining points are buffered 50cm and dissolved. The result is a projection of the green volumes of the municipality in 2D. A final step in their process correspond to the clean up

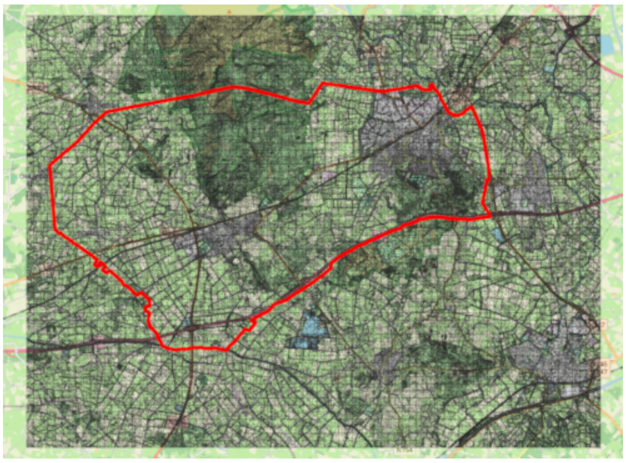
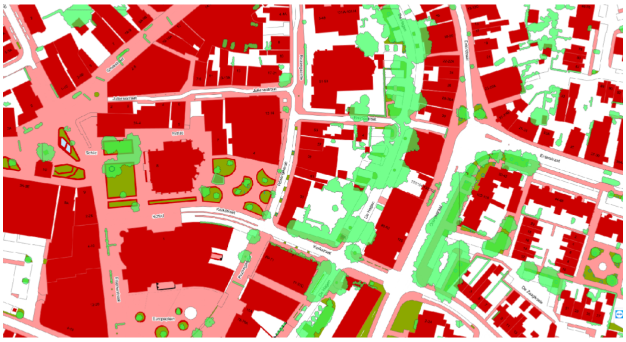


**Figure 10.** TIN of Rijssen-Holten

(a) BGT



(b) New footprints

**Figure 11.** Comparison of the Basisregistratie Grootschalige Topografie (BGT) base map and Voortman's work results. (Voortman, 2021)

by cheking it against the high resolution aerial photo available by the Dutch Kadaster services (pdok, 2021). The *Vegetation* module of CityGML v2.0 (Gröger et al., 2012) distinguishes solitary vegetation objects such as trees and vegetation areas. The former are modelled by the class *SolitaryVegetationObject* and the later by the class *PlantCover*; both classes are used in this testbed.

As the CityGML standard states (Gröger et al., 2012, p. 133), the geometry of a *SolitaryVegetationObject* "may be defined in explicit GML geometry having absolute coordinates or prototypically by an *ImplicitGeometry*". Since the modelling of trees is out of the scope of this project, we use the later for the representation of solitary trees in the study area. Figure 12 presents an sample of the solitary vegetation objects modelled for the

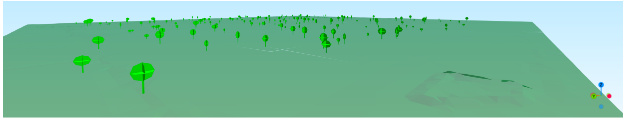


**Figure 12.** Sample of *ImplicitGeometry* Trees in Rijssen-Holten

testbed. The location of each tree is extracted from the dataset created by (Voortman, 2021). We calculate the centroid of the vegetation areas that can be represented as *SolitaryVegetationObject* and the height of each object is calculated by the delta of heights between the DTM of the testbed and a DEM created from the AHN3 pointcloud of Rijssen-Holten. At least 30.000 trees are modellled as single objects, figure 13 presents the cover area by vegetation in dark green, their centroid are presented as red points, this is the 2D location use for their *ImplicitGeometry* final l ocation. Those vegetation areas from figure 13 that do not contain a centroid are modelled as 3D *PlantCover* CityObjects.

**Figure 13.** Sample of *ImplicitGeometry* Trees in Rijssen-Holten

## 3. USE CASES

At the time of writing this document, there are already several use cases where this testbed has been used as input dataset. (Agugiaro et al., 2022) consumes the testbed for their computation of party walls.

(Jin, 2022) develops a python interface tool to simplify the interaction between CitySim (Mutani et al., 2018) and the 3DCityDB (Yao et al., 2018), the SQL encoding of CityGML. In this use case, Yuzhen uses the testbed for calculate the space heating demand of a section of Rijssen-Holten using CitySim. The simulation results are stored in a 3DCityDB-compliant dababase that supports the Energy ADE KIT profile (Agugiaro et al., 2018, Yao and Nagel, 2021).

(Tufan, 2022) uses the testbed to test a preliminary implementation of the Dutch standard NTA8800 to calculate the space heating demand of buildings. Among the calculation equations and specifications, the standard specifies values such as the total incident solar radiation for several orientations and inclinations. Tufan's work consumes the attributes calculated in the testbed for the thematic surface geometries, she also uses the area and volume of the building (parts) as well as the outdoor temperature data by (PVMD, 2022). Figure 15 presents an exceprt of their results for the space heating demand calculation in downtown Rijssen.

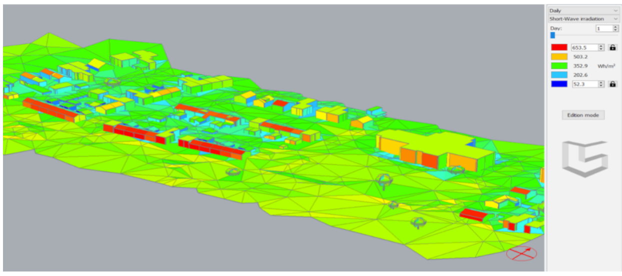


**Figure 14.** Solar radiation results in Citysim Pro GUI (Jin, 2022)


(a) Downtown Rijssen


(b) Residential area Rijssen

**Figure 15.** Sample results of the Energy demand (kWh) in Rijssen-Holten (Tufan, 2022)

## 4. CONCLUSIONS

As we mention in the introduction, the main purpose of our work is to provide an open dataset for testing UEM tools. This dataset is rich of attributes, semantics and geometries. This means for us a lot of work on data collection and preparation so errors in the provided data are minimised as much as possible. Nevertheless, it is impossible to create an error-free dataset, one example could be the building type attribute: it is supported by the energy label dataset, which as it is shown in figure 8 does not have a unique criteria for the classification of building (parts) as shown, although we have done our best to minimise this problem.

We decided to do a manual data collection with an homogeneous criteria, so "pecularities" are treated in a systematic way and in the case of errors, they can be rectified in a (desirable) simpler way. We do not use any technique or method to fill the data gaps in the dataset like for example artificial intelligence since those rely completely on the quality of the input dataset, whereas we expect out testbed to be used in future research projects that involve those methods and techniques.

The use cases mentioned in this document have provided us of feedback of the dataset, notwithstanding more tests are required to be carried out and compared from other colleagues from the energy community so it can be analysed the quality of the dataset as well as if further attributes are required.

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