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Ref. Ares(2019)2259850 - 29/03/2019

my SMART Life

Deliverable due date: M28 – March 2019

D6.5 DESCRIPTION OF 3D MODELS FOR EACH FOLLOWER CITY

WP6, Task 6.2

Transition of EU cities towards a new concept of Smart Life and Economy

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

Project Acronym	mySMARTLife		
Project Title	**Transition of EU cities towards a new concept of Smart Life and Economy**		
Project Duration	1st December 2016 – 30th November 2021 (60 Months)		
Deliverable	D6.5 Description of 3d models for each follower city		
Diss. Level	PU		
Status	Working		
	Verified by other WPs		
	Final version		
Due date	30/06/2018		
Work Package	WP6		
Lead beneficiary	TEC		
Contributing beneficiary(ies)	NBK, CAR, BYD, RIJ, PAL		
Task description	Task 6.2 is focused on the replication of advanced integrated urban planning methodology. Here, the working methodology of Task 1.4 will be replicated with follower cities in order to evaluate the direct, indirect and induced effects that the replication plan will have in each city. This ex-ante evaluation will allow follower cities to refine their replication plans and make them much more adaptable to their needs. Subtask 6.2.1: A 3D modelling. In this subtask pilots for follower cities will be modelled to identify the energy model (demand side plus existing supply side), taking into account relevant aspects such as built surface, floors, heated area, use of the building, orientation, year of construction, past retrofitting, etc. The result is the energy demand to detect passive strategies for each pilot.		
Date	**Version**	**Author**	**Comment**
30/01/2019	0.1	Eneko Arrizabalaga Jose Luis Izkara (TEC)	Interim Version
15/02/2019	0.2	Eneko Arrizabalaga Jose Luis Izkara Iñaki Prieto Nekane Hermoso (TEC)	Intermediate version
15/03/2019	0.3	Eneko Arrizabalaga Jose Luis Izkara Iñaki Prieto Nekane Hermoso (TEC)	Version for review

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28/03/2019	0.4	Eneko Arrizabalaga Jose Luis Izkara Iñaki Prieto Nekane Hermoso (TEC) Review by HEN and TSY	Reviewed version

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Abbreviations and Acronyms

Acronym	Description
ACH	Air change per hours
CAR	Fundación Cartif (beneficiary from Spain/project coordinator)
DHW	Domestic Hot Water
DSM	Digital Surface Model
DTM	Digital Terrain Model
EPSG	Spatial Reference System Code defined by the European Petroleum Survey Group
GFA	Ground floor area
HDHi,j	Heating degree hours
ID	Identifier
IG	Internal gains
KML	Keyhole Markup Language
mySMARTLife	Transition of EU cities towards a new concept of Smart Life and Economy
NBK	Nobatek
OSM	OpenStreeMap
SCH	Schedule
SG	Solar gains
SHP	ESRI Shape file format
TEC	Fundación Tecnalia Research and Innovation (participant from Spain)
Uk	Thermal transmittance
U-value	Thermal transmittance
WP	Work Package
WWR	Window to wall ratio

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1. Executive Summary

The main objective of mySMARTLife project is the demonstration of the Innovative Transformation Strategy concept through piloting different actions, considering advanced technologies, towards the global transformation of the urban life in the cities. The methodology that will be applied in the three Lighthouse cities will foster the replication of the foreseen actions, at different levels, in the follower cities and the smart city network that will be created during the project lifetime.

As a global vision, mySMARTLife will follow the next approach:

Figure 1: Global vision of the mySMARTLife Project

This Urban Transformation Strategy aims to respond in a holistic and integrated way to the transformation process, overcoming the existing technical and non-technical barriers. During this process the technical support to the different phases is a critical issue. In this regard, the application of existing methods and tools, as well as the development and the adaptation of new methods is essential to provide the needed criteria for the prioritization of measures that will guide this transformation.

In this framework, the deliverable D6.5 aims to collect all data and information available in the city, information related to the 3D model, the city cadastre, and the information evaluated in the baseline assessment to process it in a way that it serves as input for the energy modelling of the buildings of the cities. In this sense, for each of the follower cities, a zone for the assessment has been selected. The energy analysis carried out for this zone aims to serve as a preliminary work that can be replicated in other zones of the city or even in the entire city. This energy characterization of the building stock of the cities is a key phase for the urban transformation because an accurate diagnosis can help to identify the priority action lines and zones. Besides, this is a critical step, which combined with the development of the energy scenarios of the cities and the technoeconomic analysis of the interventions of the mySMARTLife project, will allow the ex-ante impact evaluation of the proposed solutions so that it provides some relevant criteria for the prioritization of the actions that will be implemented in the following years.

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2. Introduction

2.1 Purpose and target group

This deliverable is allocated within Task 6.2, which is related to evaluating impacts in follower cities from the social, economic and environmental field to understand the interaction of the different interventions as a system. The Advanced Integrated Urban Planning is divided in four stages, corresponding with the deliverables of the task:

- **Deliverable 6.5:** This deliverable is related to the subtask 6.2.1 and is focused on the description of 3D models for each area selected by each follower city. This deliverable includes the energy assessment of the area selected by each city. This is a key step which can be scaled-up to cover a larger area of the city so that it can serve to evaluate aspects that can be used to feed the different scenarios that will be evaluated for the cities in the subtask 6.2.2.
- **Deliverable 6.6:** This deliverable is related to the subtask 6.2.2 which is focused on the energy scenario development at city scale. The outcome of the subtask 6.2.2 that is described in the Deliverable 6.5 will be used for the definition of scenarios.
- **Deliverable 6.7:** This deliverable is related to the subtask 6.2.3 which is focused on the techno-economic assessment of the interventions that will be replicated in each follower city.
- **Deliverables 6.8/6.8/6.10:** These deliverables are related to the definition of the replication plan for each follower city. The information generated in this deliverable and in the above mentioned other two deliverables will generate an important part of the information needed for the definition of these plans.

The present deliverable is structured as follows:

Chapter 3: shows the overall methodological approach to the Advanced Integrated Urban Planning in mySMARTLife project, describing the relation between the different phases of the assessment for the lighthouse cities and the relation with the replication in the follower cities.

Chapter 4: Describes the approach followed for the collection, analysis and processing of the available information for the modelling of the case studies in the three follower cities of the project. The processing of data has been carried out at different scales (district / city) and with different results, depending on the available information and the complementarity of the results.

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Chapter 5: Describes more in detail the methodological approach followed for the energy analysis of the districts selected for the three follower cities.

Chapter 6: Describes the three case studies evaluated, one for each follower city. The analysis is focused on the characteristics of the buildings included in the area of study taking into account the area, the age and the use of the built environment.

Chapter 7: Describes the three case studies evaluated, one for each follower city. The analysis is focused on the analysis of the characteristics of the buildings included in the area of study and the description of the adjustment phase carried out for each case depending on the specific information available in the corresponding city.

Chapter 8: Describes the main results obtained in this deliverable. The results of the analysis are provided to each city. Therefore, this section only shows the most representative and visual results obtained by the modelling of each follower city. The files provided to the cities of the project are precisely the main result of the work. The following result files are provided to each city:

- The input shapes
- The shape file ("City Results")
- A XLSX file ("City district energy modelling results")
- A second XLSX file ("City district energy modelling results aggregated")

Chapter 9: Describes the main conclusions obtained from the work carried out in the subtask 6.2.1.

Chapter 10: Shows the references of the literature consulted to develop the work.

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2.2 Contributions of partners

The following table depicts the main contributions from participant partners in the development of this deliverable.

Table 1: Contribution of partners

Participant short name	Contributions
TEC	Overall content and redaction of all the sections of the deliverable
CAR	General review of the content of the deliverable
NBK	General review of the content of the deliverable and the subtask
PAL	Contribution (data provision) to the sections 4 and 5
BYD	Contribution (data provision) to the sections 4 and 5
RIJ	Contribution (data provision) to the sections 4 and 5
TSY	Overall review of the deliverable
HEN	Overall review of the deliverable

2.3 Relation to other activities in the project

The following table depicts the main relationship of this deliverable to other activities (or deliverables) developed within the mySMARTLife project and that should be considered along with this document for further understanding of its contents.

Table 2: Relation to other activities in the project

Deliverable Number	Contributions
D1.12	This deliverable provides the description of 3D models for each pilot of each lighthouse city
D6.1	Baseline assessment & PESTEL Analysis of Palencia’s Initial Replication Plan
D6.2	Baseline assessment & PESTEL Analysis of Bydgoszcz’s Initial Replication Plan
D6.3	Baseline assessment & PESTEL Analysis of Rijeka’s Initial Replication Plan

D6.6	This deliverable provides the compilation of energy system scenarios for each follower city which will depend on the results of this deliverable
D6.7	This deliverable provides the techno-economic analysis of each intervention for the replication which will depend on the results of this deliverable
D6.8	This deliverable provides the Replication Plan of the City of Palencia
D6.9	This deliverable provides the Replication Plan of the City of Bydgoszcz
D6.10	This deliverable provides the Replication Plan of the City of Rijeka

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3. Overall methodological approach to the Advanced Integrated Urban Planning in mySMARTLife project

This section aims to provide a general overview of the overall methodological and modelling approach of the Advanced Integrated Urban Planning of mySMARTLife project. The figure below shows how each of the phases of the methodology corresponds with the different subtask of the Task 6.2 of the project and how each subtask contributes to the rest with their corresponding outcomes.

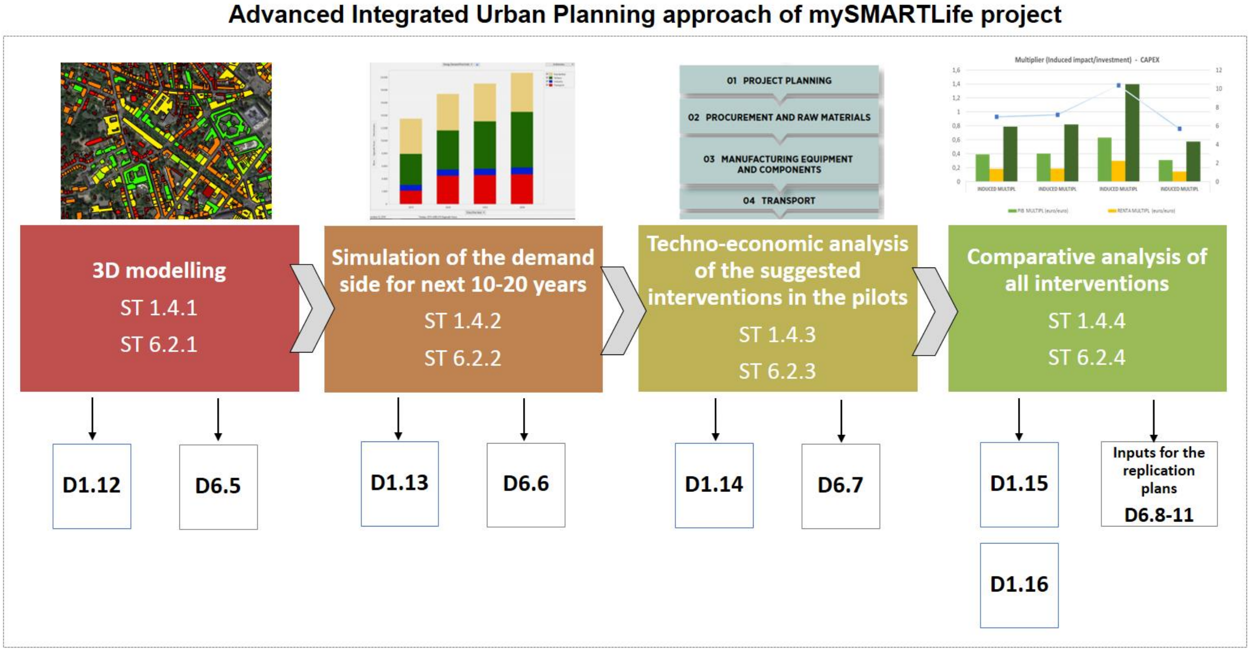

Figure 2: Methodological approach of the Advanced Integrated Urban Planning in mySMARTLife project.

The methodology is composed by four main phases that correspond with the main subtasks showed in the figure above. It can be seen, that the entire process is applied to both the lighthouse and to the follower cities of the project. The analysis is first applied to lighthouse cities (in WP1) and with the experience gained and with the lessons learnt, it is applied in a second step to the follower cities of the project (in the subtasks specified within the WP6).

The **first phase** is focused on the **3D modelling and energy demand analysis** of the three lighthouse cities. The 3D modelling is applied at city scale to prepare the data available in the city in the way that is required for the energy modelling of the building stock. In this phase the area selected in each city is evaluated through an energy model. The energy modelling evaluates the energy demand of the building stock taking into account several characteristics that are specific for each building. The results of the

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modelling provide the hourly energy demands (heating, cooling, DHW) and the hourly electricity consumption (lighting, equipment, etc.) individually for each building but also in an aggregated way according to a classification depending on the construction period and use of the buildings. The procedure is carried out in a way that the model is calibrated so that it can be used for other areas of the city or for the entire city. The visual representation of the results allows a quick understanding of the energy needs of the city but also an initial idea of the refurbishment potential or the potential for the implementation of renewable energy technologies such as the solar thermal and the solar photovoltaic systems. This is a bottom-up modelling approach that provides some specific results that are useful for the scenario definition in the following phase of the methodology which follows a top-down approach to the city energy modelling. The main outputs of this phase are the deliverables D1.12 and D6.5.

The **second phase** of the modelling methodology is focused on **simulating the energy demand for the next 10-20 years for the city**. In this case the entire city is evaluated including not only the built environment but also the rest of the sectors of the city such as the industry and mobility. In this case other types of modelling tools are required to define the energy matrix of the city (Sankey diagram) for the base year. Then, the evolution of several characteristics (such as the evolution of the socioeconomic characteristics of the city; population, GDP, etc.) are evaluated for each city, establishing the interrelation between these parameters and the future energy needs of the city. This will allow to generate the Business as Usual (BaU) scenario for the city, which defines the expected evolution of the energy demands/consumptions of the different sectors of the city, as well as the required local energy generation or the energy import needs in the following years. This BaU scenario is the base for future evaluations of the expected impact of alternative efficient scenarios that can be proposed for the cities. As explained before, the potential results of the modelling in the first phase can serve to define some aspects of these alternative scenarios. The main outputs of this phase are the deliverables D1.13 and D6.6.

The **third phase** is focused on the **technoeconomic analysis of the suggested interventions in the pilots**. In this case a supply chain analysis is carried out for the interventions that can be implemented in the pilots, evaluating the disaggregation of the cost components that compose the intervention, as well as the existing capabilities at city/regional scale for the manufacturing or distribution of each component. Besides, an analysis of the socioeconomic structure of each city and its corresponding region is carried out in order to define the sectoral disaggregation that is required for the supply chain analysis. The result of this phase will be the specific “shocks” that will serve as input for the macroeconomic modelling that is carried out in the last phase of the methodology. Each intervention will be represented as a specific increase of the production of the corresponding subsectors in the region. The main outputs of this phase are the deliverables D1.14 and D6.7.

Finally, the **fourth phase** is focused on the **comparative analysis of all the interventions based on the impact assessment results**. In this phase the impact assessment of each intervention is carried out based on the results of the previous phases. On the one hand, the shocks created in the third phase are

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used to evaluate the potential impact associated to each intervention to generate a direct, indirect and induced effect in the development of several socioeconomic characteristics of the cities/regions such as the increase of the GDP or the employment. This information can also be combined with the results of the phases one and two which will provide an idea of the deployment potential of each type of intervention in the cities which will affect the final impact. Finally, this socioeconomic analysis for each intervention is combined with the expected energy and environmental impact analysis which will provide extra criteria that will be useful for the prioritisation of the technologies. Here, a multicriteria methodology will be used to compare the different interventions for each city based on the expected impacts. The main outputs of this phase are the deliverables D1.15 and D1.6.

In the case of the follower cities, a similar process will be carried out to get a better understanding of the potential impact that the future implementation of actions can have in each follower city. This, as well as all the intermediate results obtained for the follower cities will be important inputs for the replication plans (D6.8-11).

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4. Description of the 3D models for the three follower cities

4.1 Approach to the district/city modelling

This section presents the general information and the approach followed in the project to collect, analyse and process the available information that allows carrying out the energy diagnosis for the three cases of study in the follower cities of the project (Palencia, Rijeka and Bydgoszcz). The approach followed for the follower cities in mySMARTLife is the same as the one followed for the lighthouse cities described in Deliverable D1.12 Description of 3D Models for each Pilot. The detailed description of the data modelling for each case study is presented in the following section 4.2

The process of generating the urban model that serves as input for the energy analysis is presented in the following figure (**¡Error! No se encuentra el origen de la referencia.**). Regarding the data sources that contain cadastral and cartographic information, these are sources that the municipality must provide to begin the process. The degree of precision of the results will depend to a large extent on the level of detail and the veracity of the information contained in these sources. To achieve high levels of detail and reliability for the input information, it is recommended to carry out a process of adaptation, cleaning and organization of the input data. The objective of the “Pre-process” is to have detailed geometry at the building level and the greatest number of attributes associated to that geometry. It is also very common the necessity to combine different data sources to have the required information and generally the data sources are not linked. Cadastral and cartographic data sources provide 2D information on real elements that are 3D (buildings). The 3D shape of the buildings is quite relevant for the evaluation of the energy demand. This information can be found as attributes in the cadastral information from the elevation models (DSM and DTM) together with the cartography of the area. Information collected from the data sources provided by the municipality must be conveniently processed to obtain the relevant information for calculating the energy information of each building. These calculations are performed in the "Data process".

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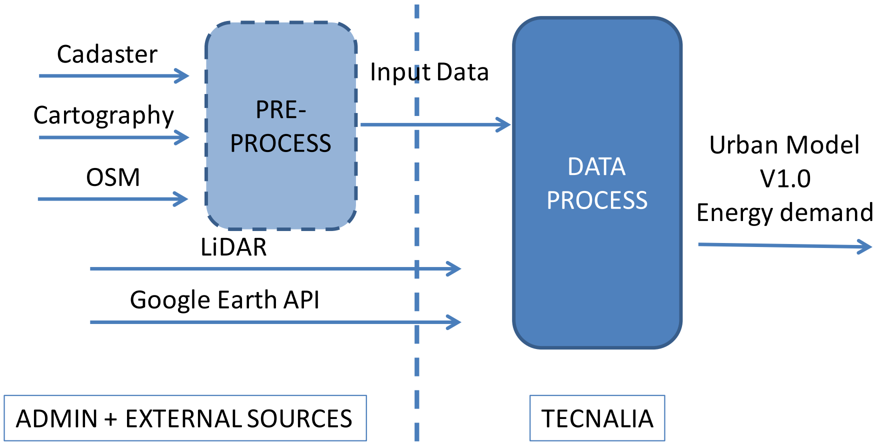

Figure 3 Approach to the urban modelling

The process of identifying information sources is critical to the success of the modelling. First, it is important to define the limits of the study area in which the analysis will be carried out. In mySMARTLife, a two-tier analysis is proposed, first, at the district scale or a reduced set of buildings, and then at the city or municipality scale. Modelling is proposed in a similar way and scope in both cases, however in the first case manual work can be carried out to check or complete relevant information when not available. In the city scale, this task is unaffordable. The minimum input information necessary to carry out the modelling is presented in the following table (**¡Error! No se encuentra el origen de la referencia.**). This table is adapted to the requirements for energy modelling of each case study in the detailed description of the modelling process for each follower city.

Table 3: List of minimum data required for the energy modelling

Name	Type	Values / Units
Building Footprint	Geometry	-
Building Height or Number of floors	Year or Number	Meters
Main Use or Function of the building	Text	-
Year of Construction	Number	Year

The required outputs of the modelling process necessary for the energy analysis are shown in the following table (**¡Error! No se encuentra el origen de la referencia.**). The results of the process for each follower city are adapted to the requirements and the available information in each case study:

Table 4: List of the outputs of the modelling process

Name	Description
Geolocation of the building	Represented by the centroid of the polygon with the geometry of the building.

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Height of the building	If not available as an input attribute, it can be estimated from number of floors of the building, considering an average height per floor. If this information is not available, it can be calculated also from the information contained in the elevation models (DSM and DTM) combined with the building footprints.
Number of floors	If not available as an input, it can be estimated from the total height of the building considering an average height per floor.
Building footprint area	Calculated from the building footprint
Roof area	It can be estimated by the floor area of the building, assuming flat roofs.
Gross floor area	Estimated from the area of the floor multiplied by the number of floors.
Envelope area	The total envelope area will be calculated as the sum of the area of each of the facades. It is necessary previously to identify the facades and the adjoining walls. It can be estimated also the area divided by the main orientation of the facades.
Volume	Calculated from the building footprint area and the height of the building
Year of Construction	Mandatory as input data
Building Use	Mandatory as input data

Finally, this task also includes the generation of the CityGML model from those of the follower cities that do not currently have such a model (in the case of the follower cities none of them have a CityGML model). The process of generating the 3D urban model based on the CityGML data model is presented in the following figure (**¡Error! No se encuentra el origen de la referencia.**). Data sources for the generation of the geometric 3D model in CityGML format must contain the geometry of the building footprints and the height of the buildings. Files with 2D cartographic information, such as the cadastre or other publicly accessible data sources such as OpenStreetMap, represent the main source of information to obtain the geometry of the building footprints. The height of the buildings can be included in the same files with the cartography or it can be extracted from digital terrain and surface models (DTM and DSM). Through the processing of this information, the CityGML model can be generated in a semi-automatic way with low levels of detail (LoD0: building floors, LoD1: Buildings represented by cubes, LoD2: Buildings as cubes separating facades and roof).

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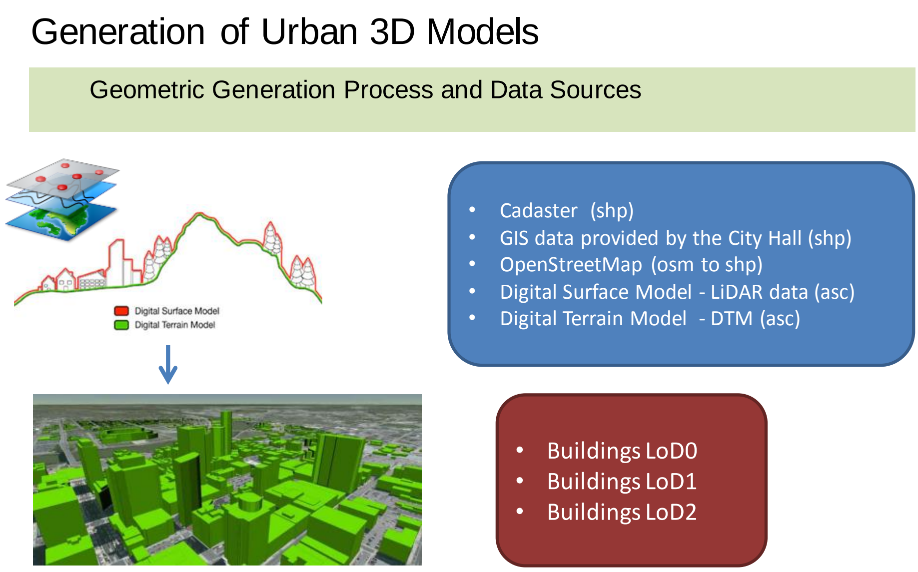

Figure 4 CityGML model generation process

4.2 Case study descriptions for the three follower cities

4.2.1 Palencia area of study

This subsection describes the main process followed for the treatment of the data for the case of Palencia. It includes a description of the situation of the city with regard to the information available, a description of the data processing at district scale, the data processing and CityGML generation at city scale and a description of the results obtained in this phase.

4.2.1.1 Description of the situation of the city

The city of Palencia has not a 3D city model in CityGML format. So, it has been created within mySMARTLife project.

Cartographic information in SHP format is available by the Electronic Office of Cadastre of Spain at the level of the municipality of Palencia. The cadastral information is also available at the same scale. The information available is detailed in the following section (section **¡Error! No se encuentra el origen de la referencia.**).

The analysis of the information is carried out in two steps, firstly, a detailed analysis at the district level and then, the analysis at the municipal level and the generation of the CityGML model.

4.2.1.2 Data processing at district scale

A) General Configuration

For the district scale analysis of Palencia, the neighbourhoods numbered as 7 and 8 have been selected (see Figure 5).

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Figure 5 Neighborhoods 7 and 8 in Palencia

First, the necessary information to carry out the development of the energy analysis has been identified. For each of the buildings of the selected district it is necessary to obtain the basic information detailed in the following table (see Table 5).

Table 5: Basic Information required for each building in Palencia Case Study

Name	Type	Values / Units
Building Unique Identifier	Unique Id	
Geometry of the building footprints	Shp file	
Building footprint area	Number	m^2
Building Height	Number	m
Main Use or Function of the building	Text	

B) Data Sources

The Table 6 shows the data sources provided by the Electronic Office of Cadastre of Spain and used for the generation of the necessary information to carry out the energy analysis of the selected district.

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Table 6: List of data sources for data processing at city scale in Palencia

Name	Source	Type	Data
Buildings split in different parts with different height	A.ES.SDGC.BU.34900.buildingpart.gml	Polygons	See table below (Table 7)
Selected neighborhoods for the case study	Zonas.shp	Polygons	Id
Digital Surface Model	PNOA_2010_Lote5_CYL-RIO_372-4650_ORT-CLA-COL.asc PNOA_2010_Lote5_CYL-RIO_372-4652_ORT-CLA-COL.asc PNOA_2010_Lote5_CYL-RIO_372-4654_ORT-CLA-COL.asc PNOA_2010_Lote5_CYL-RIO_374-4650_ORT-CLA-COL.asc PNOA_2010_Lote5_CYL-RIO_374-4652_ORT-CLA-COL.asc PNOA_2010_Lote5_CYL-RIO_374-4654_ORT-CLA-COL.asc	LIDAR	--
Digital Terrain Model	PNOA_MDT05_ETRS89_HU30_0273_LID.asc PNOA_MDT05_ETRS89_HU30_0274_LID.asc PNOA_MDT05_ETRS89_HU30_0311_LID.asc PNOA_MDT05_ETRS89_HU30_0312_LID.asc	LIDAR	--

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Table 7: Detail of data contained in A.ES.SDGC.BU.34900.buildingpart.gml (Highlighted the used data)

Code	Name
gml_id	
beginLifespanVersion	Date since it has been included in the cadastral database
localId	They are the first 14 characters of the cadastral reference
namespace	This value for cadastral parcel is: ES.SDGC.CP which corresponds with the initials of the country, agency producer and data set.
horizontalGeometryEstimatedAccuracy	Accuracy in meters. It has the value 0.1
horizontalGeometryReference	It indicates that the geometry of the building is the footprint of the buildings above ground. It has the value footprint
numberOfFloorsAboveGround	Number of floors. This figure cannot be given for the entire building, it is a value that is reflected in BuildinPart.
heightBelowGround	Below ground level height in meters. It is an estimated value calculated assuming that each floor is 3 meters height
numberOfFloorsBelowGround	Number of floors below ground

C) Data Pre-processing

The main tasks carried out to obtain the required information for the energy demand analysis of the selected district of the city are briefly described below:

- **Data reprojection:** Reprojection of the source layers to the EPSG reference system use in the process (25830).
- **Geometry validation:** Some geo-processes require that the geometries of the input layers meet certain requirements that must be previously validated.
- **Remove courtyards and other not-built areas**: In this step the buildings parts that have numberOfFloorsAboveGround parameter greater than zero have been selected. In this way, the buildings parts that not have height are removed.

  The Figure 6 shows the complete building part layer (in yellow) and the building part layer after removing the numberOfFloorsAboveGround with zero value (in grey).

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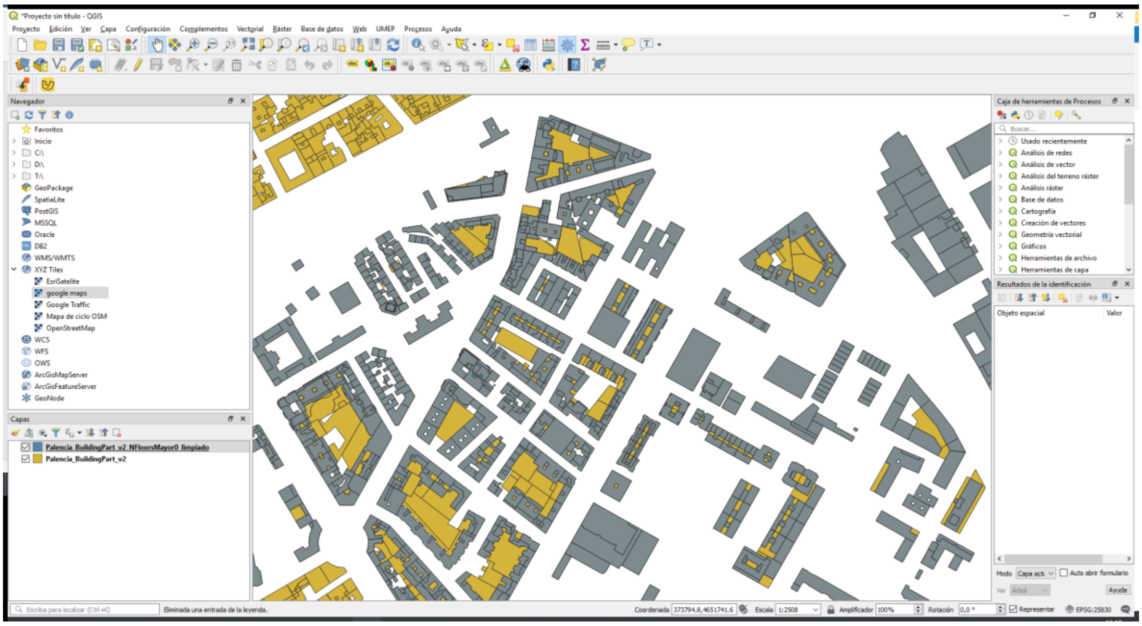

Figure 6 Remove building parts with number of floors 0

- **Limit the extension of the layer to the selected district:** The extension of the analysis focuses on the neighbourhoods 7 and 8, however, the extension of the data of the input layers extends the whole municipality of Palencia.
- **Join all the building parts in a unique building**: The geo-process called dissolve is performed to join the different buildings parts in a unique polygon. Dissolve is an application of the conceptual operators that aggregates features often referred to as 'Merge' or 'Amalgamation.' It is a process in which a new map feature is created by merging adjacent polygons, lines, or regions that have a common value for a specified attribute. In order to do that, the localId parameter (which is the cadastral reference) is used to join the different building parts.

  The Figure 7 shows the building parts layer (on the left) and the building after performing the dissolve geo-process and obtaining a unique geometry for a cadastral reference (on the right).

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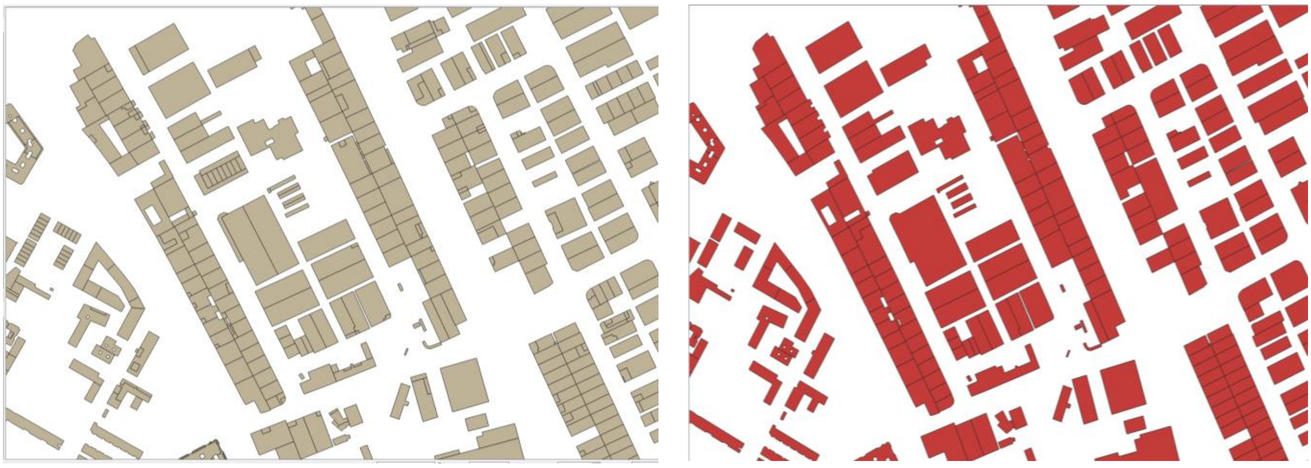

Figure 7 Join all the building parts in a unique building

- **Complete the building layer with information from other data sources at parcel level:** The exercise consists mainly of joining all the relevant information in a single layer. The joint is made on the layer of polygons so that this information can be later assigned to all the buildings contained within the same parcel. The following information has been collected from the parcel layer (Table 8):

Table 8: Layers of information at parcel level

Name	Source	Data
Data at parcel level	A.ES.SDGC.BU.34900.building.gml	ID Parcel (reference) **YearOfConstruction (beginning)** **Use (currentUse)**

To apply this information to the buildings, as first step the centroids of the buildings are calculated. Next, the information contained on these centroids is applied to the parcel layer geometries, at least to those buildings whose centroid falls within the parcel. Finally, the information of the attributes of the centroids layer that are relevant for processing is added to the layer that contains the geometry of the buildings.

- **Building height calculation**: In order to calculate the building height value, digital surface models (DSM) and digital terrain models (DTM) have been used. First, a virtual raster is created joining all the DSM files and another virtual raster is created with DTM files. Then, using the raster calculator a new raster is calculated subtracting DSM with DTM (Figure 8). In that way, for each point the real height is obtained. In the next step those points need to be assigned to building geometries. To do

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that, zonal statistics geo-process is used. This process calculates the average value of all the points that are within each geometry (which are buildings). So, in that way, the height of each building is calculated.

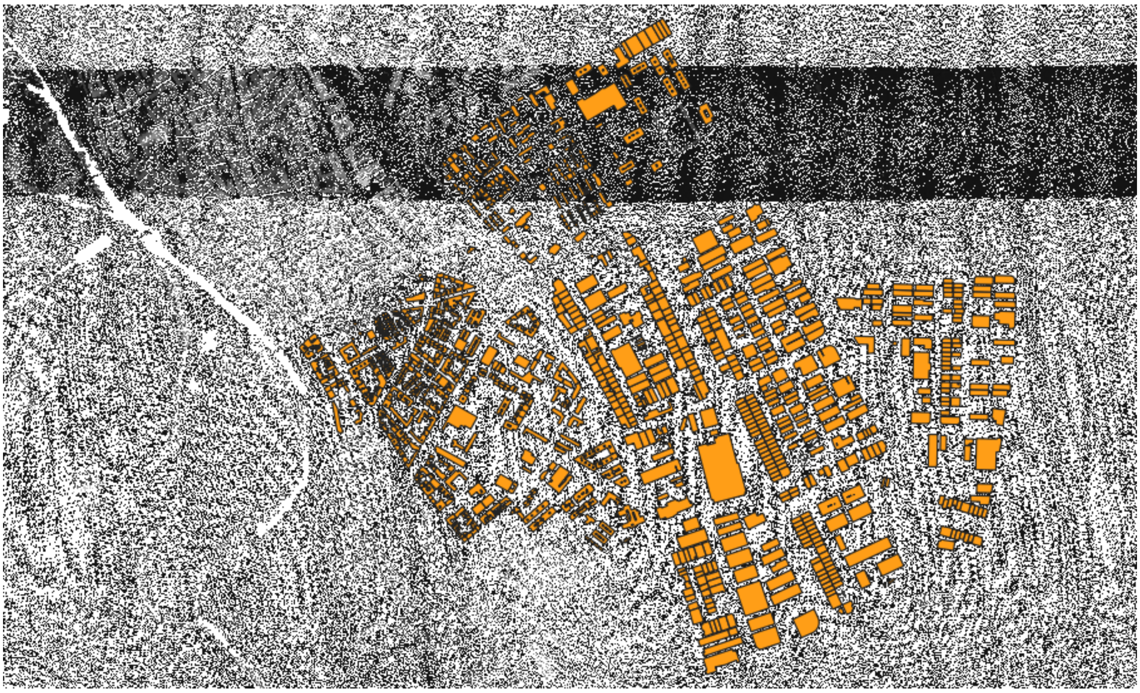

Figure 8 Building height calculation

- **Verification of the information:** The verification of the results carried out consists mainly on the identification of missing values, completing these values with data obtained from other sources or estimation, identification of discrepancies and identification of atypical values.

The result of the pre-processing produces an information layer (Palencia_BuildingPart_v2_NFloorsMayor0_limpiado_Disuelto_Semantizado_ZonaInteres_25830_Altura.shp) (Figure 9) with 1028 buildings with the following attributes:

- localAcort: Unique identifier for each building
- currentUse: Main function of the building
- area: Building footprint area
- yoc: Year of construction of the building
- altura: Height of the building

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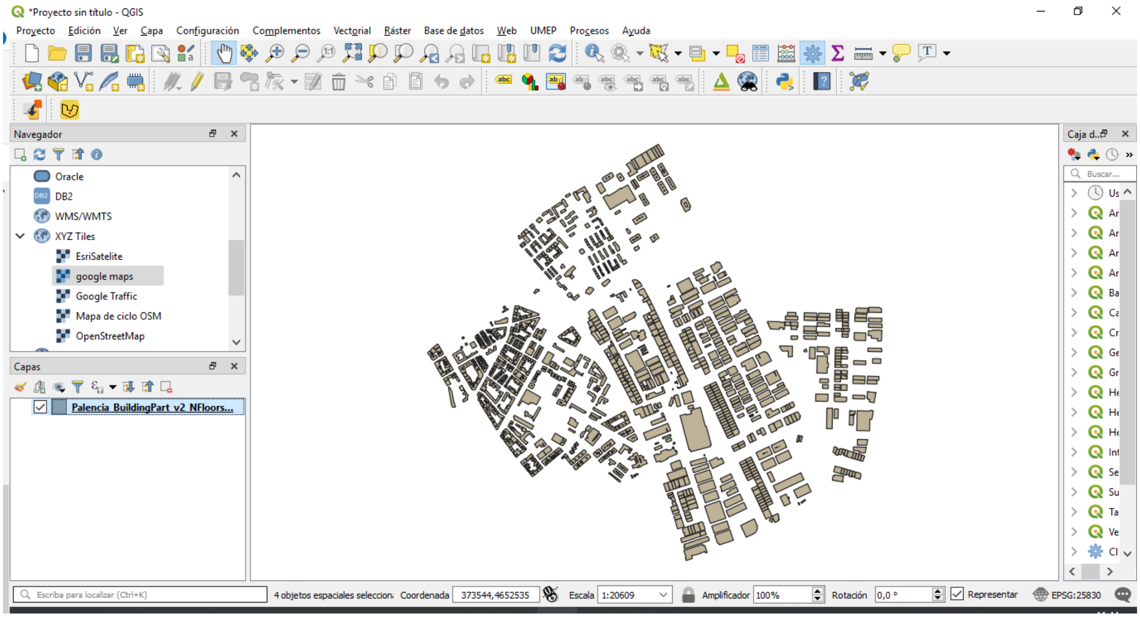

Figure 9 Palencia at district scale after pre-process

D) Data Processing

In this step, the geometric processing of the data resulting from the pre-processing of the district data has been carried out to obtain the necessary information for the analysis of energy demand. This processing is done automatically from the SHP resulting from the pre-processing. The result combines information contained in the SHP of the pre-processed, new calculated data and estimated data from the contents of the original SHP.

The main geometric processes that are carried out in this phase are for the calculation of the surfaces of the building envelope. Additionally, simple calculations are made to estimate other geometric parameters of the buildings, such as: number of floors, building volume or roof area. To calculate the surfaces of the envelope, it is necessary to previously identify which of the building's surfaces are facades and which are adjoining walls, in order to obtain precisely the area of the facades. Subsequently, the area of each façade is calculated from the footprint geometry and the height of the building. Finally, it is necessary to add the surface of all facades at the building level. It is also possible to identify in this process the orientation of the enveloping surfaces of the building, both for the facades and for the adjoining walls.

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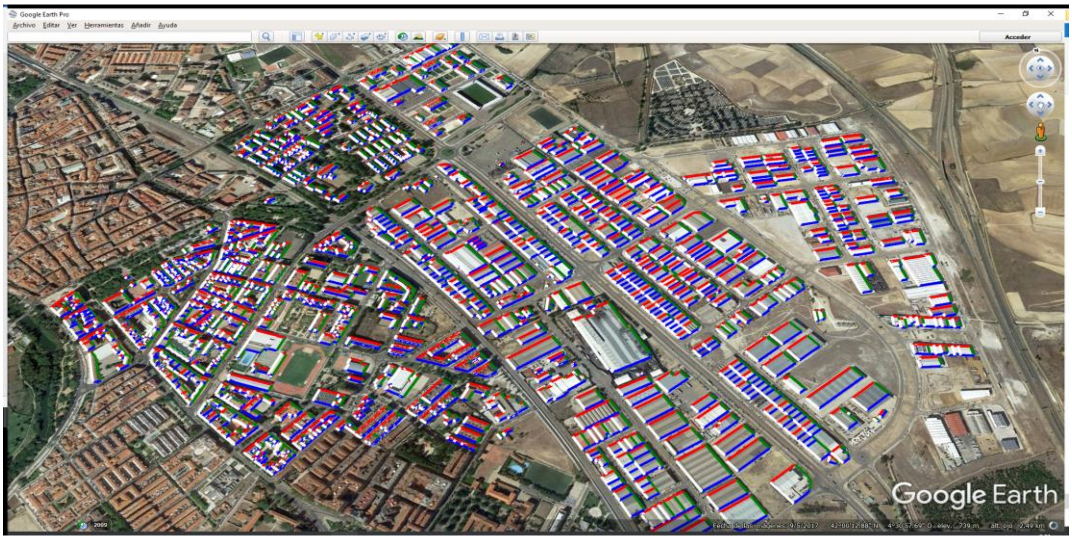

Figure 10 Main orientation of building façades in Palencia study area (Red=North, Blue=South, White=West, Green=East)

Figure 11 Building façades (in Blue) and adjoining walls (in Red) in Palencia study area

The set of parameters resulting from the geometric processing is detailed in section 4.2.1.4 in Table 10

4.2.1.3 Data processing and CityGML generation at city scale

A) General Configuration

Palencia has a population of 78 892 inhabitants (INE 2017) with an extension of an area of 94.71 km². Palencia is divided in 12 neighbourhoods (Figure 12). The reference system used in the processing at city scale is: EPSG:25830. ETRS89 / UTM zone 30N

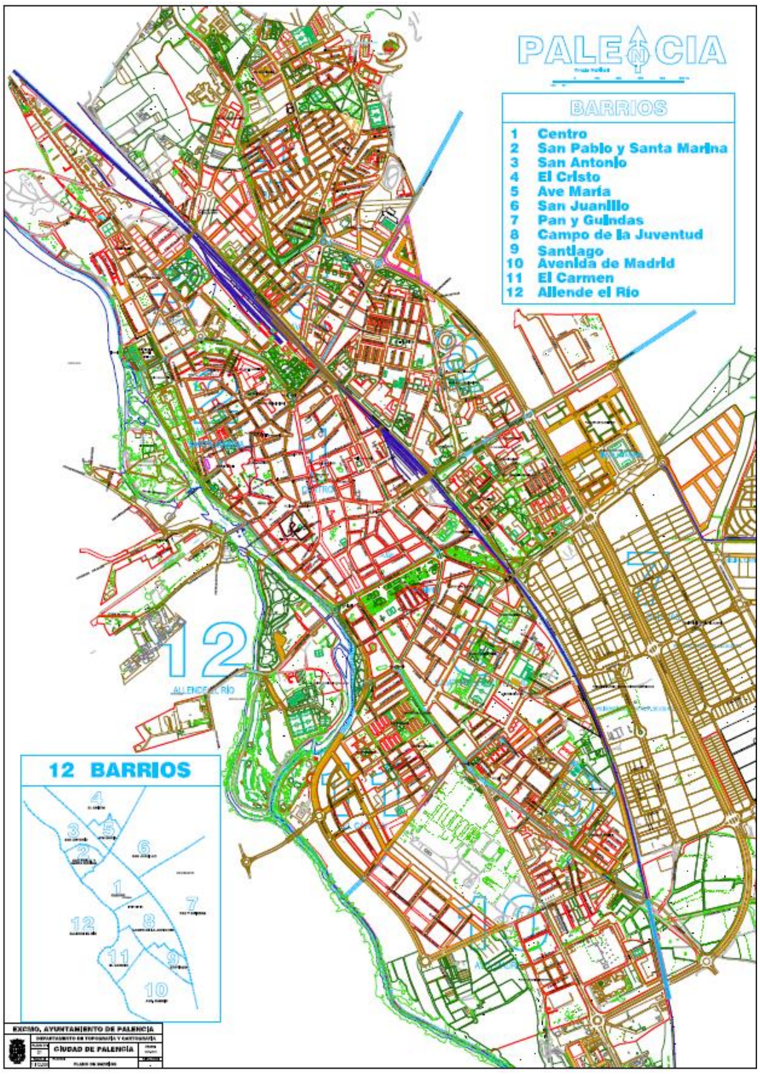

Figure 12 Palencia city scale

B) Data Sources

Data sources used for the generation of the processing and the generation of the 3D city model of the city of Palencia are the same used for the data processing at district scale (section **¡Error! No se encuentra el origen de la referencia.**).

C) Data Pre-processing

The main tasks carried out in order to obtain the required information for the energy demand analysis of the city of Palencia are very similar to the ones performed for the data processing at district level (section **¡Error! No se encuentra el origen de la referencia.**). Main differences are briefly described below:

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- **Limit the extension of layers to the 12 neighbourhoods of Palencia**: The extension of the analysis focuses on Palencia and the extension of the data of the input layers include the rest of the neighbourhoods.
- **Eliminate irrelevant information and simplify layers**: Some of the information contained in the information sources are not relevant for the object of analysis. The scale of the analysis and the excess of information generates huge files that are difficult to manage. This task is more relevant at the city level due to the size of the managed files.
- **Remove not relevant buildings**: After having a look to the geometries in Palencia, a significant number of geometries represent building parts or elements which are not relevant for the posterior analysis. So, all the geometries smaller than 30m^2 have been removed in order to reduce the number of buildings.
- **Verification of the information:** The verification of the results carried out consists mainly on the identification of missing values, which have been completed automatically, completing the missing values based on the value of the nearest building, identification of discrepancies and identification of atypical values.

The result of the pre-processing produces an information layer with 6.897 buildings (Figure 13) with the following attributes:

  - ID: Unique identifier for each building
  - Height: Average height of the building
  - YoC: Year of construction of the building
  - Area: Building footprint area
  - Use: Main function of the building.

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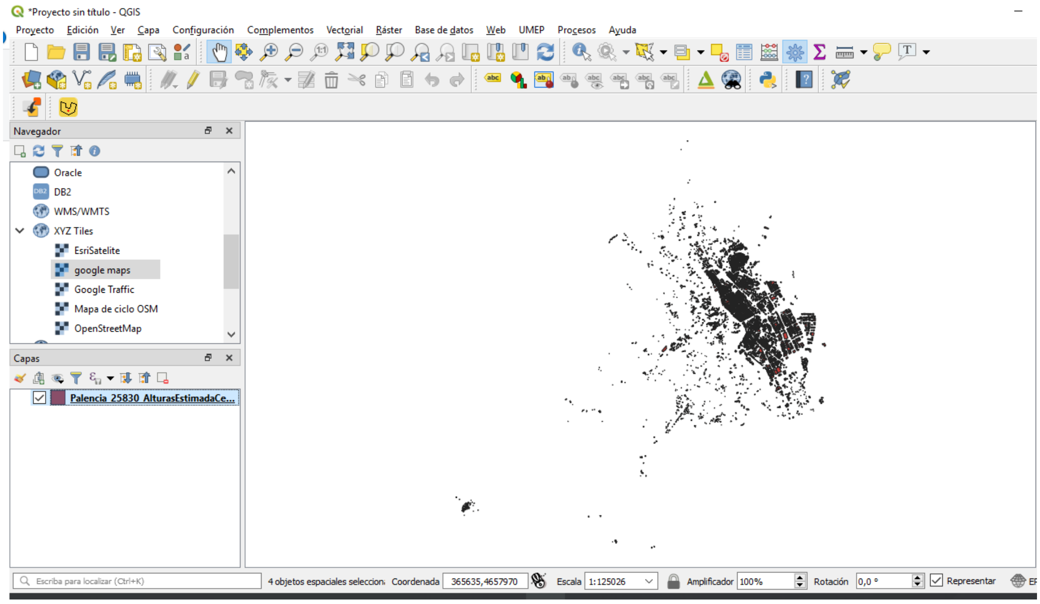

Figure 13 Palencia at city scale after pre-process

D) CityGML Generation

The process of generation of the CityGML model of the city of Palencia takes as input the data resulting from the pre-processing carried out at the city scale and previously described. The data sources used are the following ones (see Table 9):

Table 9: Data sources for CityGML generation

Name	Source	**Description**
Data source with geometry for LoD1	LoD1.shp	It contains geometric information of the buildings (6.897)
Data source with geometry for LoD2	LoD2.shp	It contains geometric information of the buildings (6.897)
Sections in which the model is divided	Agrupaciones.shp	Polygons of $1km^2$ in which the city model is divided (63 groups)
Terrain Height for LoD1	MDTLoD1.xlsx	Contains terrain height data for parcels
Terrain Height for LoD2	MDTLoD2.xlsx	Contains terrain height data for buildings
Surface Height for LoD1	LIDARLoD1.xlsx	Contains the surface height data for the parcels
Surface Height for LoD2	LIDARLoD2.xlsx	Contains the surface height data for the buildings

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The following figure shows an overview of the data source layers, building scale and the 63 groups in which the model is divided (Figure 14).

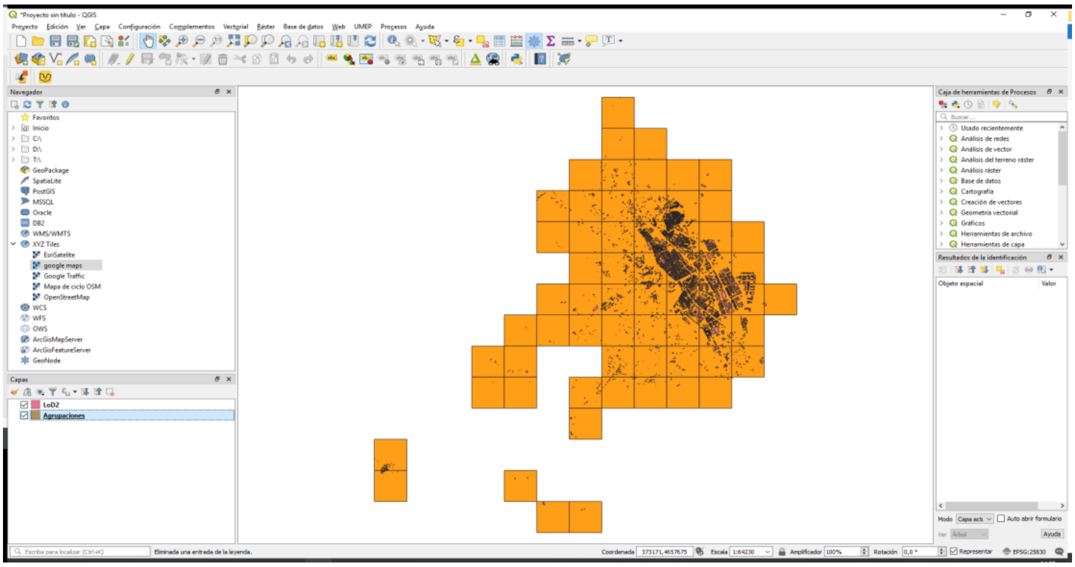

Figure 14 SHP layers with input data for the generation of the CityGML

The generation of the CityGML model is divided into two stages:

- **Geometric generation**: The geometry of the model elements is generated with two different levels of detail (LoD1 and LoD2).
- **Semantization of the model**: The geometric model is completed with the available semantic information (attributes).

The results of the generation process of the CityGML model of the city of Palencia are presented below. First, buildings with level of detail LoD1 for one of the 63 parts of the model. Next, the same piece but with the buildings in LoD2 and finally, the information of the properties associated to each building that represent the semantic information.

The FZKViewer tool is used to visualize the generated models (Figure 15 Figure 16 Figure 17).

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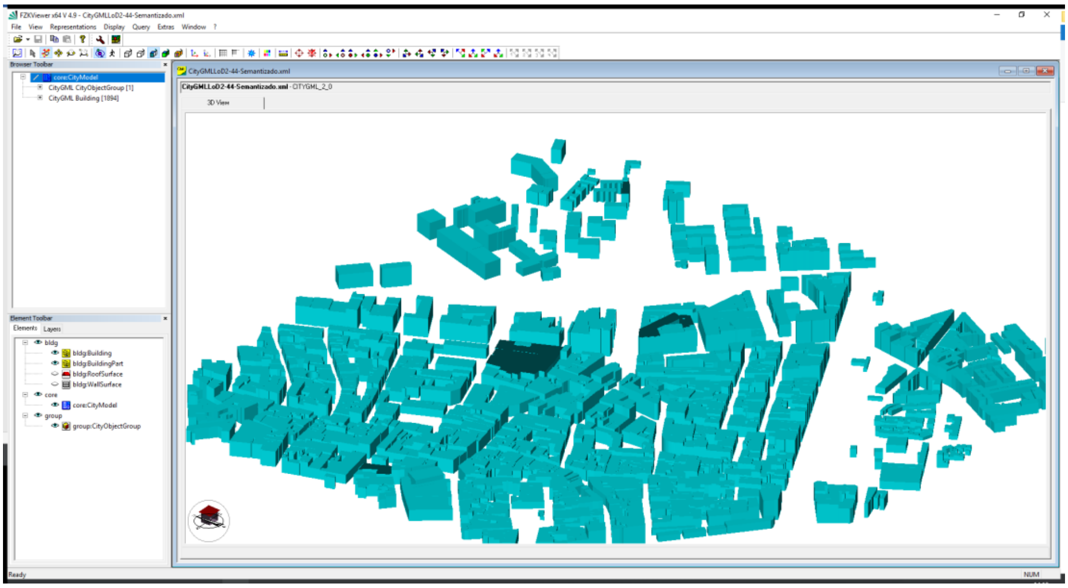

Figure 15 SHP Buildings in LoD1 for one of the areas of the city of Palencia

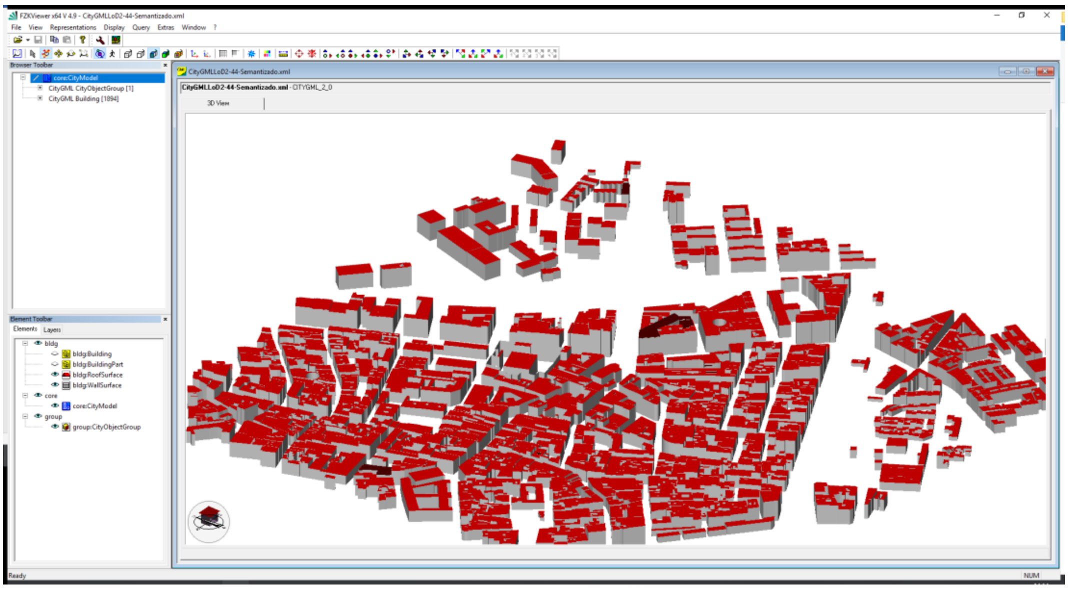

Figure 16 SHP Buildings in LoD2 for one of the areas of the city of Palencia

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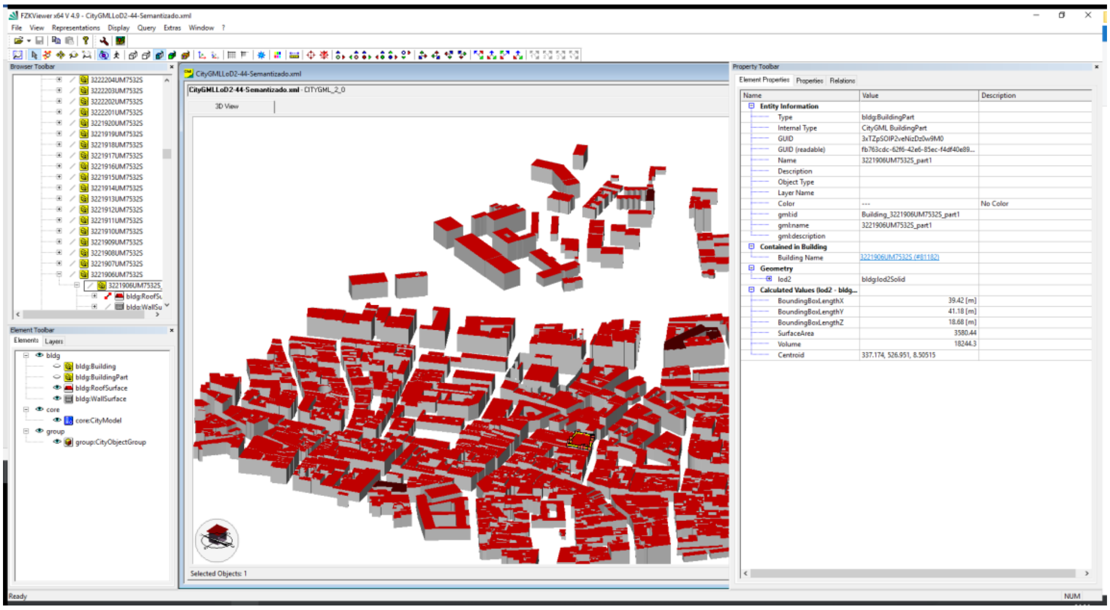

Figure 17 Semantic properties included in the CityGML model of the city of Palencia

4.2.1.4 Description of the results

In the case of Palencia, two different results have been generated. First, for the district scale, a shape file of the district with the information required for the analysis of energy demand is obtained as a result of the modelling process. On the other hand, for the city scale (12 neighbourhoods of Palencia) the shape file with the information for energy modelling and also a CityGML model in LoD1 and LoD2 of the city have been obtained.

A) Results at district level

As a result of the modelling of the Palencia study area, the necessary information for the energy analysis is obtained. The detail of the information resulting from the process is presented in the Table 10. The information is available in different formats: Excel, SHP and KML.

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Table 10: Set of parameters contained in the files resulting from the process in Palencia

Parameter	Format	Description
Reference	Unique Id	Building Unique Identifier
Centroid	UTM Coordinates	Geolocation of the building
TotalHeight	Number	Height of the building
NumberOfFloors	Number	Number of Floors
BuildingArea	Number (m^2)	Area of the building footprint
GrossFloorArea	Number (m^2)	Total area of the building
RoofArea	Number (m^2)	Area of the roof of the building
TotalEnvelopeArea	Number (m^2)	Total envelope area, including façade and adjoining walls
ExteriorEnvelopeArea	Number (m^2)	Area of the building façade
AdjoiningEnvelopeArea	Number (m^2)	Area of the adjoining walls
NorthExteriorEnvelopeArea	Number (m^2)	Area of façade whose main orientation is North
SouthExteriorEnvelopeArea	Number (m^2)	Area of façade whose main orientation is South
WestExteriorEnvelopeArea	Number (m^2)	Area of façade whose main orientation is West
EastExteriorEnvelopeArea	Number (m^2)	Area of façade whose main orientation is East
YearOfConstruction	Number (Year)	Year of construction of the building
Use	Text	Main use of the building
Volume	Number (m^3)	Volume of the building
DistrictCentroid	UTM Coordinates	Approximated geolocation of the centre of the study area

Below it is showed a screenshot of the resulting KML file (see Figure 18). The file is displayed on Google Earth. In addition, the information associated with the selected building is included

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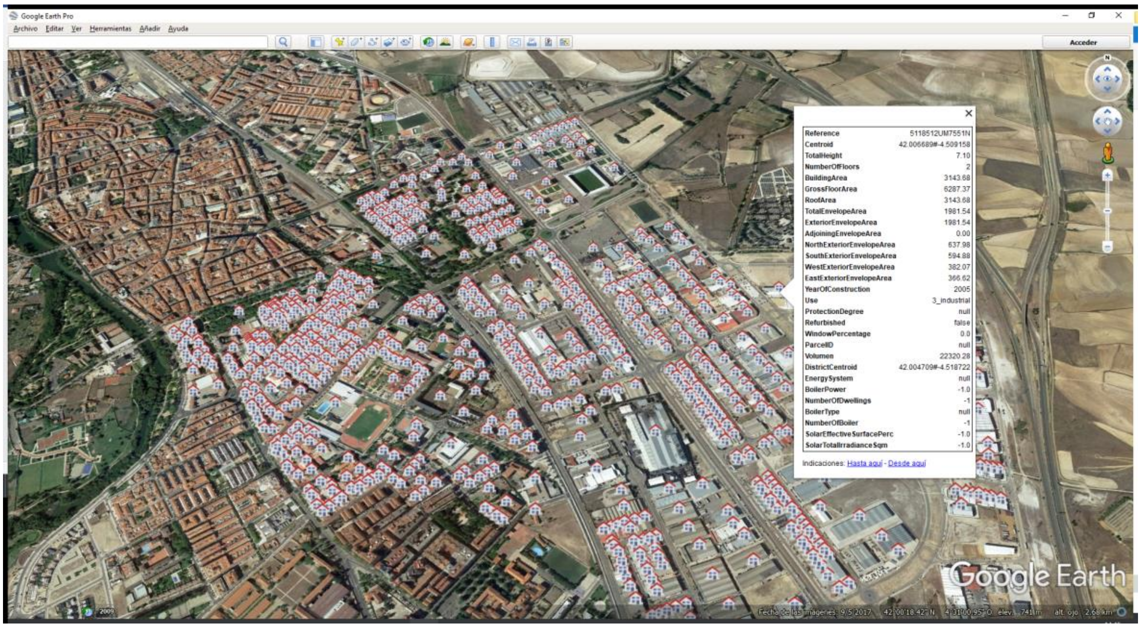

Figure 18 Results at district level in Palencia (KML format)

B) Results at city level

The results at city level contains the same information than in the study area. Due to the size of the files KML is not generated. Only Excel and SHP files are generated at the city scale.

Additionally, for the study case of Palencia, the CityGML model of the city has been generated. The results of the generation process are 63 CityGML files corresponding to each of the sections into which the model has been divided. Finally, the 63 sections of the model have been grouped into a single file. The size of this file is 154MB, which contains the following CityGML objects.

- BUILDING: 6.897
- BUILDING_PART: 6.897
- CITY_OBJECT_GROUP: 63

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4.2.2 Rijeka area of study

This subsection describes the main process followed for the treatment of the data for the case of Rijeka. It includes a description of the situation of the city with regard to the information available, a description of the data processing at district scale, the data processing and CityGML generation at city scale and a description of the results obtained in this phase.

4.2.2.1 Description of the situation of the city

The city of Rijeka has not a 3D city model in CityGML. So, it has been created within mySMARTLife project.

Cartographic information in SHP format has been also provided at the level of the retrofitting zone of Rijeka. The information available is detailed in the following section (section 4.2.2.2).

The analysis of the information is carried out in two steps, firstly, a detailed analysis at the district level and then, the analysis at the municipal level and the generation of the CityGML model.

4.2.2.2 Data processing at district scale

A) General Configuration

For the district scale analysis, the zone near the port of Rijeka has been selected (see Figure 19).

Figure 19 Selected district in Rijeka

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First, the necessary information to carry out the development of the energy analysis has been identified. For each of the buildings of the selected district it is necessary to obtain the basic information detailed in the Table 11.

Table 11: Basic Information required for each building in Rijeka Case Study

Name	Type	Values / Units
Building Unique Identifier	Unique Id	
Geometry of the building footprints	Shp file	
Building footprint area	Number	m^2
Building Height	Number	m
Main Use or Function of the building	Text	

B) Data Sources

The Table 12 shows the data sources provided by the municipality of Rijeka and used for the generation of the necessary information to carry out the energy analysis of the selected district.

Table 12: List of data sources for data processing at city scale in Rijeka

Name	Source	Type	Data
Buildings at district scale	VISINA_ZGRADA.shp	Polygons	See table below (Table 13)
Address information	ULAZI.shp	Points	See table below (Table 14)

Table 13: Detail of data contained in VISINA_ZGRADA.shp (Highlighted the used data)

Code	Name
OPIS	Description
NAZI	
ID	**Unique identification**
ETAZE_NAPO	
KOSI_KROV	Hip roof
NAPOMENA	Note
KOTA_OKOLI	Ground height
KOTA_SLJEM	Top height

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VISINA_SLJ	**Building height**
GODINA_GRA	Number of floors
POTKROVLJE	Is it a loft?

Table 14: Detail of data contained in ULAZI.shp (Highlighted the used data)

Code	Name
ID	address id
VRSTA	**Type - S=residential, P=business, SN=mixed**
NASELJE	settlement name
ULICA	street name
KATOP	cadastral municipality
KATCEST	cadastral particle
SIFRA_NASELJA	setlement code
SIFRA_ULICE	street code
ID_ADRESA	address id
ID_ZGRADE	building id
KBR	house number
KBR_DOD	house number suffix
COORDGEOCODEPOINT	Coordinates
ID_ULICE	street id
SIFRA_GRADA_OPCINE	city code
GRADOPCINA	city name
PRIJAVITELJ	Applicant
DATUM_PRIJAVE	application date
CREATED_BY	
CREATION_DATE	
LAST_UPDATED_BY	
LAST_UPDATE_DATE	
SIFRA_MO	city district code
NAPOMENA	remark

C) Data Pre-processing

The main tasks carried out in order to obtain the required information for the energy demand analysis of the selected district of the city are briefly described below:

- **Data reprojection:** Reprojection of the source layers to the EPSG reference system use in the process (3765).
- **Geometry validation:** Some geo-processes require that the geometries of the input layers meet certain requirements that must be previously validated.
- **Limit the extension of layers to the selected district:** The extension of the analysis focuses on the zone near the port of Rijeka however, the extension of the data of the input layers extends the whole municipality of Rijeka.
- **Eliminate irrelevant information and simplify layers**: Some of the information contained in the information sources are not relevant for the object of analysis. The scale of the analysis and the excess of information generates huge files that are difficult to manage.
- **Assign use of the building**. The use of the buildings is obtained from the layer ULAZI.shp, which is a layer of points. The exercise consists mainly of joining all the relevant information in a single layer. In order to do that, the points that come from ULAZI.shp layer are intersected with buildings polygons, and in case the points are inside the building the information is combined (Figure 20).

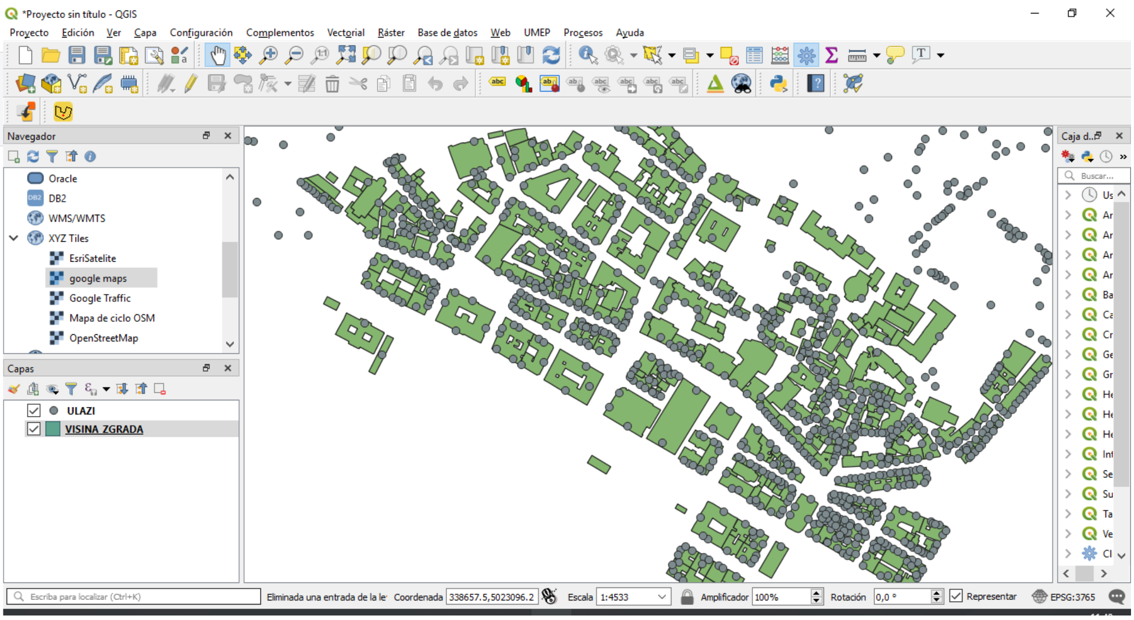

Figure 20 Rijeka use of building at district level

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- **Assignment of values to missing attributes**: The building use information is missing in multiple buildings, so the value has been inferred following the rule:

  If area is higher than 250 m^2 then assign use: Other – Industry | If area is less than 250 m^2 then assign use: Other

- **Verification of the information:** The verification of the results carried out consists mainly on the identification of missing values, identification of discrepancies and identification of atypical values.

The result of the pre-processing produces an information layer (VISINA_ZGRADA_AcortarColumnas_CorregirGeometrias_AtributosLocalizacion_CompletarManual_LimpiarColumnas.shp) (Figure 21) with 376 buildings with the following attributes:

- ID: Unique identifier for each building
- alturaComp: Height of the building
- _UsoPrinci: Main function of the building
- area: Building footprint area.

For the case of Rijeka, the year of construction value is missing.

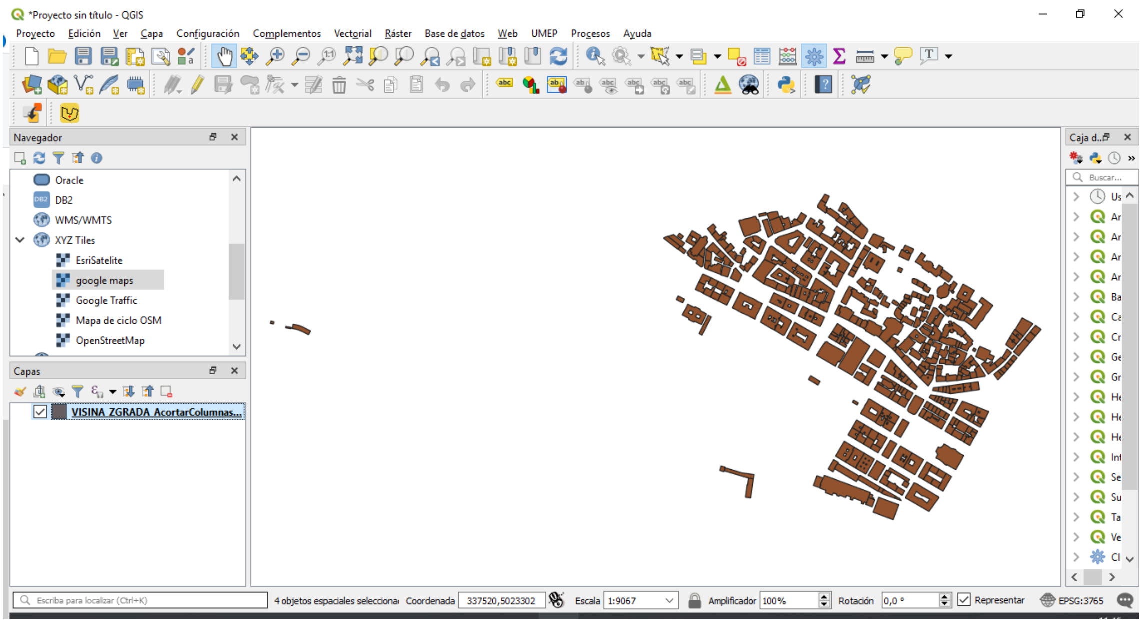

Figure 21 Rijeka at district scale after pre-processing

D) Data Processing

In this step, the geometric processing of the data resulting from the pre-processing of the district data has been carried out in order to obtain the necessary information for the analysis of energy demand. This

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processing is done automatically from the SHP resulting from the pre-processing. The result combines information contained in the SHP of the pre-processed, new calculated data and estimated data from the contents of the original SHP.

The main geometric processes that are carried out in this phase are for the calculation of the surfaces of the building envelope. Additionally, simple calculations are made to estimate other geometric parameters of the buildings, such as: number of floors, building volume or roof area. To calculate the surfaces of the envelope, it is necessary to previously identify which of the building's surfaces are facades and which are adjoining walls in order to obtain precisely the area of the facades. Subsequently, the area of each façade is calculated from the footprint geometry and the height of the building. Finally, it is necessary to add the surface of all facades at the building level. It is also possible to identify in this process the orientation of the enveloping surfaces of the building, both for the facades and for the adjoining walls.

Figure 22 Main orientation of building façades in Rijeka study area (Red=North, Blue=South, White=West, Green=East)

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Figure 23 Building façades (in Blue) and adjoining walls (in Red) in Rijeka study area

The set of parameters resulting from the geometric processing is detailed in section 4.2.2.4 in Table 17

4.2.2.3 Data processing and CityGML generation at city scale

A) General Configuration

Rijeka has a population of 128.624 inhabitants (in 2011) with an extension of an area of 44 km² (Figure 24).

The reference system used in the processing at city scale is: EPSG:3765.

Figure 24 Rijeka overview

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B) Data Sources

The Table 15 shows the data sources provided by the municipality of Rijeka and used for the generation of the necessary information to carry out the energy analysis of the city.

Table 15: List of data sources for data processing at city scale in Rijeka

Name	Source	Type	Data
Buildings at city scale	ZGRADE.shp	Polygons	Id
Buildings in 3D at city scale	grad_objekti.dwg	3D polygons	--
Address information	ULAZI.shp		See Table 14

E) Data Pre-processing

The main tasks carried out in order to obtain the required information for the energy demand analysis of the city of Rijeka are very similar to the ones performed for the data processing at district level (see section 4.2.2.2). Main differences are briefly described below:

- **Buildings height calculation:** In the case of Rijeka, there is not building height value information, and neither is LIDAR data available, such as DSM or DTM. However, they have an AutoCAD 3D file at city scale, which is grad_objekti.dwg (Figure 25). So, this time an inverse process has been performed in order to get the building height. First a geo-process that calculates the bounding box values (min and max values for X, Y, Z) for each building has been performed. Subtracting Z max and Z min values the building height is obtained.

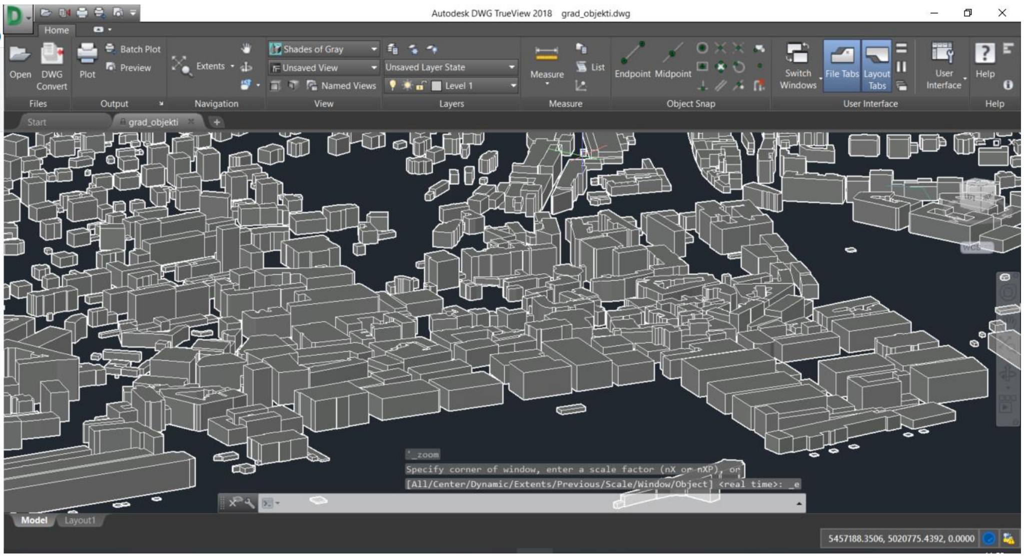

Figure 25 Rijeka AutoCAD 3D DWG

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The result of the pre-processing produces an information layer (ZGRADE_GeometriasCorregidas_Interseccion_EstadisticasZona_EliminarSinGeometria_AreaMayor30_ConUso_Compl.shp) (Figure 26) with 21.901 buildings with the following attributes:

- ID: Unique identifier for each building
- alturaComp: Height of the building
- _UsoPrinci: Main function of the building
- area: Building footprint area.

For the case of Rijeka, the year of construction value is missing.

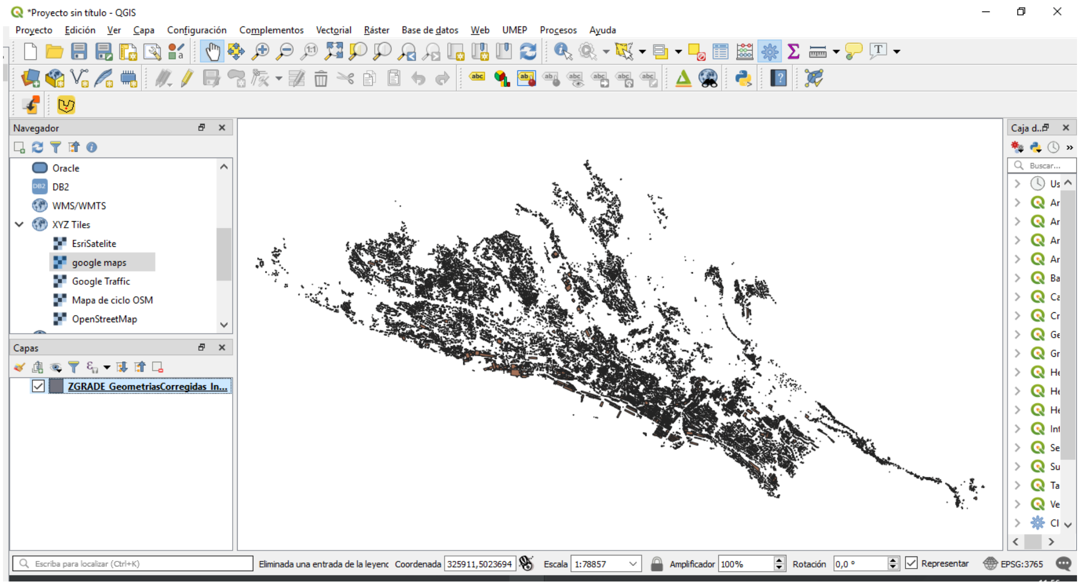

Figure 26 Rijeka at city scale after pre-processing

C) CityGML Generation

The process of generation of the CityGML model of the city of Rijeka takes as input the data resulting from the pre-processing carried out at the city scale and previously described. The data sources used are the following ones (see Table 16):

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Table 16: Data sources for CityGML generation

Name	Source	Description
Data source with geometry for LoD1	LoD1.shp	It contains geometric information of the buildings (21.901 records)
Data source with geometry for LoD2	LoD2.shp	It contains geometric information of the buildings (21.901 records)
Sections in which the model is divided	Agrupaciones.shp	Polygons of $1km^2$ in which the city model is divided (66 groups)
Terrain Height for LoD1	MDTLoD1.xlsx	Contains terrain height data for parcels
Terrain Height for LoD2	MDTLoD2.xlsx	Contains terrain height data for buildings
Surface Height for LoD1	LIDARLoD1.xlsx	Contains the surface height data for the parcels
Surface Height for LoD2	LIDARLoD2.xlsx	Contains the surface height data for the buildings

The following figure shows an overview of the data source layers, building scale and the 66 groups in which the model is divided (Figure 27).

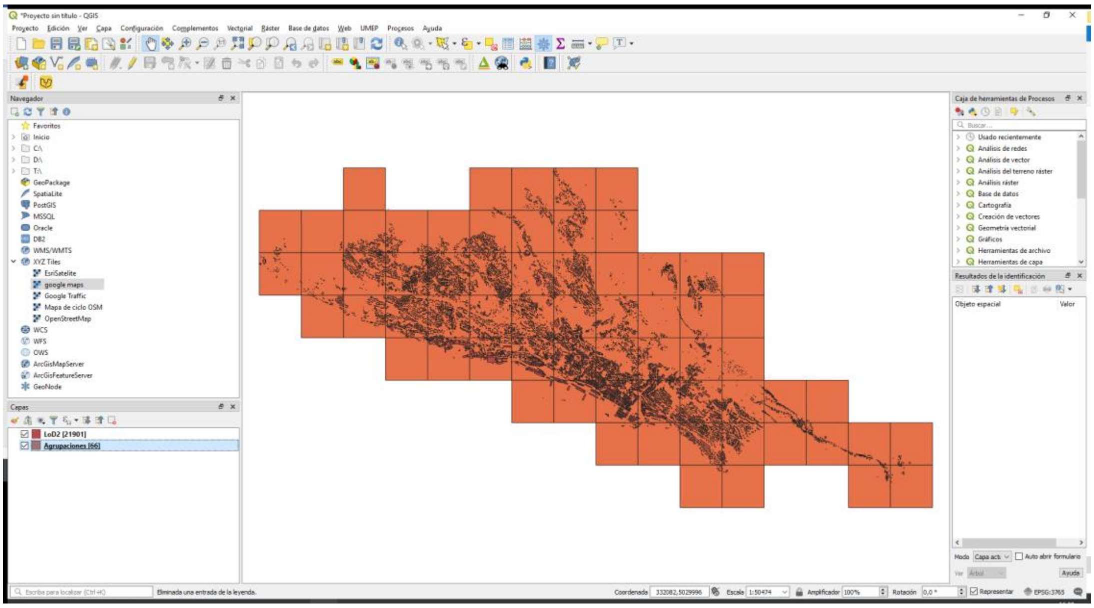

Figure 27 SHP layers with input data for the generation of the CityGML

The generation of the CityGML model is divided into two stages:

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- Geometric generation: The geometry of the model elements is generated with two different levels of detail (LoD1 and LoD2).
- Semantization of the model: The geometric model is completed with the available semantic information (attributes).

The results of the generation process of the CityGML model of the city of Rijeka are presented below. First, buildings with level of detail LoD1 for one of the 66 parts of the model. Next, the same piece but with the buildings in LoD2 and finally, the information of the properties associated to each building that represent the semantic information.

The FZKViewer tool is used to visualize the generated models (Figure 28 Figure 29 Figure 30).

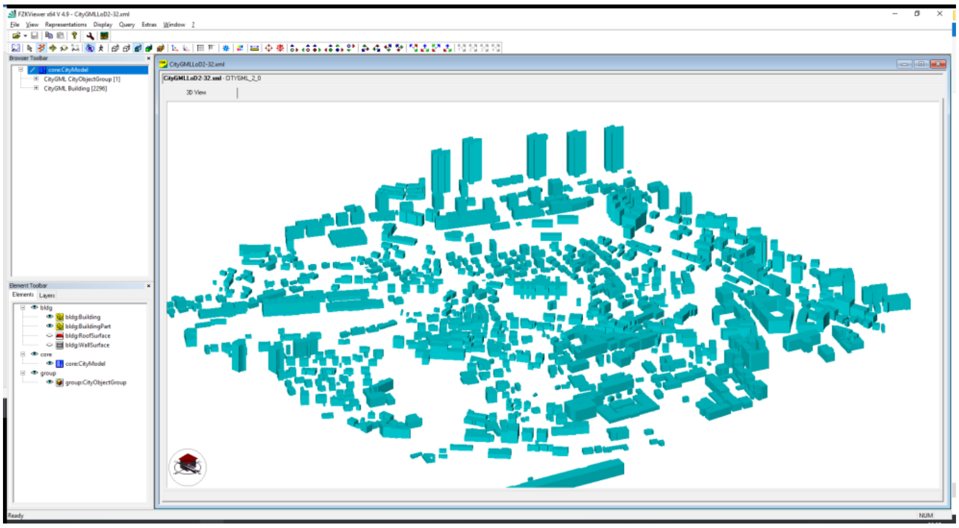

Figure 28 SHP Buildings in LoD1 for one of the areas of the city of Rijeka

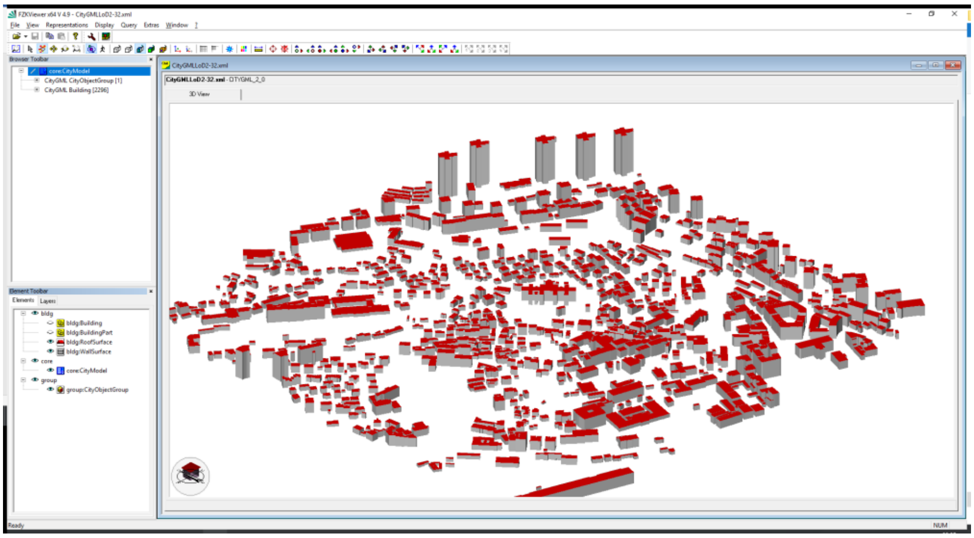

Figure 29 SHP Buildings in LoD2 for one of the areas of the city of Rijeka

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

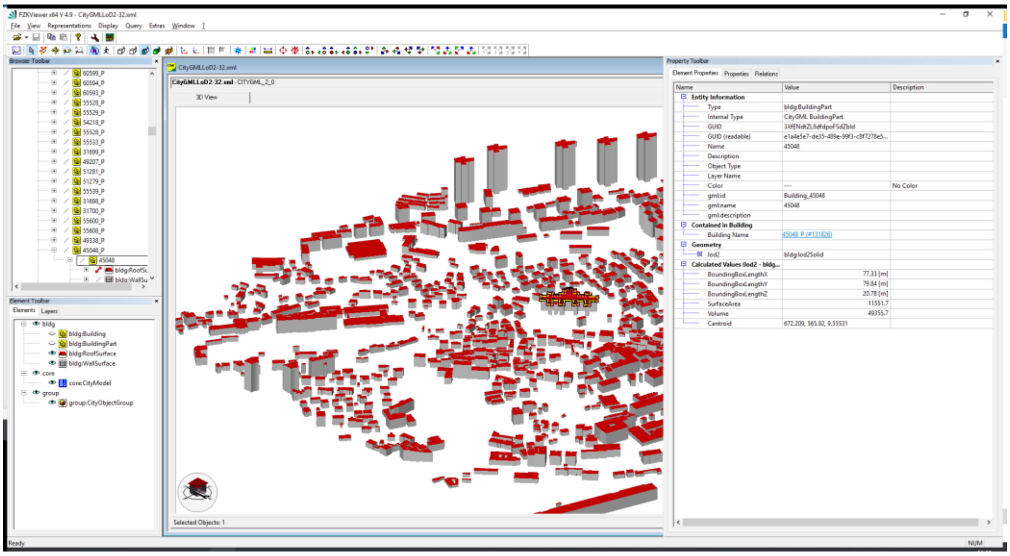

Figure 30 Semantic properties included in the CityGML model of the city of Rijeka

4.2.2.4 Description of the results

In the case of Rijeka, two different results have been generated. First, for the district scale, a shape file of the district with the information required for the analysis of energy demand is obtained as a result of the modelling process. On the other hand, for the city scale the shape file with the information for energy modelling and also a CityGML model in LoD1 and LoD2 of the city have been obtained.

A) Results at district level

As a result of the modelling of the Rijeka study area, the necessary information for the energy analysis is obtained. The detail of the information resulting from the process is presented in the following table (Table 10). The information is available in different formats: Excel, SHP and KML.

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Table 17: Set of parameters contained in the files resulting from the process in Rijeka

Parameter	Format	Description
Reference	Unique Id	Building Unique Identifier
Centroid	UTM Coordinates	Geolocation of the building
TotalHeight	Number	Height of the building
NumberOfFloors	Number	Number of Floors
BuildingArea	Number (m^2)	Area of the building footprint
GrossFloorArea	Number (m^2)	Total area of the building
RoofArea	Number (m^2)	Area of the roof of the building
TotalEnvelopeArea	Number (m^2)	Total envelope area, including façade and adjoining walls
ExteriorEnvelopeArea	Number (m^2)	Area of the building façade
AdjoiningEnvelopeArea	Number (m^2)	Area of the adjoining walls
NorthExteriorEnvelopeArea	Number (m^2)	Area of façade whose main orientation is North
SouthExteriorEnvelopeArea	Number (m^2)	Area of façade whose main orientation is South
WestExteriorEnvelopeArea	Number (m^2)	Area of façade whose main orientation is West
EastExteriorEnvelopeArea	Number (m^2)	Area of façade whose main orientation is East
YearOfConstruction	Number (Year)	Year of construction of the building
Use	Text	Main use of the building
Volume	Number (m^3)	Volume of the building
DistrictCentroid	UTM Coordinates	Approximated geolocation of the centre of the study area

Below it is showed a screenshot of the resulting KML file (see Figure 31). The file is displayed on Google Earth. In addition, the information associated with the selected building is included.

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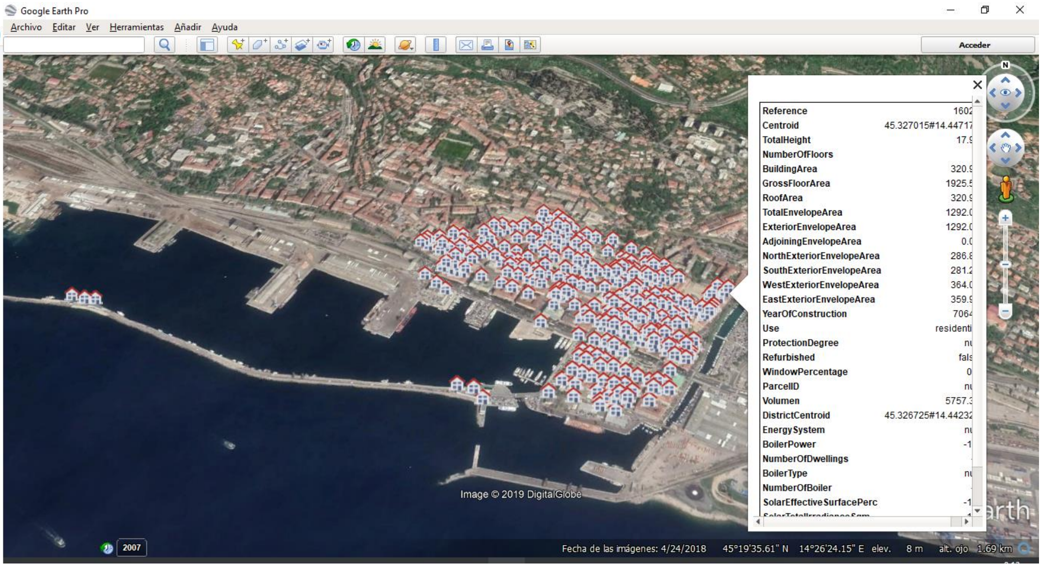

Figure 31 Results at district level in Rijeka (KML format)

B) Results at city level

The results at city level contains the same information than in the study area. Due to the size of the files KML is not generated. Only Excel and SHP files are generated at the city scale.

Additionally, for the study case of Rijeka, the CityGML model of the city has been generated. The results of the generation process are 66 CityGML files corresponding to each of the sections into which the model has been divided. Finally, the 66 sections of the model have been grouped into a single file. The size of this file is 312MB, which contains the following CityGML objects.

- BUILDING: 21.901
- BUILDING_PART: 21.901
- CITY_OBJECT_GROUP: 66

4.2.3 Bydgoszcz area of study

This subsection describes the main process followed for the treatment of the data for the case of Bydgoszcz. It includes a description of the situation of the city with regard to the information available, a description of the data processing at district scale, the data processing and CityGML generation at city scale and a description of the results obtained in this phase.

4.2.3.1 Description of the situation of the city

The city of Bydgoszcz has not a 3D city model in CityGML. So, it has been created within mySMARTLife project.

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Cartographic information in SHP format has been also provided at the level of the study area of Bydgoszcz. The information available is detailed in the following section (section 4.2.3.2).

The analysis of the information is carried out in two steps, firstly, a detailed analysis at the district level and then, the analysis at the municipal level and the generation of the CityGML model.

4.2.3.2 Data processing at district scale

A) General Configuration

For the district scale analysis, the central area of Bydgoszcz has been selected (Figure 32).

Figure 32 Selected district in Bydgoszcz

First, the necessary information to carry out the development of the energy analysis has been identified. For each of the buildings of the selected district it is necessary to obtain the basic information detailed in the Table 18.

Table 18: Basic Information required for each building in Bydgoszcz Case Study

Name	Type	Values / Units
Building Unique Identifier	Unique Id	
Geometry of the building footprints	Shp file	
Building footprint area	Number	m^2
Building Height	Number	m
Main Use or Function of the building	Text	

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B) Data Sources

The Table 19 shows the data sources provided by the Bydgoszcz municipality and used for the generation of the necessary information to carry out the energy analysis of the selected district.

Table 19: List of data sources for data processing at city scale in Bydgoszcz

Name	Source	Type	Data
District scale delimitation	obszar testowy.shp	Polygons	Id
Buildings geometry	MAkus16_Budynek.shp		See table below (Table 20)

Table 20: Detail of data contained in MAkus16_Budynek.shp (Highlighted the used data)

Code	Name
ELEMID	**ID**
RZEDNA_GRU	Terrain elevation
RZEDNA_DAC	Surface elevation
WYSOKOSC	**Height**
FUNKCJA	**Function**
KONDYGNACK	Number of floors
ZRODLO	Source

C) Data Pre-processing

The main tasks carried out in order to obtain the required information for the energy demand analysis of the selected district of the city are briefly described below:

- **Data reprojection:** Reprojection of the source layers to the EPSG reference system use in the process (2177).
- **Geometry validation:** Some geo-processes require that the geometries of the input layers meet certain requirements that must be previously validated.
- **Limit the extension of the layer to the selected district:** The extension of the analysis focuses on 4 neighborhoods called: Nazwa, Blonie, Okole and Jary-Wilczak (Figure 33).

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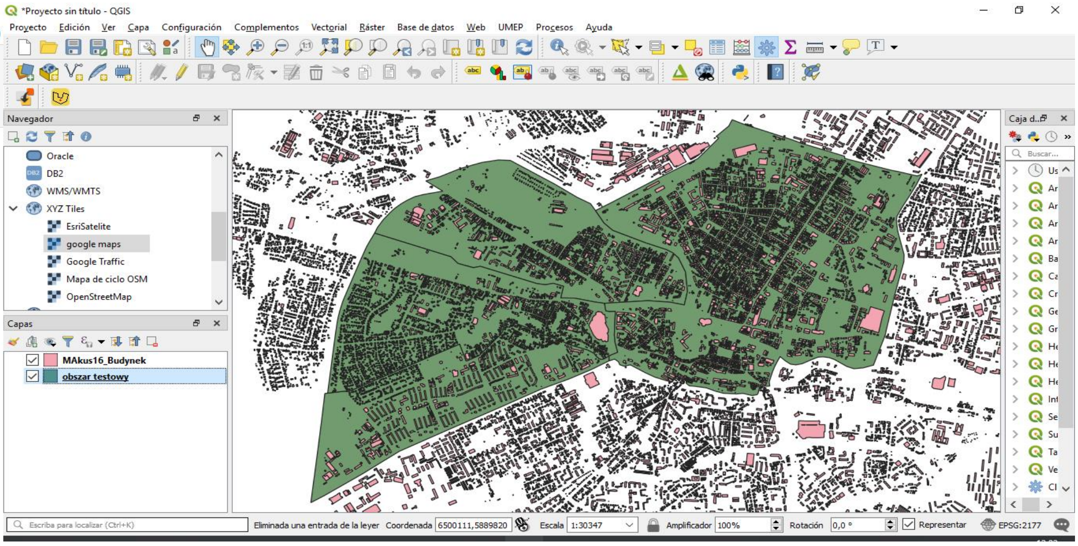

Figure 33 Limit the extension of the layer to the selected district

- **Eliminate irrelevant information and simplify layers**: Some of the information contained in the information sources are not relevant for the object of analysis. The scale of the analysis and the excess of information generates huge files that are difficult to manage.
- **Remove not relevant buildings**: After having a look to the geometries in Bydgoszcz, a significant number of geometries represent building parts or elements which are not relevant for the posterior analysis. So, all the geometries with less than $25m^2$ have been removed in order to reduce the number of buildings in the city.
- **Complete the building layer with information from other data sources:** The information about the year of construction of the buildings is missing in the layer that contains the building geometries. Another layer was provided with information about the year of construction, however the reference identifiers are not connected. The information about the year of construction has been collected from the following layer (Table 21):

Table 21: Layers of information about year of construction

Name	Source	Data
Layer with information about year of construction	BYDGOSZCZ_BUDYNKI1.shp	**YearOfConstruction (ROKBUDOWY)**

To apply this information to the buildings, as first step the centroids of the buildings are calculated. Next, the information contained on these centroids is applied to the building geometries, for those buildings whose centroid falls within the building geometry. Finally, the information of the year of

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construction is added to the layer that contains the geometry of the buildings. For those buildings that do not have year of construction value completed, a default value has been set. The default value is 1955.

- **Building use**: The building use has been translated to English:

  - przemysłowy = industrial
  - inny = other
  - nieznany = unknown
  - transportu = transport
  - mieszkalny = residential
  - gospodarczy = commercial
  - nieokreślony = not defined
  - w ruinie = in ruin
  - biurowy = office
  - zdrowia = health services
  - usługowy = services (commercial)
  - kultury I oświaty = education & culture
  - magazyn = storage
- **Remove duplicated geometries**: After having a look to the geometries in Bydgoszcz duplicated geometries have been identified, so they have been removed.
- **Verification of the information:** The verification of the results carried out consists mainly on the identification of missing values, completing these values with data obtained from other sources or estimation, identification of discrepancies and identification of atypical values.

The result of the preprocessing produces an information layer (MAkus16_Budynek_Validado_ZonaInteres_Validado_InfoAlturas_Limpieza_2_AreaMayor25_YoC1955_usos_CompletadoUsos_SinDuplicados.shp) (Figure 34) with 8.192 buildings with the following attributes:

- ID: Unique identifier for each building
- Altura: Average height of the building
- YoC: Year of construction of the building
- area: Building footprint area
- Use: Main function of the building.

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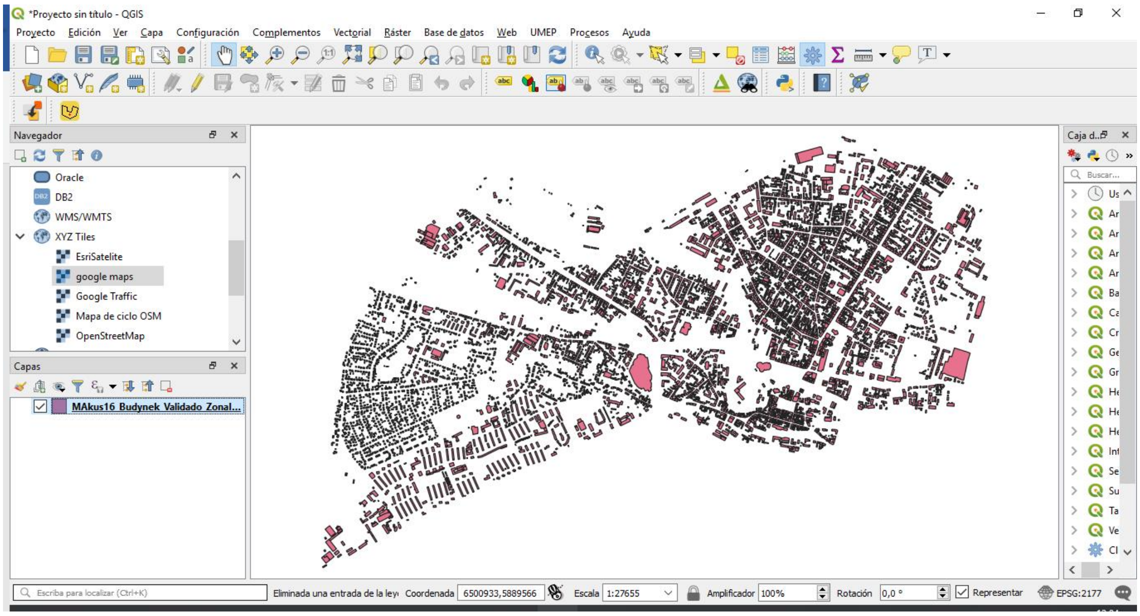

Figure 34 Bydgoszcz at district scale after pre-processing

D) Data Processing

In this step, the geometric processing of the data resulting from the pre-processing of the district data has been carried out in order to obtain the necessary information for the analysis of energy demand. This processing is done automatically from the SHP resulting from the pre-processing. The result combines information contained in the SHP of the pre-processed, new calculated data and estimated data from the contents of the original SHP.

The main geometric processes that are carried out in this phase are for the calculation of the surfaces of the building envelope. Additionally, simple calculations are made to estimate other geometric parameters of the buildings, such as: number of floors, building volume or roof area. To calculate the surfaces of the envelope, it is necessary to previously identify which of the building's surfaces are facades and which are adjoining walls in order to obtain precisely the area of the facades. Subsequently, the area of each façade is calculated from the footprint geometry and the height of the building. Finally, it is necessary to add the surface of all facades at the building level. It is also possible to identify in this process the orientation of the enveloping surfaces of the building, both for the facades and for the adjoining walls.

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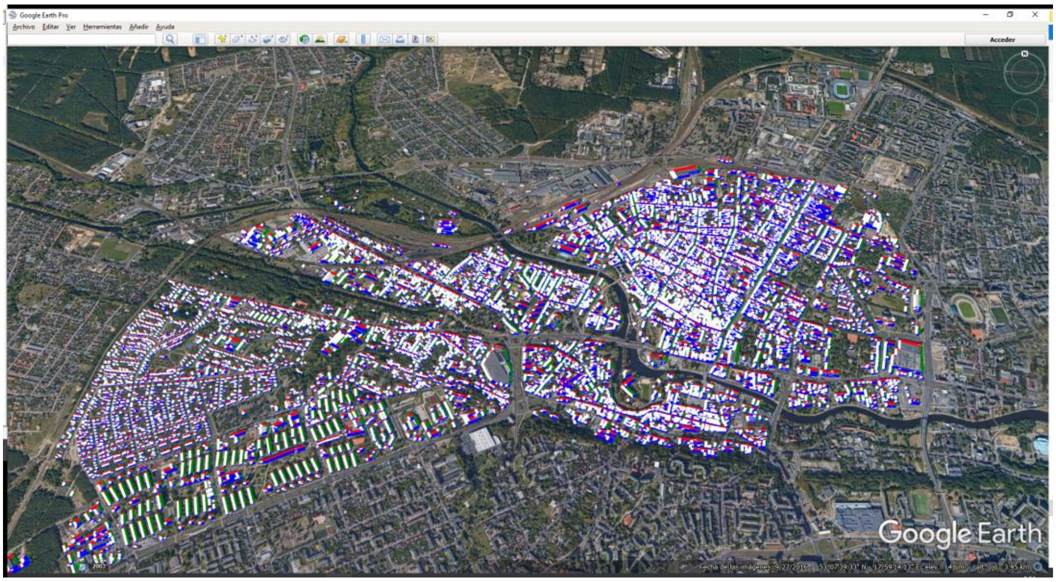

Figure 35 Main orientation of building façades in Bydgoszcz study area (Red=North, Blue=South, White=West, Green=East)

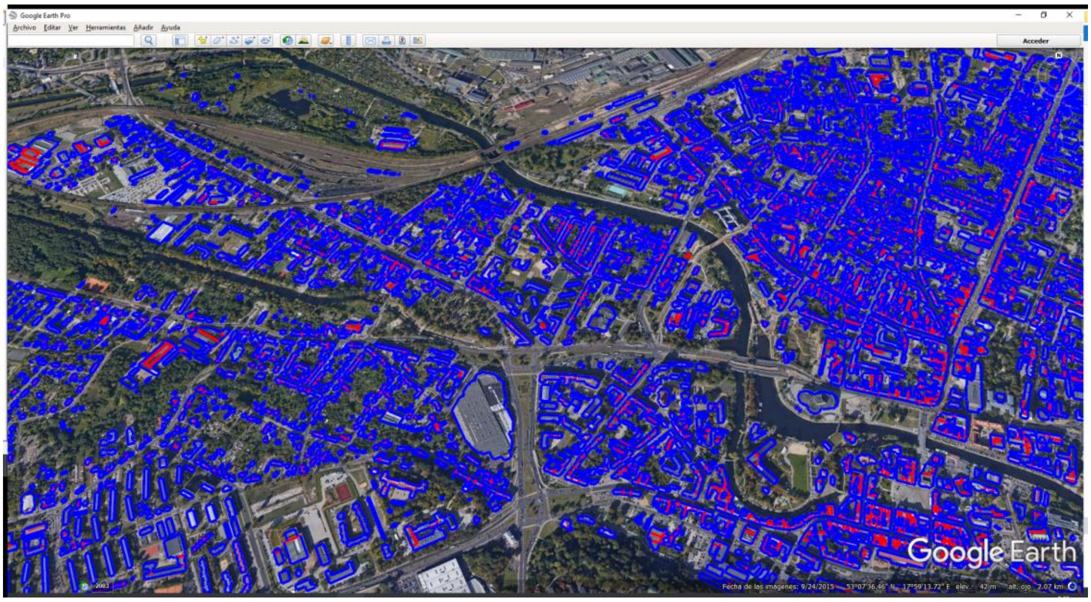

Figure 36 Building façades (in Blue) and adjoining walls (in Red) in Bydgoszcz study area

The set of parameters resulting from the geometric processing is detailed in section 4.2.3.4 in Table 23

4.2.3.3 Data processing and CityGML generation at city scale

A) General Configuration

Bydgoszcz has a population of 358 614 inhabitants (in 2014) with an extension of an area of 175 km² (Figure 37). The reference system used in the processing at city scale is: EPSG:2177.

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Figure 37 Bydgoszcz at city scale overview

B) Data Sources

Data sources used for the generation of the processing and the generation of the 3D City model of the city of Bydgoszcz are the same used for the data processing at district scale (section 4.2.3.2).

C) Data Pre-processing

The main tasks carried out in order to obtain the required information for the energy demand analysis of the city of Bydgoszcz are very similar to the ones performed for the data processing at district level (section 4.2.3.2). Main differences are briefly described below:

- **Remove buildings which are not representative for the analysis**: Similar to the process performed at district level, all the geometries with less than 25m^2 have been removed in order to reduce the number of buildings in the city. In addition to that, those buildings whose use is “other” and the building area is less than 80m^2 are also removed. Those buildings with area greater than 1500m^2 have also been removed.

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- **Assignment of values to missing attributes**: There are some buildings which have not complete the value for the "use" attribute, they have been completed in the following way. If building area is less than 900m^2 then the use is residential, and if is higher than 1500m^2 then the use of the nearest building is set. For other attributes which were incomplete, they have been completed based on the value of the nearest building.
- **Verification of the information:** The verification of the results carried out consists mainly on the identification of missing values, identification of discrepancies and identification of atypical values.

The result of the preprocessing produces an information layer (Bydgoszcz_Result) with 44.066 buildings (Figure 38) with the following attributes:

- ELEMID: Unique identifier for each building
- HEIGHT: Average height of the building
- CONS_YEAR: Year of construction of the building
- CALC_AREA: Building footprint area
- CADNAT_DSC: Main function of the building.

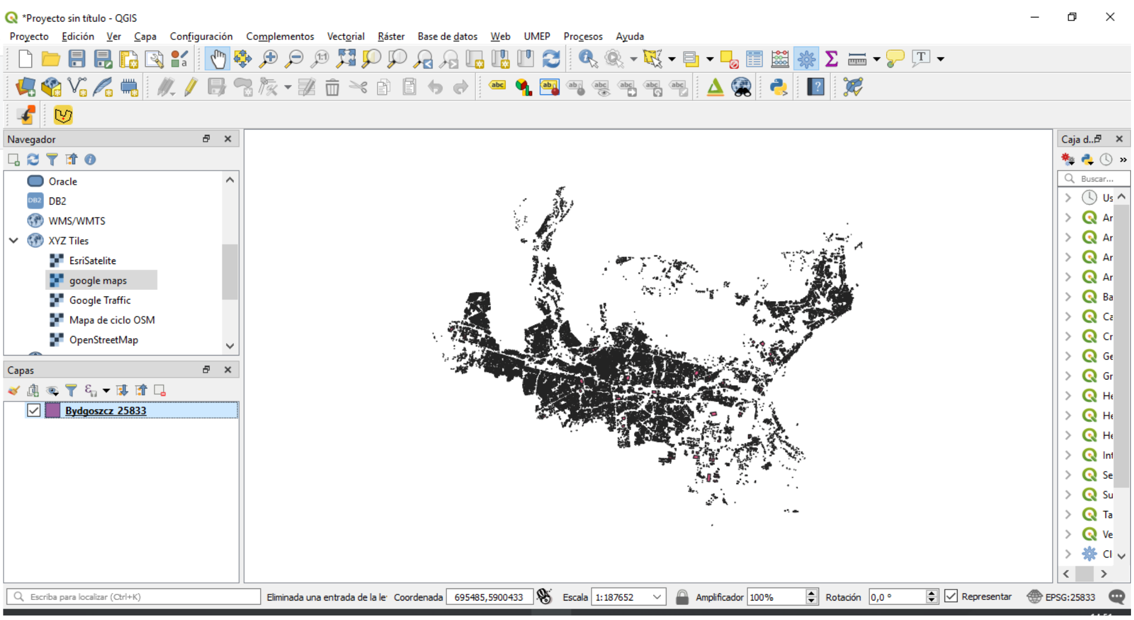

Figure 38 Bydgoszcz at city scale after pre-processing

D) CityGML Generation

The process of generation of the CityGML model of the city of Bydgoszcz takes as input the data resulting from the pre-processing carried out at the city scale and previously described. The data sources used are the following ones (Table 22):

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Table 22: Data sources for CityGML generation

Name	Source	Description
Data source with geometry for LoD1	LoD1.shp	It contains geometric information of the buildings (44.066)
Data source with geometry for LoD2	LoD2.shp	It contains geometric information of the buildings (44.066)
Sections in which the model is divided	Agrupaciones.shp	Polygons of $1km^2$ in which the city model is divided (180 groups)
Terrain Height for LoD1	MDTLoD1.xlsx	Contains terrain height data for parcels
Terrain Height for LoD2	MDTLoD2.xlsx	Contains terrain height data for buildings
Surface Height for LoD1	LIDARLoD1.xlsx	Contains the surface height data for the parcels
Surface Height for LoD2	LIDARLoD2.xlsx	Contains the surface height data for the buildings

The following figure (Figure 39) shows an overview of the data source layers, both building and parcel scale and the 180 groups in which the model is divided.

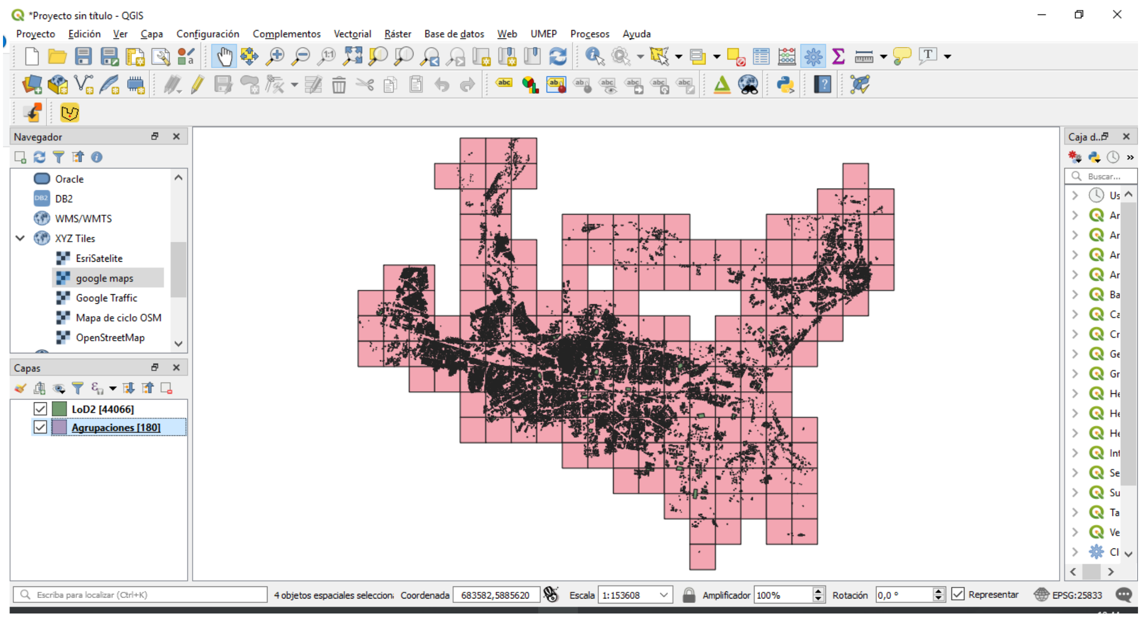

Figure 39 SHP layers with input data for the generation of the CityGML

- **Geometric generation**: The geometry of the model elements is generated with two different levels of detail (LoD1 and LoD2).

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- **Semantization of the model**: The geometric model is completed with the available semantic information (attributes).

The results of the generation process of the CityGML model of the city of Bydgoszcz are presented below. First, buildings with level of detail LoD1 for one of the 180 parts of the model. Next, the same piece but with the buildings in LoD2 and finally, the information of the properties associated to each building that represent the semantic information.

The FZKViewer tool is used to visualize the generated models (Figure 40 Figure 41 Figure 42).

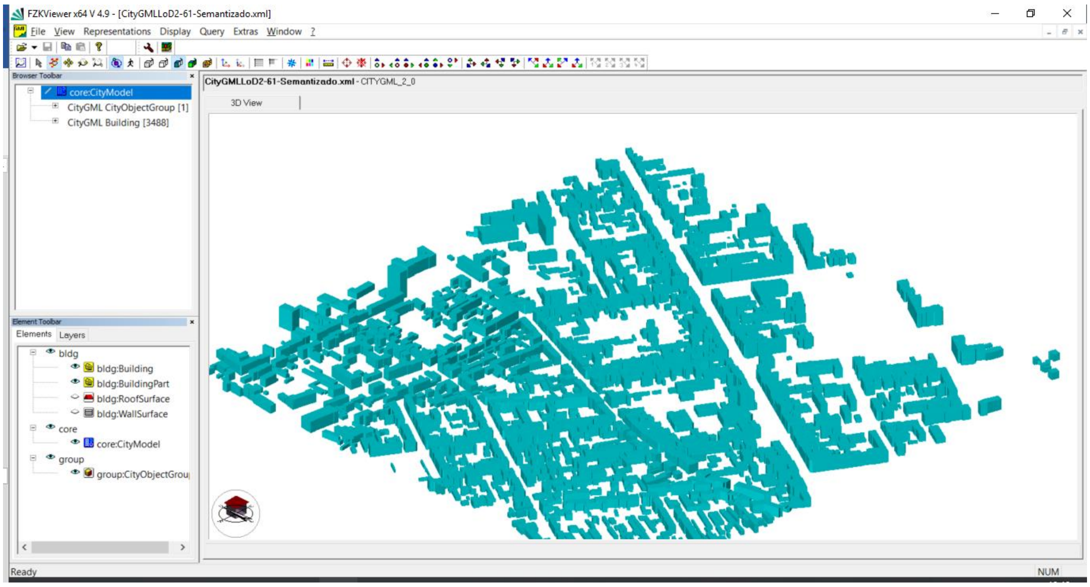

Figure 40 Buildings in LoD1 for one of the areas of the city of Bydgoszcz

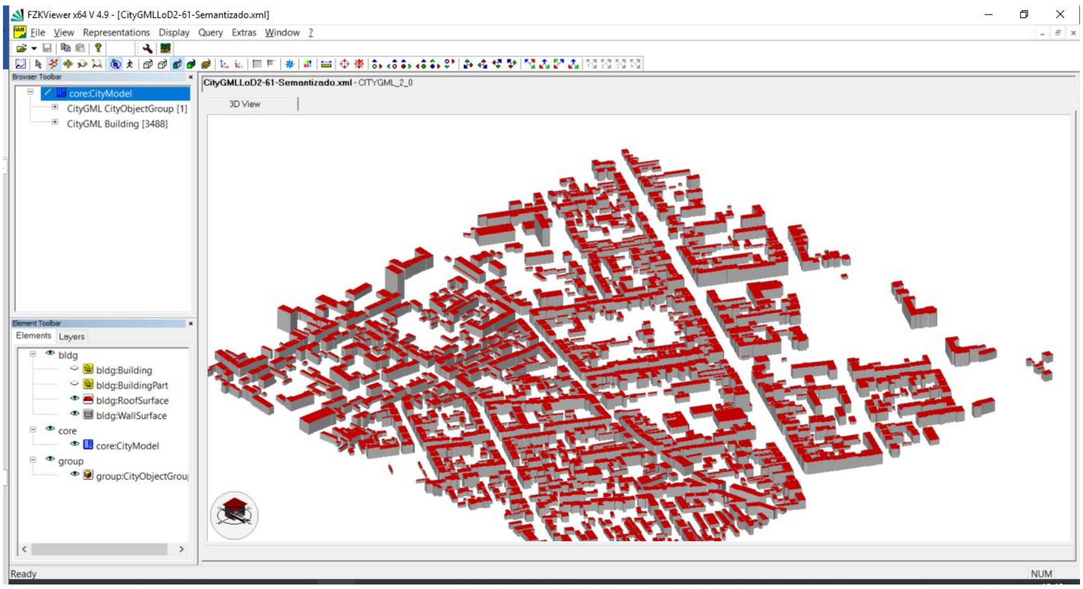

Figure 41 SHP Buildings in LoD2 for one of the areas of the city of Bydgoszcz

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

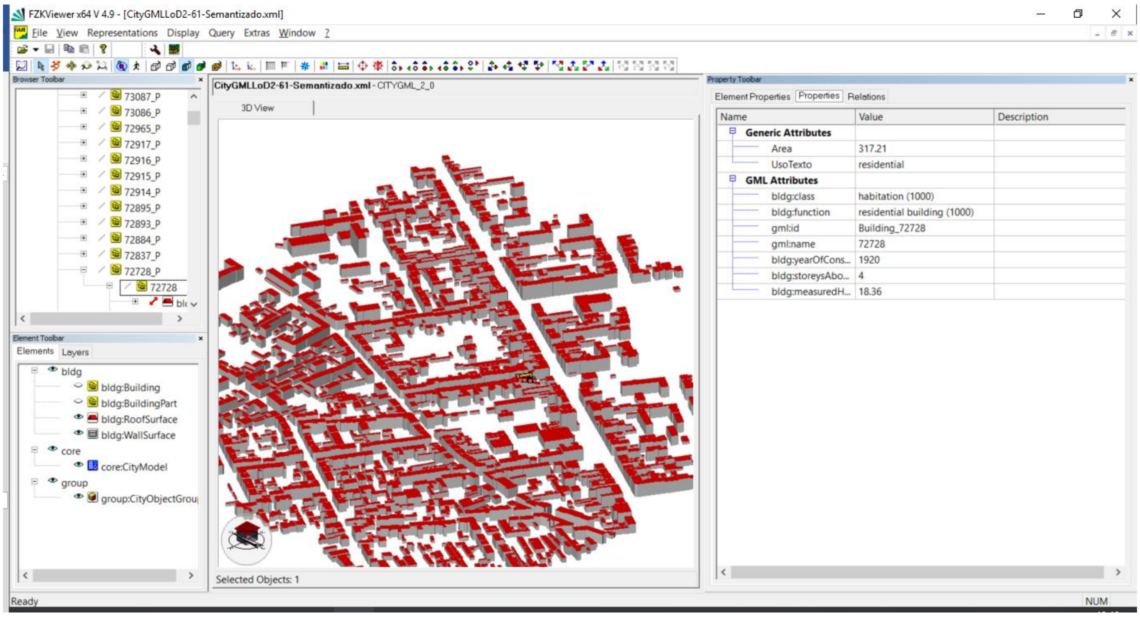

Figure 42 Semantic properties included in the CityGML model of the city of Bydgoszcz

4.2.3.4 Description of the results

In the case of Bydgoszcz, two different results have been generated. First, for the district scale, a shape file of the district with the information required for the analysis of energy demand is obtained as a result of the modelling process. On the other hand, for the city scale the shape file with the information for energy modelling and also a CityGML model in LoD1 and LoD2 of the city have been obtained.

C) Results at district level

As a result of the modelling of the Bydgoszcz study area, the necessary information for the energy analysis is obtained. The detail of the information resulting from the process is presented in the following table (Table 10). The information is available in different formats: Excel, SHP and KML.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

Table 23: Set of parameters contained in the files resulting from the process in Bydgoszcz

Parameter	Format	Description
Reference	Unique Id	Building Unique Identifier
Centroid	UTM Coordinates	Geolocation of the building
TotalHeight	Number	Height of the building
NumberOfFloors	Number	Number of Floors
BuildingArea	Number (m^2)	Area of the building footprint
GrossFloorArea	Number (m^2)	Total area of the building
RoofArea	Number (m^2)	Area of the roof of the building
TotalEnvelopeArea	Number (m^2)	Total envelope area, including façade and adjoining walls
ExteriorEnvelopeArea	Number (m^2)	Area of the building façade
AdjoiningEnvelopeArea	Number (m^2)	Area of the adjoining walls
NorthExteriorEnvelopeArea	Number (m^2)	Area of façade whose main orientation is North
SouthExteriorEnvelopeArea	Number (m^2)	Area of façade whose main orientation is South
WestExteriorEnvelopeArea	Number (m^2)	Area of façade whose main orientation is West
EastExteriorEnvelopeArea	Number (m^2)	Area of façade whose main orientation is East
YearOfConstruction	Number (Year)	Year of construction of the building
Use	Text	Main use of the building
Volume	Number (m^3)	Volume of the building
DistrictCentroid	UTM Coordinates	Approximated geolocation of the centre of the study area

Below it is showed a screenshot of the resulting KML file (see Figure 43). The file is displayed on Google Earth. In addition, the information associated with the selected building is included.

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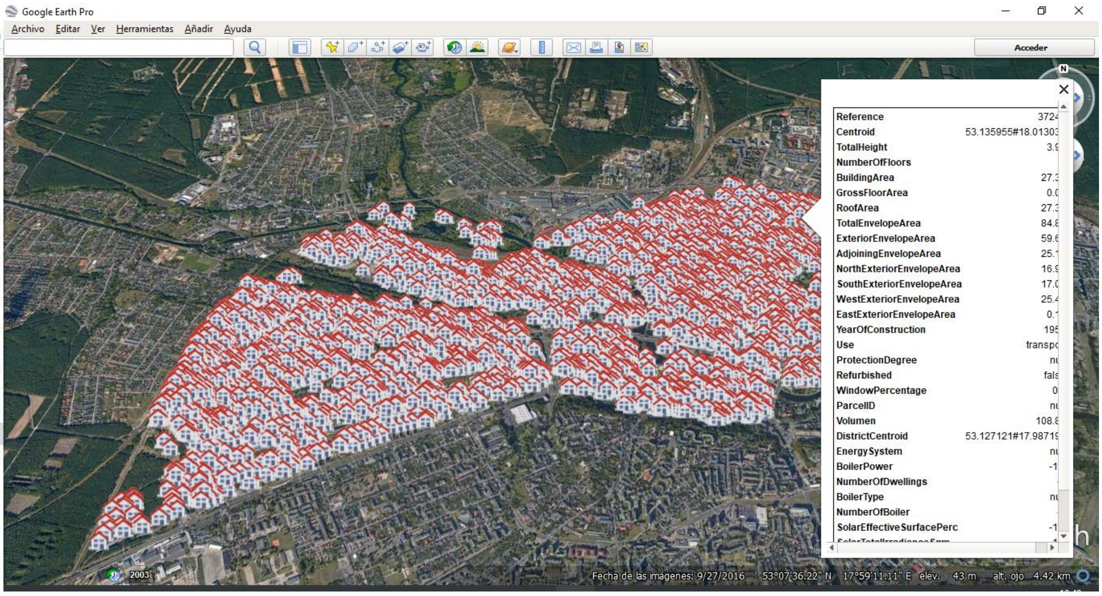

Figure 43 Results at district level in Bydgoszcz (KML format)

D) Results at city level

The results at city level contains the same information than in the study area. Due to the size of the files KML is not generated. Only Excel and SHP files are generated at the city scale.

Additionally, for the study case of Bydgoszcz, the CityGML model of the city has been generated. The results of the generation process are 180 CityGML files corresponding to each of the sections into which the model has been divided. Finally, the 180 sections of the model have been grouped into a single file. The size of this file is 533MB, which contains the following CityGML objects.

- BUILDING: 44.066
- BUILDING_PART: 44.066
- CITY_OBJECT_GROUP: 180

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5. Methodological approach to the energy analysis of the three follower cities

5.1 General description and purpose

Based on the results obtained in the Section 4 the energy demand analysis of the areas selected for each follower city are evaluated. The methodological approach is the same used for the case of the analysis of lighthouse cities. This approach is described more in detail in the deliverable D 1.12. However, this section describes briefly the general approach adopted for the energy demand analysis.

As described above, the main objective of the analysis is to develop the baseline energy characterization of each district selected by each follower city. This baseline situation allows a better understanding of the initial situation and the existing improvement potential in each case.

In contrast to other approaches, in this case an energy analysis methodology is used for evaluating the specific energy demand of each house or building block taking into account their specific characteristics such as the envelope surfaces, building use, area, year of construction, etc. These building attributes are obtained from the previous phase related to the 3D modelling, City GML and city cadastre analysis and treated and used for the energy analysis in this phase.

Besides, it needs to be understood that although the methodology allows the energy demand calculations in an hourly basis for each building, it is designed in a way that allows its application to larger areas following the same procedure. Therefore, the energy demand analysis of a city is initiated at district scale and once that it is adjusted and calibrated for this district, it can be relatively easily extended to the entire city if necessary and if the information required is available.

This energy characterization has been applied to the three follower cities of the project for the districts that have been selected by the municipalities.

5.2 Description of the energy demand calculation

The energy characterization of the districts selected in the project by the three cities has been carried out following an innovative method that allows municipalities to carry out energy studies of their existing building stock using cadastral information. This method for the building energy demand characterization at city scale was developed by Tecnalia in the European research project PlanHeat [1] and has been completed and improved to allow also the electricity energy consumption analysis.

A complete description of the energy demand analysis methodology can be consulted in the public deliverable “D2.1 –Models for mapping and quantifying current and future H&C demand in cities” of the PLANHEAT project (H2020-EE-2016-RIA-IA).

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The methodology needs the following information to calculating the energy demand of the district:

Table 24: Inputs for the energy modelling phase obtained from the 3D model information pre-processing.

Parameter	Mandatory or Optional
Building ID	Mandatory
Building Geometry	Mandatory
Footprint area	Mandatory
Height 1	Mandatory
Height 2	Optional
Number of floors 2	Mandatory
Number of floors 1	Optional
Hourly outside air temperature	Mandatory
Year of construction	Mandatory
Building Use	Mandatory
Gross floor area	Optional
Roof area	Optional

5.2.1 Energy demand and consumption calculations

The energy demand profiles at district scale are obtained following a bottom-up approach and following the Energy Performance of Buildings Directive [2], which proposes the static equations [3] for the calculation of the heating, cooling and domestic hot water (DHW) energy demands based on the Degree-Days method. However, in order to obtain a more detailed analysis, the calculation is done on an hourly basis and also considers internal gains, solar gains, ventilation losses.

The energy demand and consumption analysis is carried out for each of the building uses covering in principle the following uses; Residential, office, health care, education, commerce, public administration, hotel, restaurant and sport centre.

However, taking into account that the analysis carried out is at district scale the most relevant part of the building stock is covered by the residential and tertiary (offices, commerce, public buildings). This classification of buildings is complemented also with the consideration of the period of construction of the buildings. The period considered are defined according to the information available in the city cadastre or the information available for the calibration of the model.

With regard to the energy demand calculations, the hourly heating demand of each building is determined. Different internal gains related to occupancy, lighting, appliances and solar gains are taken into account. Ventilation losses (calculated considering different base temperatures for heating-h or cooling-c) are also assumed. These ventilation losses are reduced (according to the efficiency of the heat recovery system) in the case that a mechanical ventilation system with heat recovery is installed. As mentioned before, the detailed description of the energy modelling equations can be consulted in the deliverable D1.12. of mySMARTLife project.

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5.2.2 Results obtained with the analysis for each building of the district

Two different results are obtained with the described analysis for each building within the boundaries of the selected district. The first output is the georeferenced generic and energetic information per building (see Table 25). This information is obtained in two different file-formats;

- XLSX file and
- SHAPE file.

In this way, the end-user could analyse the results with different tools (for example an “excel” for the XLSX file and the QGIS for the SHAPE file).

Table 25: Outputs of the energetic analysis of each building of the district.

Parameter	Unit
Building generic data	
Building ID	-
Centroid of the building	Coordinates
Use	Name
Footprint area	m^2
Height	Number
Number of floors	Number
Gross floor area	m^2
External opaque facade area	m^2
Roof area	m^2
Window area	m^2
Volume	m^3
Year of construction	Number
Building energetic data	
Annual heating demand	$kWh \cdot year^{-1}$
Annual cooling demand	$kWh \cdot year^{-1}$
Annual DHW demand	$kWh \cdot year^{-1}$
Annual heating demand per square meter	$kWh \cdot m^{-2} \cdot year^{-1}$
Annual cooling demand per square meter	$kWh \cdot m^{-2} \cdot year^{-1}$
Annual DHW demand per square meter	$kWh \cdot m^{-2} \cdot year^{-1}$
Annual lighting electricity energy consumption	$kWh \cdot year^{-1}$
Annual equipment electricity energy consumption	$kWh \cdot year^{-1}$
Annual lighting electricity energy consumption per square meter	$kWh \cdot m^{-2} \cdot year^{-1}$
Annual equipment electricity energy consumption per square meter	$kWh \cdot m^{-2} \cdot year^{-1}$

The second output is the hourly heating, cooling and DHW energy demand data per each building of the area under study. This information can be obtained in a XLSX file.

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5.3 Description of the calibration/adjustment of the results obtained

As in the case of the lighthouse cities, the methodology used for the energy demand calculation of follower cities is generic and can be used for the analysis of different districts of different locations and with different conditions. Moreover, the calculations need to be particularized to each case study by providing specific value for each of the parameters used in the equations mentioned. This particularization is usually done as a first step by using existing values obtained from literature. However, experience and several studies show that the obtained values can have relevant differences respect to the actual data obtained from other sources such as monitoring data or energy bills [4]. The reason of obtaining these differences come from aspects that are difficult to foresee or control, aspects such as the user behaviour or the actual situation of the building envelope, infiltrations, etc. This is the reason why it is recommended to adjust or calibrate the model with existing data.

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6. Energy modelling analysis: Case studies

6.1 Case study description for the three follower cities

This section includes the description of the districts selected by each follower city as the case studies for the energy demand analysis. The selection has been done taking into account the specific interests of each city and also taking into account that the district evaluated is interesting for this type of analysis which aims to serve also as an initial point for the evaluation of the replication potential of this analysis in other areas of the city.

6.1.1 Palencia area of study

The area of study selected by the city of Palencia is composed by two districts; Pan y Guindas and Campo de la Juventud. The sum of the two districts cover an important area of the city integrating buildings with different uses; residential, offices, health care, sports public administration and industry (the industrial area is out of the scope of the energy characterization study). The following table shows a summary of the building heated floor area by use and by construction period.

Table 26 Building heated floor area (m^2) of Palencia by building type and age

	1900-1945	1945-1960	1960-1979	1979-2006	2006-2013	Post 2013	Total	%
Residential	13.758	31.560	247.916	348.177	62.146	9.823	713.379	87%
House	6.086	1.223	310	1.733	89	55	9.497	1%
Office	-	-	9.935	5.866	2.609	545	18.955	2%
Education	7.260	6.404	16.063	1.661	-	-	31.387	4%
Health care	-	-	-	2.398	-	-	2.398	0,5%
Public administration	-	521	11.137	13.621	5.763	-	31.042	4%
Sport	-	13.926	-	-	-	-	13.926	1,5%
Total	**27.104**	**53.634**	**285.361**	**373.455**	**70.608**	**10.422**	**820.584**	**100%**

It is observed that 45,5% of buildings were constructed between 1979 and 2006, 35% between 1960 and 1979, 9% between 2006 and 20113, 7% between 1945 and 1960, 4% between 1900 and 1945 and only less than 2% after 2013. Therefore, it can be said that there is in principle high potential for building refurbishment.

The figure below shows the area of study distinguishing the buildings by use.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

Figure 44 Different building uses of the Palencia study area

In terms of number of buildings, 77% are residential in building blocks, 14% residential in individual houses, 5% public administration, 2% office and the rest correspond to education, health care and sport. The following figure shows the building distribution (in number of buildings) by use for the area of study.

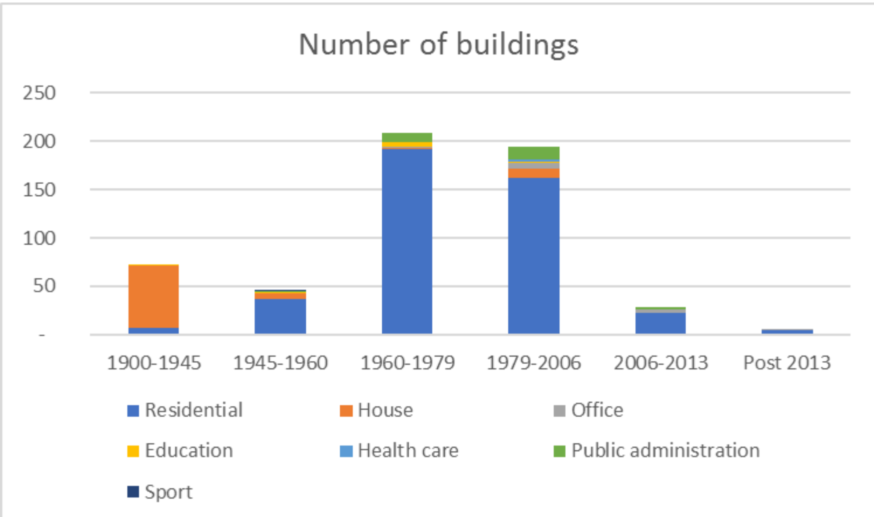

Figure 45 Number of buildings of Palencia study area by use and age.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

6.1.2 Rijeka area of study

The area of study selected by the city of Rijeka covers a small area of the city, but it has been selected due to the interest of the municipality on that specific area of the city. This area integrates buildings with different uses; residential, offices, and commerce. The following table shows a summary of the building heated floor area by use. According to the information provided by the city all the buildings were constructed in 1800.

Table 27 Building heated floor area of Rijeka by building type

Use	Total	%
Residential	53.788	78,29%
Office	3.830	5,57%
Commerce	11.089	16,14%
Total	**68.708**	**100,00%**

The figure below shows the area of study distinguishing the buildings by use. In terms of number of buildings, it is observed that 28 buildings have residential use, 4 office and 4 commerce.

Figure 46 Different building uses of the Rijeka study area

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

6.1.3 Bydgoszcz area of study

The area of study selected by the city of Bydgoszcz is a large area. As in the case of the other two cities, this area integrates buildings with different uses; residential, offices, education, health care and commerce. The following table shows a summary of the building heated floor area by use and age.

Table 28 Building heated floor area of Bydgoszcz by building type and age

Heated floor area (m2)	Pre-1945	1946-1966	1967-1985	1986-1992	1993-2002	2003-2008	Post-2008	Total	%
Residential	903.005	216.961	172.643	28.543	38.529	36.354	63.518	1.459.553	56%
House	230.452	26.237	77.724	4.193	3.485	5.890	6.145	354.126	14%
Office	62.136	61.705	35.440	5.698	14.891	2.432	13.601	195.903	8%
Education	66.468	41.643	37.486	5.078	9.017	22.874	20.159	202.724	8%
Health care	8.985	4.918	6.626	3.106	17	222	1.794	25.667	1%
Commerce	94.673	22.752	43.657	1.619	59.333	116.833	12.142	351.009	13%
Total	1.365.719	374.215	373.575	48.236	125.273	184.605	117.359	2.588.981	100%

It is observed that 53% of buildings were constructed before 1945, 14,5% between 1946 and 1966, 14,5% between 1967 and 1985, 7% between 2003 and 2008, 5% between 1993 and 2002, 4,5% after 2008 and the rest between 1986 and 1992. Therefore, it can be said that in this case also there is in principle a high potential for building refurbishment.

The figure below shows the area of study distinguishing the buildings by use.

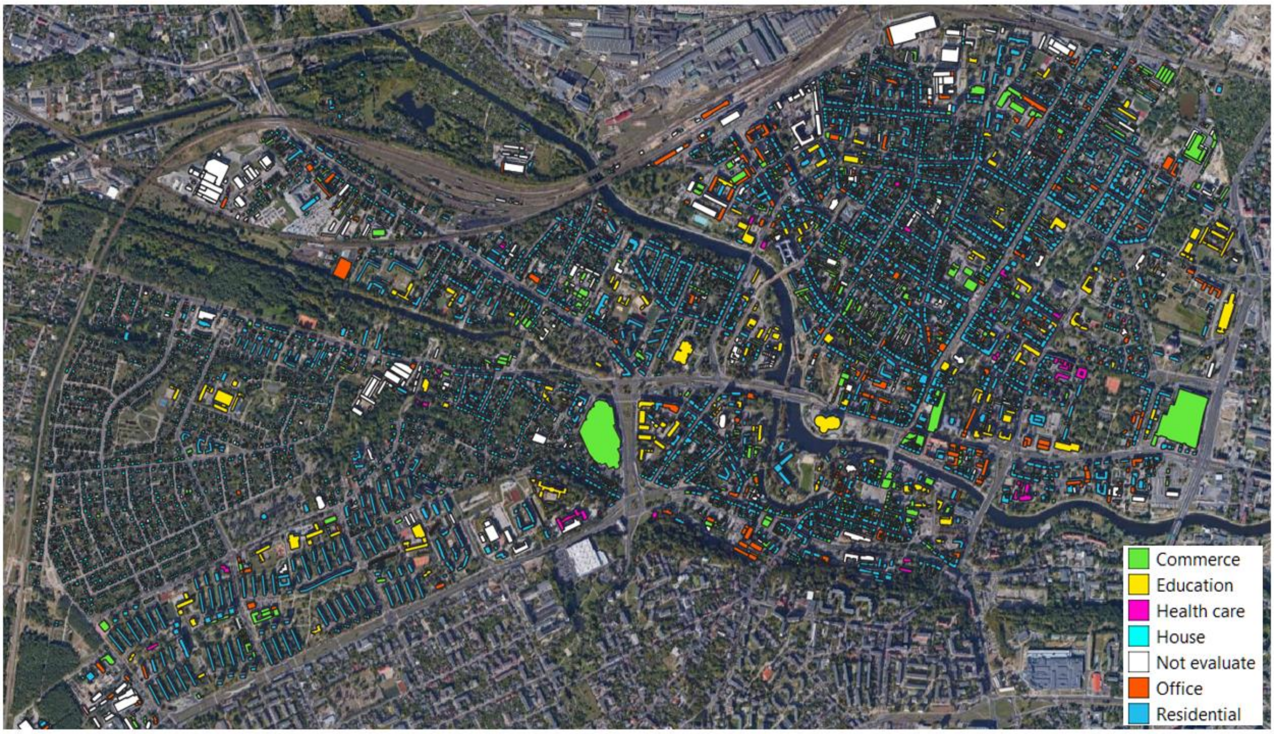

Figure 47 Different building uses of the Bydgoszcz study area

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

In terms of number of buildings, 30% are residential in building blocks, 49% residential in individual houses, 5% office, 4% education, 13% commerce and the rest health care. The following figure shows the building distribution (in number of buildings) by use for the area of study.

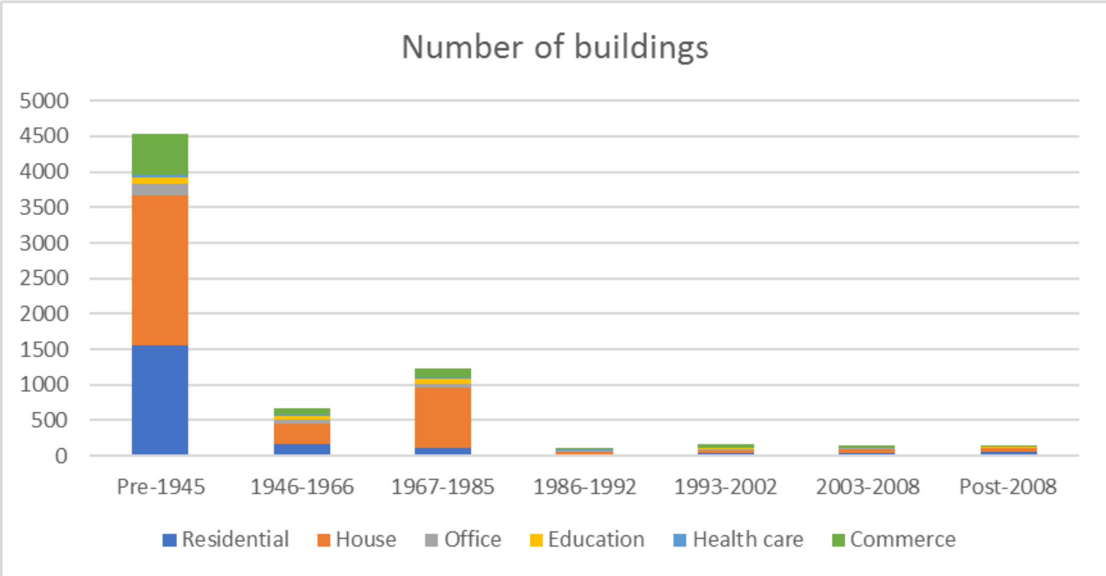

Figure 48 Number of buildings of Bydgoszcz study area by use and age.

6.2 Energy modelling and adjustment of the models

This section describes the main steps followed in the case of each follower city for the energy modelling and adjustment phase of the model. The procedure followed is the same applied in the case of lighthouse cities.

6.2.1 Palencia area of study

The energy model generated for the area of study of Palencia has been adjusted specifying more in detail some of the characteristics of the internal database of the modelling tool. The main values adjusted in terms of the thermal transmittance of the building envelopes and in terms of the air changes per hour (ACH) considered are detailed in the table below for each of the construction periods defined for the buildings.

Table 29 Thermal transmittance values of the different construction solutions of the building envelope and the considered air changes per hour (ACH)

	Pre 1900 [5]	1900-1945 [5]	1945-1960 [5]	1960-1979 [6]	1979-2006 [7]	2006-2013 [7]	Post 2013 [7]
Roof	4,17	4,17	3,08	3,08	0,9	0,49	0,4
Wall	3	3	2,56	2,56	1,3	0,86	0,6
Window	5,35	5,35	5,35	4,59	3,3	3,3	2,7
ACH [8]	1,2	1,2	1,2	1,05	0,9	0,9	0,9

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

With regard to other characteristics that are necessary in the energy model (Equipment internal gains, occupancy internal gains, lighting power, window to wall ratio (WWR), annual DHW demand), for the case of Palencia the following table shows the values adjusted for each of the construction periods defined for the buildings.

Table 30 Main parameters adjusted in the district energy model according to the building use

Parameter	Residential	Single Family House	Hotel	Health care	Education	Office	Commerce	Restaurant	Sport	Public adm.
Equipment internal gains [W/m2] [9]	6,27	4,44	3,15	3,58	4,70	11,77	5,20	18,88	16,02	5,48
Occupancy internal gains [W/m2] [9]	1,76	1,76	4,72	7,33	29,82	7,05	8,18	11,00	25,50	5,94
Lighting power [W/m2] [9]	0,85	0,66	10,76	13,02	10,66	15,00	15,07	9,69	10,76	9,69
WWR [10]–[14]	0,27	0,27	0,17	0,23	0,28	0,50	0,20	0,30	0,20	0,50
Annual DHW demand [kWh/m²] [15]	13,90	13,90	126,40	133,40	57,20	3,20	3,20	35,30	256,00	3,20

Finally, the schedules used for the hourly energy demand characterization of Palencia are detailed in the following table depending on the use (heating, cooling, occupancy, lighting, equipment) and depending on the use of the building.

Table 31 Schedules used for the modelling of the Palencia study area (According to the database of Design Builder and adapted with National reports for residential buildings)

	Heating	Cooling	Occupancy	Lighting	Equipment
Residential	Winter: Until: 07:00, 0; Until: 23:00, 1; Until: 24:00, 0;	Summer: Until: 15:00, 0; Until: 23:00, 1; Until: 24:00, 0;	Until: 07:00, 1; Until: 08:00, 0.5; Until: 15:00, 0.25; Until: 23:00, 0.5; Until: 24:00, 1	Until: 01:00, 0.3 ; Until: 05:00, 0.01 ; Until: 06:00, 0.05 ; Until: 07:00, 0.3 ; Until: 09:00, 1 ; Until: 10:00, 0.5 ; Until: 11:00, 0.3 ; Until: 13:00, 0.2 ; Until: 16:00, 0.4; Until: 18:00, 0.5; Until: 19:00, 0.7; Until: 23:00, 1 ; Until: 24:00, 0.5	Until: 01:00, 0.5; 06:00, 0.1 ; Until: 07:00, 0.2 ; Until: 08:00, 0.3 ; Until: 18:00, 0.4; Until: 19:00, 0.5; Until: 20:00, 0.7 ; Until: 21:00, 0.8 ; Until: 23:00, 1 ; Until: 24:00, 0.8
	Summer: Until: 24:00, 0.	Winter: Until: 24:00, 0.			
Hotel	Winter: Until: 24:00, 1	Summer: Until: 24:00, 1	Until: 08:00, 1; Until: 09:00, 0.25; Until: 21:00, 0; Until: 22:00, 0.25; Until: 23:00, 0.75; Until: 24:00, 1	Until: 08:00, 0; Until: 09:00, 1; Until: 21:00, 0; Until: 24:00, 1	Until: 07:00, 0; Until: 08:00, 0.53; Until: 09:00, 1; Until: 10:00, 0.53; Until: 17:00, 0; Until: 18:00, 0.3; Until: 19:00, 0.53; Until: 20:00, 0.77; Until: 22:00, 1; Until: 23:00, 0.77; Until: 24:00, 0.3
	Summer: Until: 24:00, 0	Winter: Until: 24:00, 0			
	Summer: Until: 24:00, 0	Winter: Until: 24:00, 0			
Education	Winter: Until: 05:00, 0; Until: 18:00, 1; Until: 24:00, 0;	Summer: Until: 05:00, 0; Until: 18:00, 1; Until: 24:00, 0;	Until: 07:00, 0; Until: 08:00, 0.1; Until: 09:00, 0.25; Until: 10:00, 0.75; Until: 12:00, 1; Until: 14:00, 0.5; Until: 16:00, 1; Until: 18:00, 0.5; Until: 24:00, 0; Weekends and holidays: Until 24:00: 0	Until: 07:00, 0; Until: 19:00, 1; Until: 24:00, 0; Weekends and holidays: Until 24:00: 0	Until: 07:00, 0; 21:00, 1; Until: 24:00, 0; Weekends and holidays: Until 24:00: 0
	Summer, weekends and holidays: Until 24:00: 0	Winter, weekends and holidays: Until 24:00: 0			
Office	Winter: Until:	Summer: Until:	Until: 07:00, 0; Until:	Until: 07:00, 0; Until: 19:00, 1;	Until: 07:00, 0; 20:00, 1; Until:

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	05:00, 0; Until: 19:00, 1; Until: 24:00, 0;	05:00, 0; Until: 19:00, 1; Until: 24:00, 0;	08:00, 0.25; Until: 09:00, 0.5; Until: 12:00, 1; Until: 14:00, 0.75; Until: 17:00, 1; Until: 18:00, 0.5; Until: 19:00, 0.25; Until: 24:00, 0; Weekends and holidays: Until 24:00: 0	Until: 24:00, 0; Weekends and holidays: Until 24:00: 0	24:00, 0; Weekends and holidays: Until 24:00: 0
	Summer, weekends and holidays: Until 24:00: 0	Winter, weekends and holidays: Until 24:00: 0			
Commerce	Winter: Until: 07:00, 0; Until: 18:00, 1; Until: 24:00, 0;	Summer: Until: 07:00, 0; Until: 18:00, 1; Until: 24:00, 0;	Until: 09:00, 0; Until: 10:00, 0.75; Until: 12:00, 1; Until: 14:00, 0.75; Until: 17:00, 1; Until: 18:00, 0.75; Until: 24:00, 0; Sundays and holidays: Until 24:00: 0	Until: 09:00, 0; Until: 18:00, 1; Until: 24:00, 0; Sundays and holidays: Until 24:00: 0	Until: 08:00, 0; 18:00, 1; Until: 24:00, 0; Sundays and holidays: Until 24:00: 0
	Summer, Sundays and holidays: Until 24:00: 0	Winter, Sundays and holidays: Until 24:00: 0			
Public adm.	Winter: Until: 05:00, 0; Until: 19:00, 1; Until: 24:00, 0;	Summer: Until: 05:00, 0; Until: 19:00, 1; Until: 24:00, 0;	Until: 07:00, 0; Until: 08:00, 0.25; Until: 09:00, 0.5; Until: 12:00, 1; Until: 14:00, 0.75; Until: 17:00, 1; Until: 18:00, 0.5; Until: 19:00, 0.25; Until: 24:00, 0; Weekends and holidays: Until 24:00: 0	Until: 07:00, 0; Until: 19:00, 1; Until: 24:00, 0; Weekends and holidays: Until 24:00: 0	Until: 07:00, 0; 18:00, 1; Until: 24:00, 0; Weekends and holidays: Until 24:00: 0
	Summer, weekends and holidays: Until 24:00: 0	Winter, weekends and holidays: Until 24:00: 0			
	Summer and holidays: Until 24:00: 0	Winter and holidays: Until 24:00: 0			
Sport	Winter: Until: 05:00, 0; Until: 21:00, 1; Until: 24:00, 0;	Summer: Until: 05:00, 0; Until: 21:00, 1; Until: 24:00, 0;	Until: 06:00, 0; Until: 07:00, 0.25; Until: 09:00, 1; Until: 12:00, 1; Until: 14:00, 0.5; Until: 18:00, 0.5; Until: 20:00, 1; Until: 22:00, 0.5; Until: 24:00, 0	Until: 06:00, 0; Until: 22:00, 1; Until: 24:00, 0	Until: 06:00, 0; Until: 22:00, 1; Until: 24:00, 0
	Summer and holidays: Until 24:00: 0	Winter and holidays: Until 24:00: 0			

Conclusions of the adjustment phase:

Once that the main modelling parameters have been specified more in detail for the case study, the results obtained have been compared with the main reference values that are available for the city. In the case of Palencia, this data corresponds to the energy label that are available for the dwellings of the districts covered.

The figure below shows the difference between the modelling results for the residential buildings respect to the energy labels distinguishing the buildings per energy label (from A to G).

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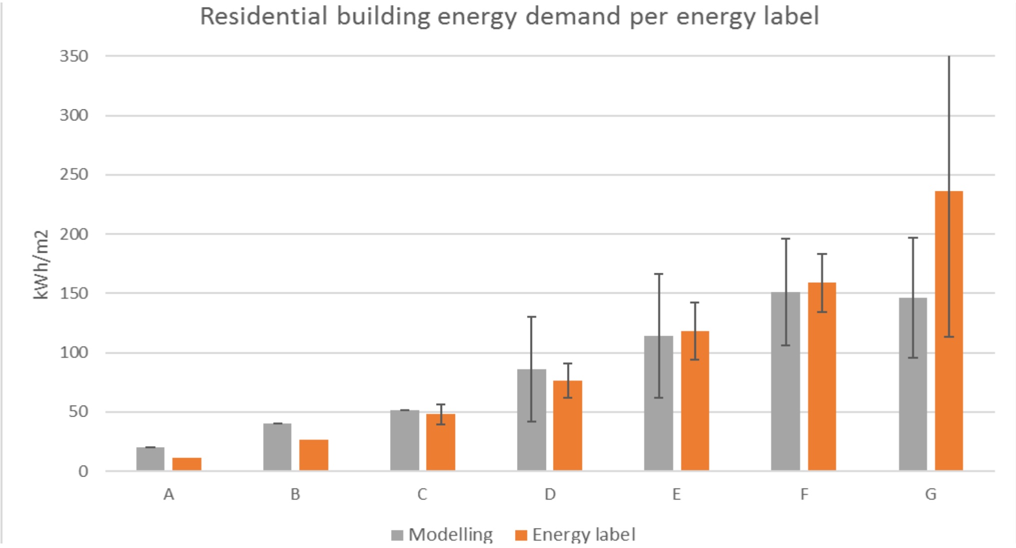

Figure 49 Energy demand comparison for the area of study of Palencia. Modelling results vs energy label of buildings.

The differences observed are up to 42% for buildings with an energy label of A, 33% for buildings with an energy label of B, 8% for buildings with an energy label of C, 11% for buildings with an energy label of D, 4% for buildings with an energy label of E, 5% for buildings with an energy label of F and 61% for buildings with an energy label of G.

Although these differences seem high in some cases it needs to be considered that in this case the data available does not correspond to actual energy consumptions of buildings obtained from energy monitoring. In this case the data available corresponds to energy labels (from A to G) which also have in many cases an important performance gap respect to actual consumptions. Besides, it needs to be considered also that these labels are only available in each building block for some of its dwellings but not for all of them which makes the comparison more difficult since some hypothesis need to be also considered for the assignation of an equivalent energy label per each building.

Finally, it needs to be also taken into account that it has been widely proven that building energy labels are more inefficient in the definition of the energy demand of buildings in the case of buildings which are in the extremes (therefore those with A, B and F, G). It is proven that although the theoretic energy label assigns a very low energy demand to buildings with a label A or B and a high energy demand to buildings with a F and G, actual values (which take into account the user behaviour, etc.) show that the difference between the two extremes is much lower. This is in line with the modelling results obtained in mySMARTLife project for Palencia.

The figure below shows the tendency of the performance gap obtained in literature between energy label respect to actual values and the performance gap obtained in the modelling between the energy modelling

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and the energy labels of Palencia. It is concluded that the tendency obtained in the project corresponds well with the obtained in other studies and that the model has been properly adjusted.

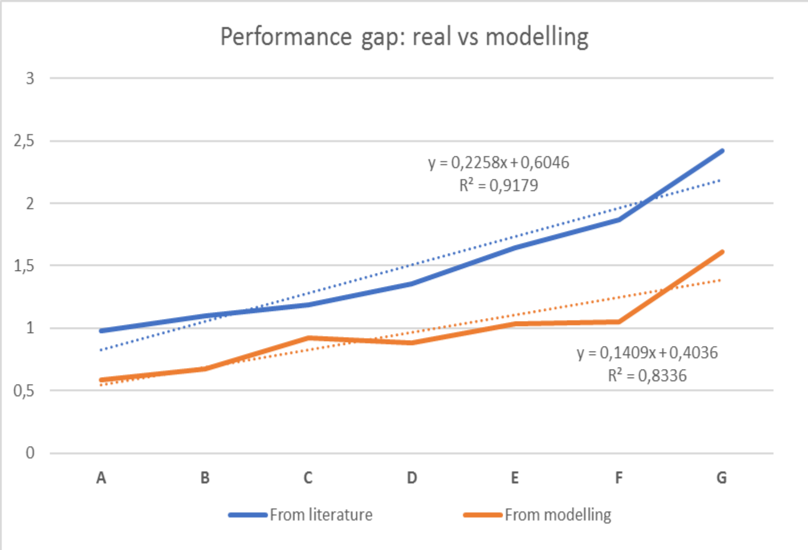

Figure 50 Performance gap obtained in literature between energy label respect to actual values and the performance gap obtained in the modelling between the energy modelling and the energy labels of Palencia.

6.2.2 Rijeka area of study

The energy model generated for the area of study of Rijeka has also been adjusted specifying more in detail some of the characteristics of the internal database of the modelling tool. The main values adjusted in terms of the thermal transmittance of the building envelopes and in terms of the air changes per hour (ACH) considered are detailed in the table below for each of the construction periods defined for the buildings.

Table 32 Thermal transmittance values of the different construction solutions of the building envelope and the considered air changes per hour (ACH)

U Values [6]		**Pre-1945**	**1945-1969**	**1970-1979**	**1980-1989**	**1990-1999**	**2000-2010**	**Post-2010**
Residential	Roof	2,4	1	0,9	0,5	0,3	0,2	0,2
	Wall	1,8	1,8	1,3	0,6	0,4	0,4	1,47
	Window	4,8	4,8	4,6	4,6	2,7	2	2
Non-residential	Roof	1,9	1,8	0,9	0,5	0,3	0,2	0,93
	Wall	1,8	1,7	1,3	0,7	0,5	0,4	1,47
	Window	4,9	4,9	4,9	4,6	2,7	1,8	1,8
ACH [8]		1,2	1,2	0,9	0,9	0,9	0,9	0,9

With regard to other characteristics that are necessary in the energy model (Equipment internal gains, occupancy internal gains, lighting power, window to wall ratio (WWR), annual DHW demand), for the case

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of Rijeka the following table shows the values adjusted for each of the construction periods defined for the buildings.

Table 33 Main parameters adjusted in the district energy model according to the building use

Parameter	Residential	Single Family House	Hotel	Health care	Education	Office	Commerce	Restaurant	Sport	Public adm.
Equipment internal gains [W/m2] [9]	4,40	4,40	3,15	3,58	4,70	11,77	5,20	18,88	16,02	5,48
Occupancy internal gains [W/m2] [9]	1,76	1,76	4,72	7,33	29,82	7,05	8,18	11,00	25,50	5,94
Lighting power [W/m2] [9]	6,46	6,46	10,76	13,02	10,66	15,00	15,07	9,69	10,76	9,69
WWR [10]–[14]	0,27	0,27	0,17	0,23	0,28	0,50	0,20	0,30	0,20	0,50
Annual DHW demand [Kwh/m^2] [15]	13,90	13,90	126,40	133,40	57,20	3,20	3,20	35,30	256,00	3,20

Finally, the schedules used for the hourly energy demand characterization of Rijeka are detailed in the following table depending on the use (heating, cooling, occupancy, lighting, equipment) and depending on the use of the building.

Table 34 Schedules used for the modelling of the Rijeka study area (According to the database of Design Builder)

	Heating	Cooling	Occupancy	Lighting	Equipment
Residential	Winter: Until: 07:00, 0; Until: 23:00, 1; Until: 24:00, 0;	Summer: Until: 15:00, 0; Until: 23:00, 1; Until: 24:00, 0;	Until: 07:00, 1; Until: 08:00, 0.5; Until: 15:00, 0.25; Until: 23:00, 0.5; Until: 24:00, 1	Until: 07:00, 0.1; Until: 18:00, 0.3; Until: 19:00, 0.5; Until: 23:00, 1; Until: 24:00, 0	Until: 07:00, 0.1; Until: 18:00, 0.3; Until: 19:00, 0.5; Until: 23:00, 1; Until: 24:00, 0
	Summer: Until: 24:00, 0.	Winter: Until: 24:00, 0.			
Hotel	Winter: Until: 24:00, 1	Summer: Until: 24:00, 1	Until: 08:00, 1; Until: 09:00, 0.25; Until: 21:00, 0; Until: 22:00, 0.25; Until: 23:00, 0.75; Until: 24:00, 1	Until: 08:00, 0; Until: 09:00, 1; Until: 21:00, 0; Until: 24:00, 1	Until: 07:00, 0; Until: 08:00, 0.53; Until: 09:00, 1; Until: 10:00, 0.53; Until: 17:00, 0; Until: 18:00, 0.3; Until: 19:00, 0.53; Until: 20:00, 0.77; Until: 22:00, 1; Until: 23:00, 0.77; Until: 24:00, 0.3
	Summer: Until: 24:00, 0	Winter: Until: 24:00, 0			
	Summer: Until: 24:00, 0	Winter: Until: 24:00, 0			
Education	Winter: Until: 05:00, 0; Until: 18:00, 1; Until: 24:00, 0;	Summer: Until: 05:00, 0; Until: 18:00, 1; Until: 24:00, 0;	Until: 07:00, 0; Until: 08:00, 0.1; Until: 09:00, 0.25; Until: 10:00, 0.75; Until: 12:00, 1; Until: 14:00, 0.5; Until: 16:00, 1; Until: 18:00, 0.5; Until: 24:00, 0; Weekends and holidays: Until 24:00: 0	Until: 07:00, 0; Until: 19:00, 1; Until: 24:00, 0; Weekends and holidays: Until 24:00: 0	Until: 07:00, 0; 21:00, 1; Until: 24:00, 0; Weekends and holidays: Until 24:00: 0
	Summer, weekends and holidays: Until 24:00: 0	Winter, weekends and holidays: Until 24:00: 0			
Office	Winter: Until: 05:00, 0; Until: 19:00, 1; Until: 24:00, 0;	Summer: Until: 05:00, 0; Until: 19:00, 1; Until: 24:00, 0;	Until: 07:00, 0; Until: 08:00, 0.25; Until: 09:00, 0.5; Until: 12:00, 1; Until: 14:00, 0.75; Until: 17:00, 1; Until: 18:00, 0.5; Until: 19:00, 0.25; Until: 24:00, 0; Weekends and holidays: Until 24:00: 0	Until: 07:00, 0; Until: 19:00, 1; Until: 24:00, 0; Weekends and holidays: Until 24:00: 0	Until: 07:00, 0; 20:00, 1; Until: 24:00, 0; Weekends and holidays: Until 24:00: 0
	Summer, weekends and holidays: Until 24:00: 0	Winter, weekends and holidays: Until 24:00: 0			

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Commerce	Winter: Until: 07:00, 0; Until: 18:00, 1; Until: 24:00, 0;	Summer: Until: 07:00, 0; Until: 18:00, 1; Until: 24:00, 0;	Until: 09:00, 0; Until: 10:00, 0.75; Until: 12:00, 1; Until: 14:00, 0.75; Until: 17:00, 1; Until: 18:00, 0.75; Until: 24:00, 0; Sundays and holidays: Until 24:00: 0	Until: 09:00, 0; Until: 18:00, 1; Until: 24:00, 0; Sundays and holidays: Until 24:00: 0	Until: 08:00, 0; 18:00, 1; Until: 24:00, 0; Sundays and holidays: Until 24:00: 0
	Summer, Sundays and holidays: Until 24:00: 0	Winter, Sundays and holidays: Until 24:00: 0			
Public adm.	Winter: Until: 05:00, 0; Until: 19:00, 1; Until: 24:00, 0;	Summer: Until: 05:00, 0; Until: 19:00, 1; Until: 24:00, 0;	Until: 07:00, 0; Until: 08:00, 0.25; Until: 09:00, 0.5; Until: 12:00, 1; Until: 14:00, 0.75; Until: 17:00, 1; Until: 18:00, 0.5; Until: 19:00, 0.25; Until: 24:00, 0; Weekends and holidays: Until 24:00: 0	Until: 07:00, 0; Until: 19:00, 1; Until: 24:00, 0; Weekends and holidays: Until 24:00: 0	Until: 07:00, 0; 18:00, 1; Until: 24:00, 0; Weekends and holidays: Until 24:00: 0
	Summer, weekends and holidays: Until 24:00: 0	Winter, weekends and holidays: Until 24:00: 0			
	Summer and holidays: Until 24:00: 0	Winter and holidays: Until 24:00: 0			
Sport	Winter: Until: 05:00, 0; Until: 21:00, 1; Until: 24:00, 0;	Summer: Until: 05:00, 0; Until: 21:00, 1; Until: 24:00, 0;	Until: 06:00, 0; Until: 07:00, 0.25; Until: 09:00, 1; Until: 12:00, 1; Until: 14:00, 0.5; Until: 18:00, 0.5; Until: 20:00, 1; Until: 22:00, 0.5; Until: 24:00, 0	Until: 06:00, 0; Until: 22:00, 1; Until: 24:00, 0	Until: 06:00, 0; Until: 22:00, 1; Until: 24:00, 0
	Summer and holidays: Until 24:00: 0	Winter and holidays: Until 24:00: 0			

Conclusions of the adjustment phase:

Once that the main modelling parameters have been specified for the case study, the results obtained from energy modelling have been compared with the main reference values that are available for the city in order to evaluate the potential deviations. In the case of Rijeka, this data corresponds to national literature values for residential buildings that are summarized in the figure below.

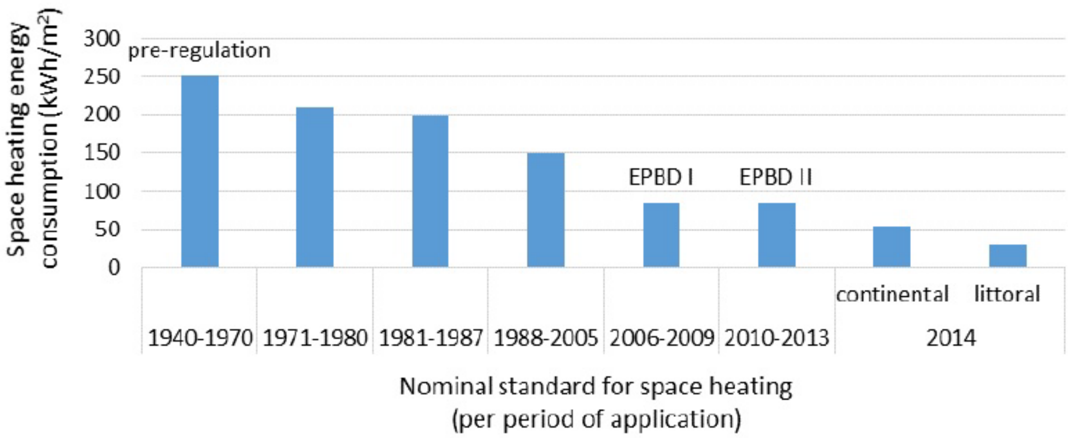

Figure 51 Energy consumption in Croatia for the heating of residential buildings per periods

Taking into account that all the buildings of the area of study selected by Rijeka have the same construction period, the table below shows the potential deviations obtained from modelling.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

Table 35 Difference between the energy modelling results and the national values from literature for the heating energy demand of residential buildings.

	Modelled heating energy consumption (kWh/m2)	Heating energy: values from literature	Error (%)
Residential pre 1945	243	250	3%

Obtained results show a good adjustment for residential buildings heating energy use with 3% of average difference. Therefore, due to the lack of more specific energy data of representative buildings of the city, it is considered that the modelling results provide an appropriate energy characterization. The model could be compared with more specific data in the future if extra information is provided by the municipality.

6.2.3 Bydgoszcz area of study

The energy model generated for the area of study of Bydgoszcz has also been adjusted specifying more in detail some of the characteristics of the internal database of the modelling tool. The values adjusted in terms of the thermal transmittance of the building envelopes and in terms of the air changes per hour (ACH) considered are detailed in the table below for each of the construction periods defined for the buildings.

Table 36 Thermal transmittance values of the different construction solutions of the building envelope and the considered air changes per hour (ACH)

U_values [5]	**Pre 1945** [6]	**1946-1966**	**1967-1985**	**1986-1992**	**1993-2002**	**2003-2008**	**Post 2008**
Roof	0,7	0,5	0,6	0,5	0,5	0,4	0,3
Wall	1,4	1,4	1,3	1,1	0,19	0,18	0,18
Window	3,6	2,6	2,6	2,6	1,6	1,5	1,4
ACH [8]	1,2	1,2	0,9	0,9	0,9	0,9	0,9

With regard to other characteristics that are necessary in the energy model (Equipment internal gains, occupancy internal gains, lighting power, window to wall ratio (WWR), annual DHW demand), for the case of Bydgoszcz the following table shows the values adjusted for each of the construction periods defined for the buildings.

Table 37 Main parameters adjusted in the district energy model according to the building use

Parameters	Residential	Single Family House	Hotel	Health care	Education	Office	Commerce	Restaurant	Sport	Public adm.
Equipment internal gains [W/m2] [9]	4,40	4,40	3,15	3,58	4,70	11,77	5,20	18,88	16,02	5,48
Occupancy internal gains [W/m2] [9]	1,76	1,76	4,72	7,33	29,82	7,05	8,18	11,00	25,50	5,94

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Lighting power [W/m2] [9]	6,46	6,46	10,76	13,02	10,66	15,00	15,07	9,69	10,76	9,69
WWR [10]–[14]	0,27	0,27	0,17	0,23	0,28	0,50	0,20	0,30	0,20	0,50
Annual DHW demand $[kWh/m^2]$ [15]	13,90	13,90	126,40	133,40	57,20	3,20	3,20	35,30	256,00	3,20

Finally, the schedules used for the hourly energy demand characterization of Bydgoszcz are detailed in the following table depending on the use (heating, cooling, occupancy, lighting, equipment) and depending on the use of the building.

Table 38 Schedules used for the modelling of the Bydgoszcz study area (According to the database of Design Builder)

	Heating	Cooling	Occupancy	Lighting	Equipment
Residential	Winter: Until: 07:00, 0; Until: 23:00, 1; Until: 24:00, 0; Summer: Until: 24:00, 0.	Summer: Until: 15:00, 0; Until: 23:00, 1; Until: 24:00, 0; Winter: Until: 24:00, 0.	Until: 07:00, 1; Until: 08:00, 0.5; Until: 15:00, 0.25; Until: 23:00, 0.5; Until: 24:00, 1	Until: 07:00, 0.1; Until: 18:00, 0.3; Until: 19:00, 0.5; Until: 23:00, 1; Until: 24:00, 0	Until: 07:00, 0.1; Until: 18:00, 0.3; Until: 19:00, 0.5; Until: 23:00, 1; Until: 24:00, 0
Hotel	Winter: Until: 24:00, 1 Summer: Until: 24:00, 0 Summer: Until: 24:00, 0	Summer: Until: 24:00, 1 Winter: Until: 24:00, 0 Winter: Until: 24:00, 0	Until: 08:00, 1; Until: 09:00, 0.25; Until: 21:00, 0; Until: 22:00, 0.25; Until: 23:00, 0.75; Until: 24:00, 1	Until: 08:00, 0; Until: 09:00, 1; Until: 21:00, 0; Until: 24:00, 1	Until: 07:00, 0; Until: 08:00, 0.53; Until: 09:00, 1; Until: 10:00, 0.53; Until: 17:00, 0; Until: 18:00, 0.3; Until: 19:00, 0.53; Until: 20:00, 0.77; Until: 22:00, 1; Until: 23:00, 0.77; Until: 24:00, 0.3
Education	Winter: Until: 05:00, 0; Until: 18:00, 1; Until: 24:00, 0; Summer, weekends and holidays: Until 24:00: 0	Summer: Until: 05:00, 0; Until: 18:00, 1; Until: 24:00, 0; Winter, weekends and holidays: Until 24:00: 0	Until: 07:00, 0; Until: 08:00, 0.1; Until: 09:00, 0.25; Until: 10:00, 0.75; Until: 12:00, 1; Until: 14:00, 0.5; Until: 16:00, 1; Until: 18:00, 0.5; Until: 24:00, 0; Weekends and holidays: Until 24:00: 0	Until: 07:00, 0; Until: 19:00, 1; Until: 24:00, 0; Weekends and holidays: Until 24:00: 0	Until: 07:00, 0; 21:00, 1; Until: 24:00, 0; Weekends and holidays: Until 24:00: 0
Office	Winter: Until: 05:00, 0; Until: 19:00, 1; Until: 24:00, 0; Summer, weekends and holidays: Until 24:00: 0	Summer: Until: 05:00, 0; Until: 19:00, 1; Until: 24:00, 0; Winter, weekends and holidays: Until 24:00: 0	Until: 07:00, 0; Until: 08:00, 0.25; Until: 09:00, 0.5; Until: 12:00, 1; Until: 14:00, 0.75; Until: 17:00, 1; Until: 18:00, 0.5; Until: 19:00, 0.25; Until: 24:00, 0; Weekends and holidays: Until 24:00: 0	Until: 07:00, 0; Until: 19:00, 1; Until: 24:00, 0; Weekends and holidays: Until 24:00: 0	Until: 07:00, 0; 20:00, 1; Until: 24:00, 0; Weekends and holidays: Until 24:00: 0
Commerce	Winter: Until: 07:00, 0; Until: 18:00, 1; Until: 24:00, 0; Summer, Sundays and holidays: Until 24:00: 0	Summer: Until: 07:00, 0; Until: 18:00, 1; Until: 24:00, 0; Winter, Sundays and holidays: Until 24:00: 0	Until: 09:00, 0; Until: 10:00, 0.75; Until: 12:00, 1; Until: 14:00, 0.75; Until: 17:00, 1; Until: 18:00, 0.75; Until: 24:00, 0; Sundays and holidays: Until 24:00: 0	Until: 09:00, 0; Until: 18:00, 1; Until: 24:00, 0; Sundays and holidays: Until 24:00: 0	Until: 08:00, 0; 18:00, 1; Until: 24:00, 0; Sundays and holidays: Until 24:00: 0
Public adm.	Winter: Until: 05:00, 0; Until: 19:00, 1; Until: 24:00, 0; Summer, weekends and holidays: Until 24:00: 0 Summer and holidays: Until	Summer: Until: 05:00, 0; Until: 19:00, 1; Until: 24:00, 0; Winter, weekends and holidays: Until 24:00: 0 Winter and holidays: Until	Until: 07:00, 0; Until: 08:00, 0.25; Until: 09:00, 0.5; Until: 12:00, 1; Until: 14:00, 0.75; Until: 17:00, 1; Until: 18:00, 0.5; Until: 19:00, 0.25; Until: 24:00, 0; Weekends and holidays: Until 24:00: 0	Until: 07:00, 0; Until: 19:00, 1; Until: 24:00, 0; Weekends and holidays: Until 24:00: 0	Until: 07:00, 0; 18:00, 1; Until: 24:00, 0; Weekends and holidays: Until 24:00: 0

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	24:00: 0	24:00: 0			
Sport	Winter: Until: 05:00, 0; Until: 21:00, 1; Until: 24:00, 0;	Summer: Until: 05:00, 0; Until: 21:00, 1; Until: 24:00, 0;	Until: 06:00, 0; Until: 07:00, 0.25; Until: 09:00, 1; Until: 12:00, 1; Until: 14:00, 0.5; Until: 18:00, 0.5; Until: 20:00, 1; Until: 22:00, 0.5; Until: 24:00, 0	Until: 06:00, 0; Until: 22:00, 1; Until: 24:00, 0	Until: 06:00, 0; Until: 22:00, 1; Until: 24:00, 0
	Summer and holidays: Until 24:00: 0	Winter and holidays: Until 24:00: 0			

<u>Conclusions of the adjustment phase:</u>

In the case of Bydgoszcz, obtained results from the modelling of the district have been compared respect to the values provided in literature, from Tabula (European Union, "TABULA WebTool) in this case. Tabula provides reference heating energy demands for the residential buildings of Poland distinguishing the construction period of buildings.

The figure below shows the results of the comparison.

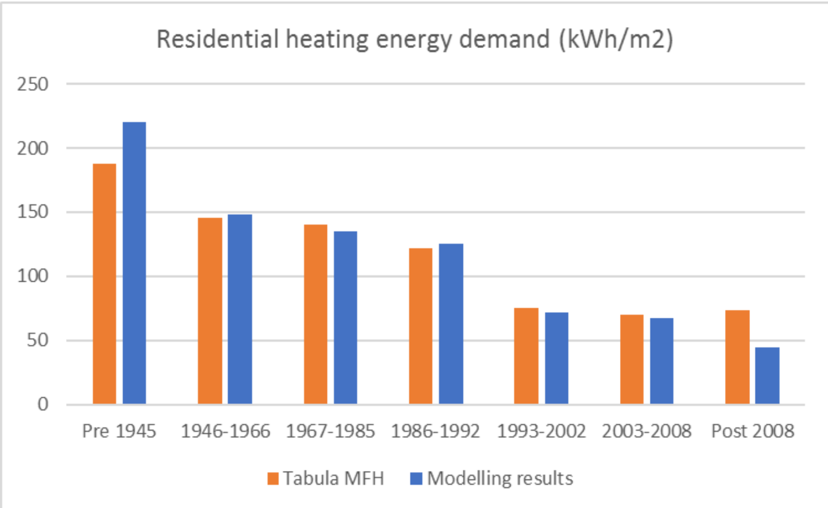

Figure 52 Residential heating energy demand comparison: tabula values vs mySMARTLife modelling results.

The comparison shows a good approach of the modelling energy characterization respect to actual building energy demands from Tabula. The variation obtained per each period is detailed in the following table.

Table 39 Comparison of the modelling results respect to the values provided in Tabula database

	Tabula	Modelling results	Error (%)
Pre1945	187,3	220	18%
1946-1966	145,8	148	2%
1967-1985	140,6	135	4%

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1986-1992	122,2	125	2%
1993-2002	75,2	71	4%
2003-2008	69,5	67	4%
Post 2008	73,8	45	40%

Results obtained show that the main difference would be obtained for those buildings constructed before 1945 after 2008. This is in line also with the results obtained in Palencia. Therefore, modelling results can be overestimated for the older buildings and underestimated for the newest buildings. In any case the results obtained are considered appropriate compared to the differences observed with other modelling tools.

Besides, the results obtained have also been compared respect to other references from literature. These references are detailed in the table below and use for the comparison the average values for the heating demand of buildings. In the area of study of Bydgoszcz modelling results show an average heating demand of 183 kWh/m^2 taking into account all the buildings.

Table 40 Comparison of the modelling results respect to the values provided in different sources of information

Source	Average heating demand [kWh/m^2]	Año	Difference
Energy efficiency in Poland in years 2006 – 2016 [17]	193,1	2007	5%
NEEAP Poland 2014 [18]	181,18	2007	1,20%
Energy Efficiency trends and policies in Poland in years 2006-2016 [19]	191,04	2009	4%

The comparison shows that in any case the difference observed is lower that 5%. Therefore, it is considered that the model provides appropriate results for the case of study and that it has been adequately adjusted.

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7. Case study results

The case study results are included in the files that are linked to this deliverable and that provided to the cities. These files include for each city and for each of the selected district all the information and the results obtained in this task. Considering that the output of the task includes a great amount of information, this section is focused on providing a general overview and a brief description of the results obtained. This section includes some of the most representative figures of the results obtained.

Therefore, for each city/district the following files are provided;

- **The input shapes** of the area evaluated for each city.
- **The shape file ("City Results")** of the area evaluated for each district which includes the following information specifically for each building;

Table 41: Information included in the shape files

Information included
Building ID
Annual Heating Demand
Annual Heating Demand Square Meter
Annual Cooling Demand
Annual Cooling Demand Square Meter
Annual DHW Demand
Annual DHW Demand Square Meter
Use Map (Use of the building)
Year of Construction
Total Height
Foot Print Area
Gross Floor Area
Number of Floors
Roof Area
Exterior Envelope Area
Window Area
Volume

- **A XLSX file ("City district energy modelling results")** which includes the same type of information as the included in the shape file.
- **A second XLSX file ("City district energy modelling results aggregated")** which includes aggregated information and results by building typology and age groups. In this case the following results are included for each building group;

Table 42: Information included in the second XLSX file

Information included
Use
Period

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Number of Buildings
Total Gross Floor Area
Net Heated Floor Area
Annual Useful Heating Demand
Annual Useful Cooling Demand
Annual Useful DHW Demand
Annual Useful Heating Demand Square Meter
Annual Useful Cooling Demand Square Meter
Annual Useful DHW Demand Square Meter

- **A third file ("City Hourly Results.db")** that should be opened with database (such us DB Browser for SQLite). This file includes information for each of the buildings of the district but in this case in an hourly basis. The information included for each building is the following;

Table 43: Information included in the second XLSX file

Information included
Period
Use
Day of Year
Hour of Day
Season
Heating
Cooling
DHW

7.1 Palencia area of study

This section includes just a summary of the results obtained from the modelling of the area of study of Palencia. The table below serves as a quick characterization of the annual energy needs of the area of study of Palencia showing the energy demands for heating, cooling (mainly for tertiary buildings), DHW, electricity needs for equipment and lighting per each building periods.

Table 44 Total heating, cooling and DHW demand and electric consumptions of the buildings of area evaluated in Palencia

	Heating demand [kWh/year]	Cooling demand [kWh/year]	DHW demand [kWh/year]	Equipment demand [kWh/year]	Lighting demand [kWh/year]
1900-1945	3.904.909	125.908	691.108	411.033	662.579
1945-1960	6.748.492	465.880	4.388.699	1.870.269	1.783.776
1960-1979	37.245.497	619.440	4.436.556	4.416.565	6.603.509
1979-2006	21.861.628	595.219	5.340.971	5.588.631	8.241.092
2006-2013	2.847.163	167.509	891.859	1.085.470	1.617.056
Post 2013	414.787	16.043	139.040	164.446	235.112
Total	**73.022.476**	**1.989.999**	**15.888.232**	**13.536.414**	**19.143.124**

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The figure below shows a higher level of detail of the energy demands specifying their allocation depending on the use of the buildings. It is observed that the residential sector (represented in the figure in the secondary axis) is the main responsible of the heating energy demand of the area with 89% (with most of the buildings constructed between 1960 and 1979), followed by public administration with 4%, education with 4%, and by office and health care with 1% each.

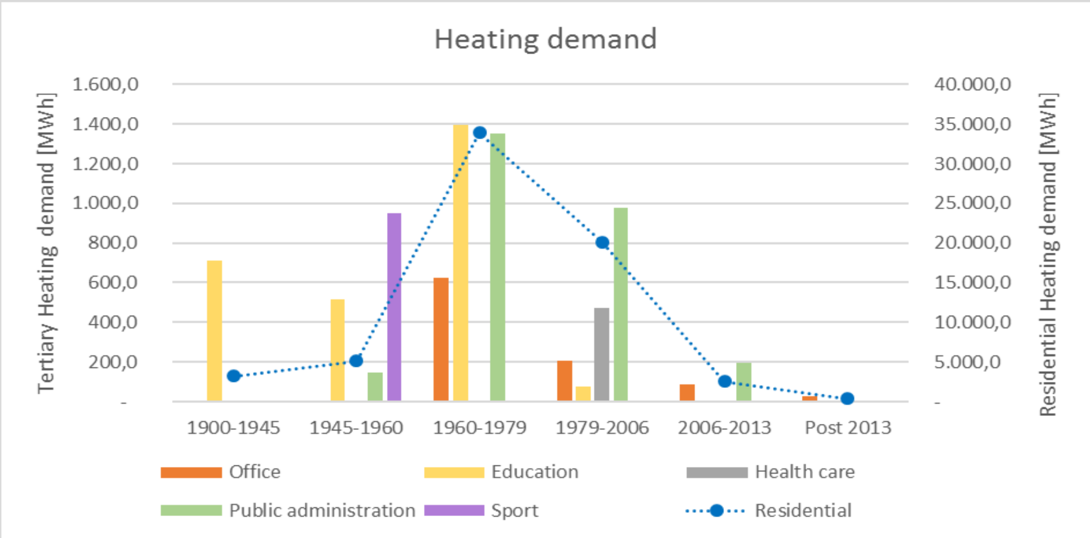

Figure 53 Heating demand of the buildings evaluated for Palencia

With regard to the electricity use of the buildins that are within the boundaries of the area selected, the figure below shows the dsitribution of these needs per building use and period. It is observed that 77% of the electricity needs correspond to residential buildings, 7% sport facilities, 5% public adminsitration, 5% office, 5% eduation and 1% health care.

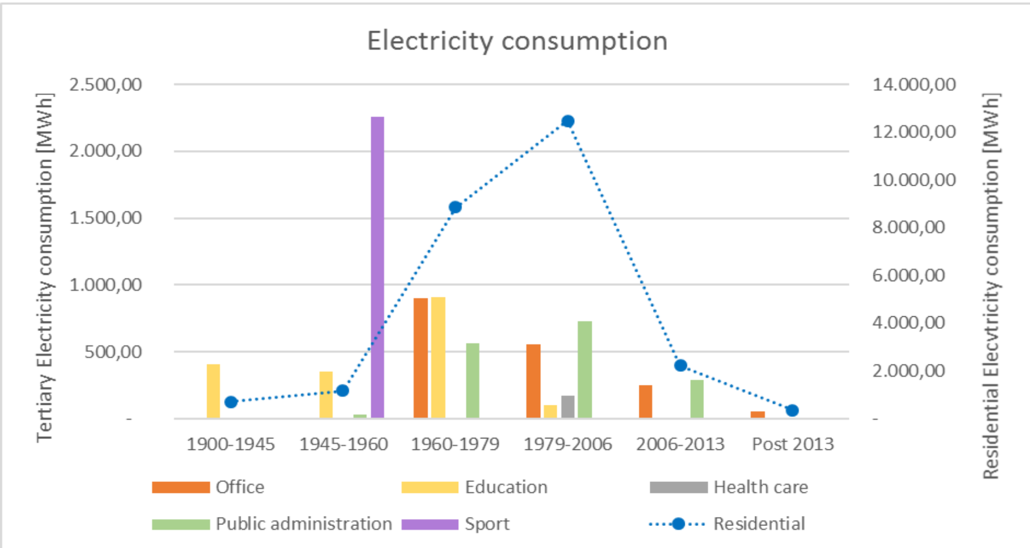

Figure 54 : Electricity consumption of the buildings evaluated for Palencia

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

All this information is included in the shape resutls of the modelling which are compatible with the cityGML of the city. As an example of the visual respresentation of the resutlts oftained in the modelling, the following two figures show respectively the heating demand (kWh/m2) and the electricity needs (kWh/m2) of the district selected in Palencia in visual way with a colour scale.

In the same way, the rest of the results obtained in the modelling can be also visualized. All this visualization is available for each city in the files that are linked to this subtask.

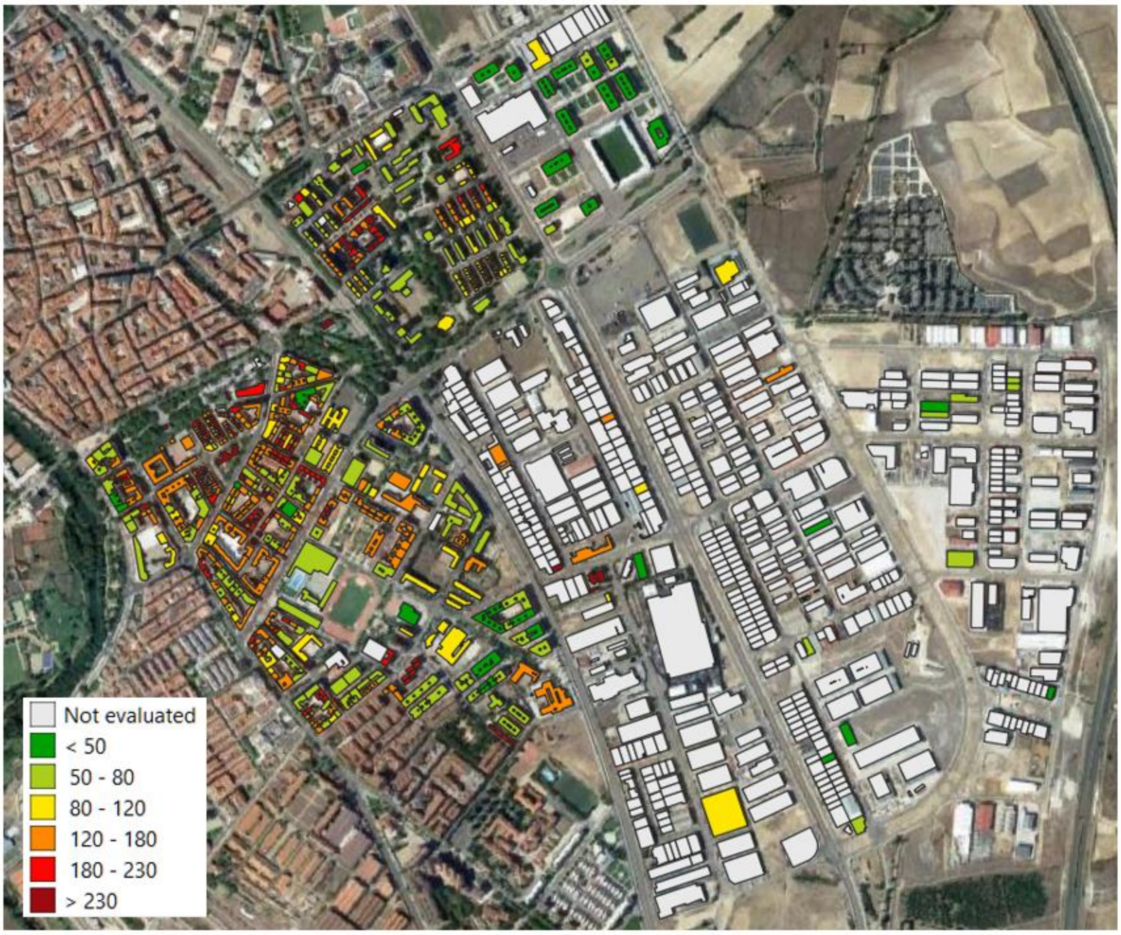

Figure 55 Heating demand (kWh/m^2) of the district selected in Palencia

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

Figure 56 Total electricity consumption (kWh/m2) of the district selected in Palencia

Finally, although it is out of the scope of the project, as it was done for the lighthouse cities in this case taking into account that the required input data is available in the adequate format for the entire city and considering that the model has been adjusted properly, the same analysis has been carried out not only for the area of study but also for the entire city of Palencia. All the results are tehrefore provided to the municipality.

The figure below is just a visual representation of the type of resutls obtained for the entire city of Palencia. In thi case for the total heat demand.

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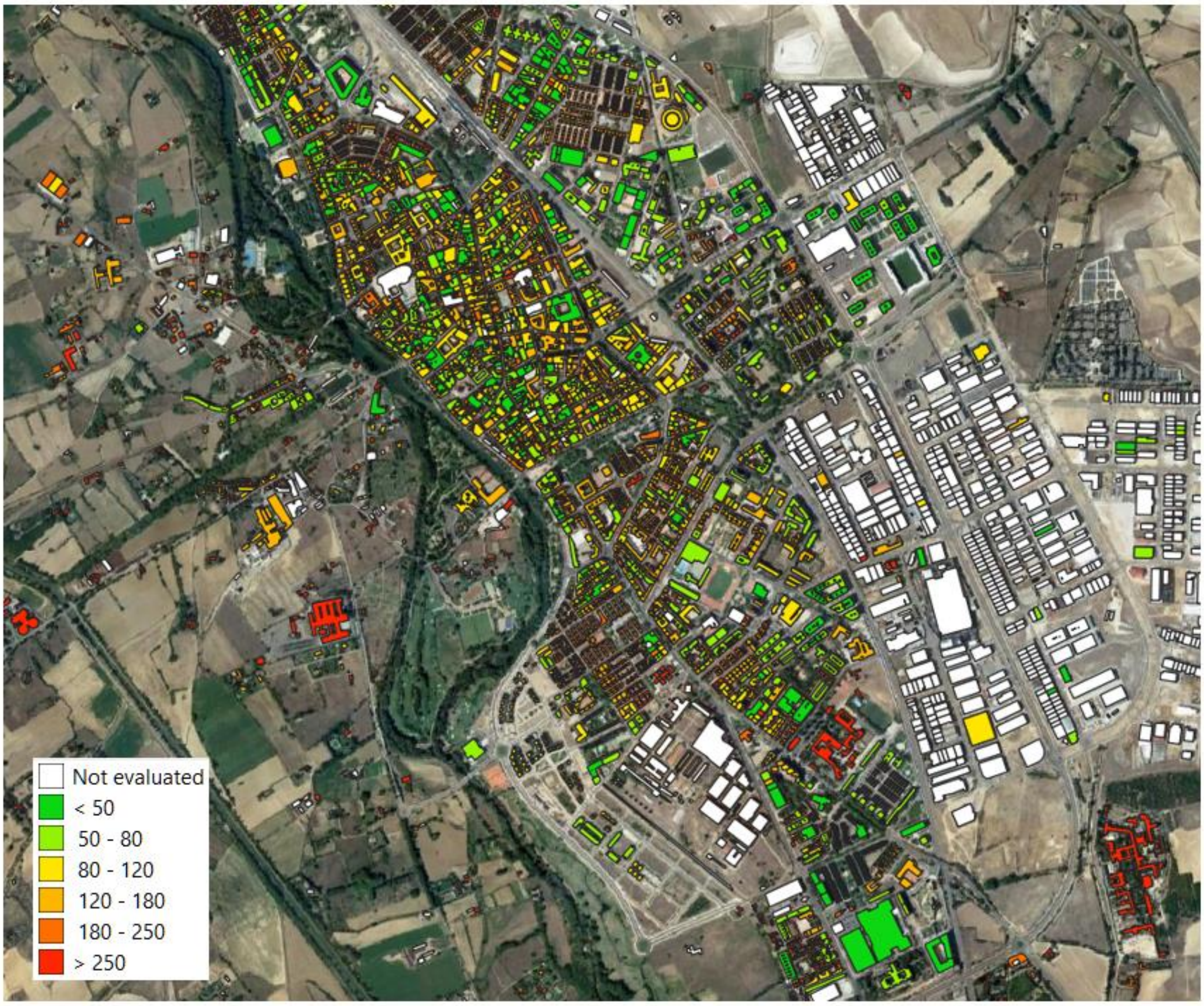

Figure 57 Heat demand (kWh/m^2) of a larger area of Palencia (the analysis has been carried out for the entire city of Palencia)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

7.2 Rijeka area of study

This section includes a summary of the results obtained from the modelling of the area of study of Rijeka. The table below serves as a characterization of the annual energy needs for the area of study of Palencia showing the energy demands for heating, cooling, DHW, electricity needs for equipment and lighting per each building period (in this case only one building period is required).

Table 45 Total heating, cooling and DHW demand and electric consumptions of the buildings of area evaluated in Rijeka

	Heating demand [kWh/year]	Cooling demand [kWh/year]	DHW demand [kWh/year]	Lighting demand [kWh/year]	Equipment demand [kWh/year]
Pre 1945	12.175.885	243.185	795.393	1.109.747	1.789.965

The following figure shows a higher level of detail for the distribution per use of the heating energy demand of the area selected by the city. The residential sector is responsible of the 86% of the total heating demand and the office buildings and commerce are responsible of the 5% and 9% respectively.

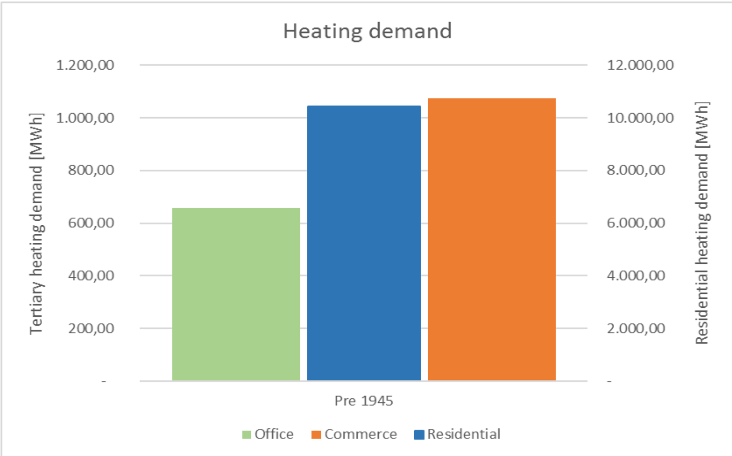

Figure 58 Heating demand of the buildings evaluated for Rijeka

In the same way, the figure below shows a higher level of detail for the distribution per use of the electricity needs of the area selected by the city. The residential sector is responsible of the 64% of the total electricity needs and the office buildings and commerce are responsible of the 12% and 23% respectively.

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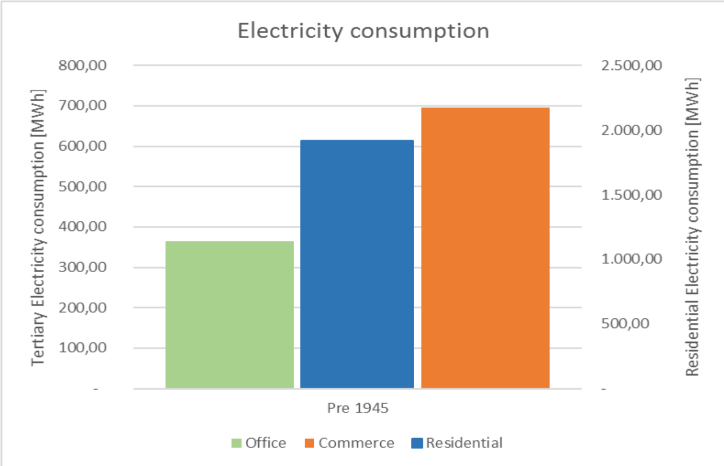

Figure 59 Electricity consumption of the buildings evaluated for Rijeka

As described in the case of palencia, all this information is included in the shape resutls of the modelling which are compatible with the cityGML of the city. As an example of the visual respresentation of the results obtained in the modelling, the following two figures show respectively the heating demand (kWh/m2) and the electricity needs (kWh/m2) for the district selected in Rijeka.

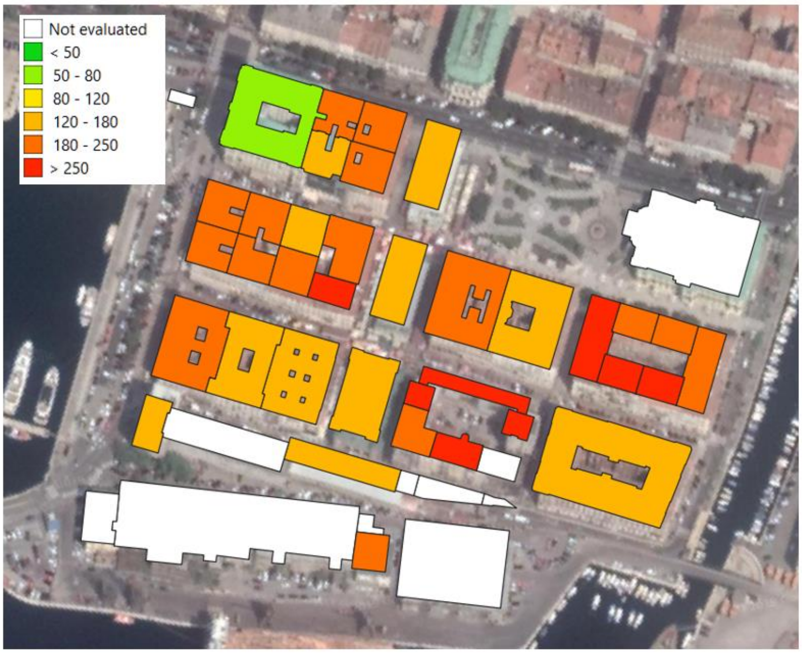

Figure 60 Heating demand (kWh/m^2) of the district selected in Rijeka

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

Figure 61 Total electricity consumption (kWh/m^2) of the district selected in Rijeka

In contrast to the case of Palencia in this case it was not possible to scale-up the entire study to the city scale since the mandatory data for the energy modelling, information such as the building age and their height, is not available for the buildings of the city. However, as a first step that can be useful for the future energy modelling studies, the height of the buildings has been obtained and prepared in the necessary way to be used (and also included in the CityGML of the city) in the energy modelling. In any case, the age of the building was still missing.

Therefore, buildings geometry has been obtained for the entire city as it is showed in the figure below.

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research and innovation programme under grant agreement No 731297.

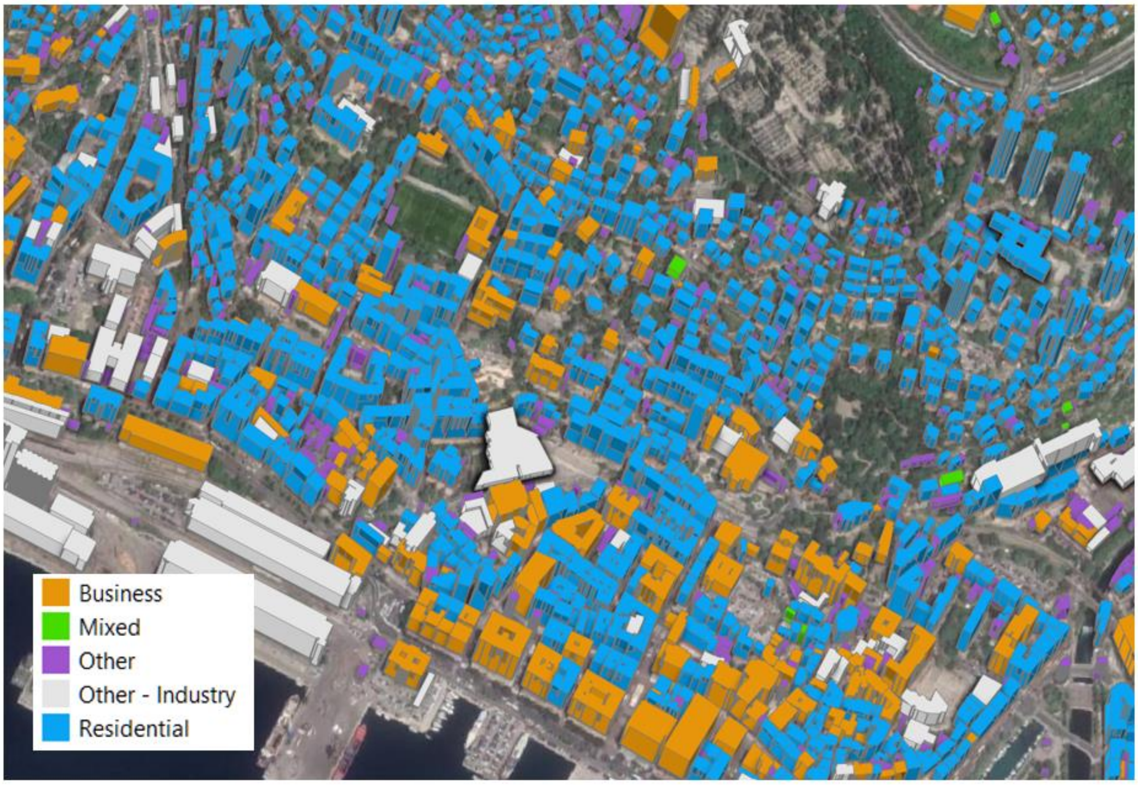

Figure 62 Building geometry for the city of Rijeka compatible with the CityGML and prepared for the future energy modelling.

In this case, the information regarding the use of buildings is also limited in the cadastre of the city to the following five uses; Residential, mixed, business, other – industry and other. The table below shows the floor area of the city per use of building.

Table 46 Ground floor area (GFA) of the city of Rijeka per use of building.

	GFA [m^2]
Other	1.229.962
Other - Industry	1.907.674
Residential	7.988.189
Mixed	289.502
Business	2.046.039

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

7.3 Bydgoszcz area of study

This section includes a summary of the results obtained from the modelling of the area of study of Bydgoszcz. The table below serves as a characterization of the annual energy needs for the area of study of Bydgoszcz showing the energy demands for heating, cooling, DHW, electricity needs for equipment and lighting per each building period.

Table 47 Total heating, cooling and DHW demand and electric consumptions of the buildings of area evaluated in Palencia

	Heating demand [kWh/year]	Cooling demand [kWh/year]	DHW demand [kWh/year]	Lighting demand [kWh/year]	Equipment demand [kWh/year]
Pre-1945	279.813.519	2.588.253	21.257.392	33.455.620	21.809.810
1946-1966	47.379.952	1.460.097	6.688.671	10.548.400	7.205.723
1967-1985	42.571.583	1.283.767	6.761.247	10.270.457	6.586.068
1986-1992	5.326.733	179.128	1.183.159	1.294.684	910.381
1993-2002	5.675.815	612.045	1.339.589	4.399.707	2.317.109
2003-2008	4.485.018	818.650	2.306.887	6.721.881	3.001.134
Post-2008	4.030.603	466.481	2.443.098	3.354.531	2.146.116
Total	**389.283.223**	**7.408.423**	**41.980.043**	**70.045.280**	**43.976.340**

The following figure shows a higher level of detail for the distribution per use of the heating energy demand of the area selected by the city. The residential sector is responsible of the 85% of the total heating demand and the office buildings, office 4%, education 4%, health care 3% and commerce 3%.

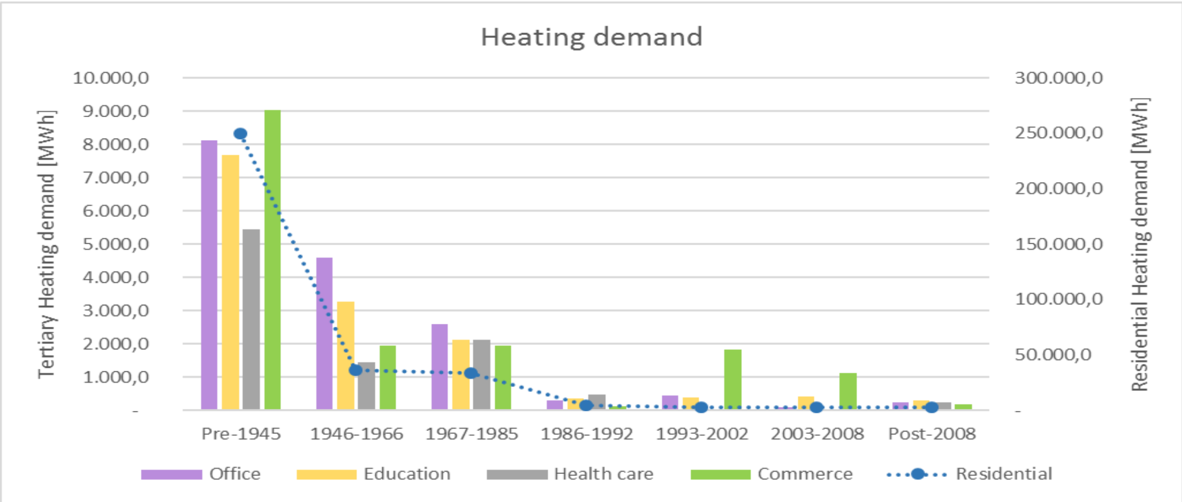

Figure 63 Heating demand of the buildings evaluated for Bydgoszcz

In the same way, the figure below shows a higher level of detail for the distribution per use of the electricity needs of the area selected by the city. The residential sector is responsible of the 67% of the total electricity needs, office 18%, education 11%, health care 2% and commerce 2%.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

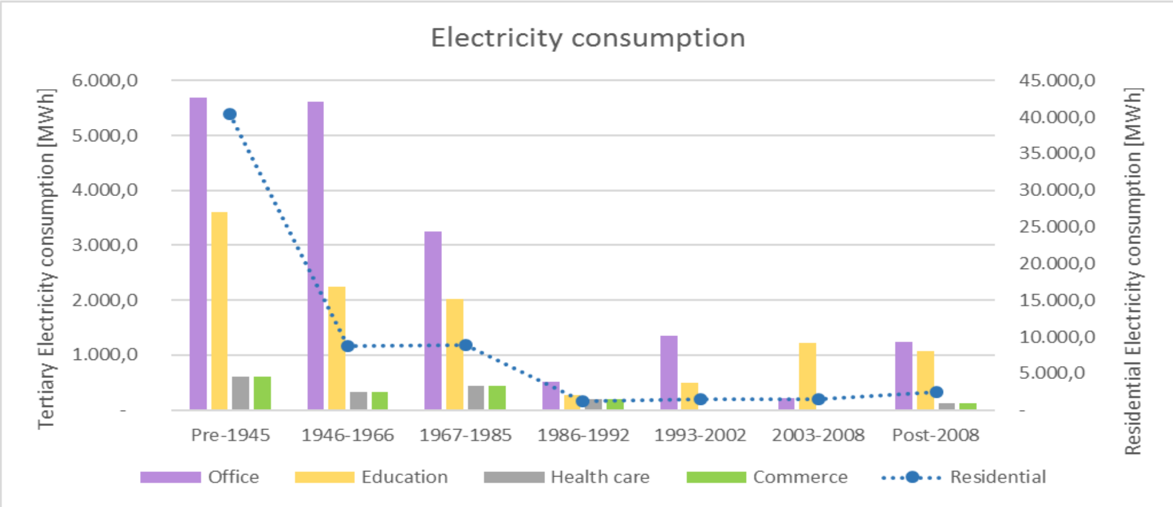

Figure 64 Electricity consumption of the buildings evaluated for Bydgoszcz

As descrived for the previous cases, all this information is included in the shape resutls of the modelling which are compatible with the cityGML of the city. As an example of the visual respresentation of the resutlts oftained in the modelling, the following two figures show respectively the heating demand (kWh/m2) and the electricity needs (kWh/m2) for the district selected in Bydgoszcz.

Figure 65 Heating demand (kWh/m^2) of the district selected in Bydgoszcz

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

Figure 66 Total electricity consumption (kWh/m^2) of the district selected in Bydgoszcz

Finally, although it is out of the scope of the project, as it was done for the lighthouse cities and in the case of Palencia, in this case taking into account that the required input data is available in the adequate format for the entire city and considering that the model has been adjusted properly, the same analysis has been carried out not only for the area of study but also for the entire city of Bydgoszcz. All the results are therefore provided to the municipality.

The figure below is just a visual representation of the type of resutls obtained for the entire city of Bydgoszcz. In this case the total heat demand of buildings is represented.

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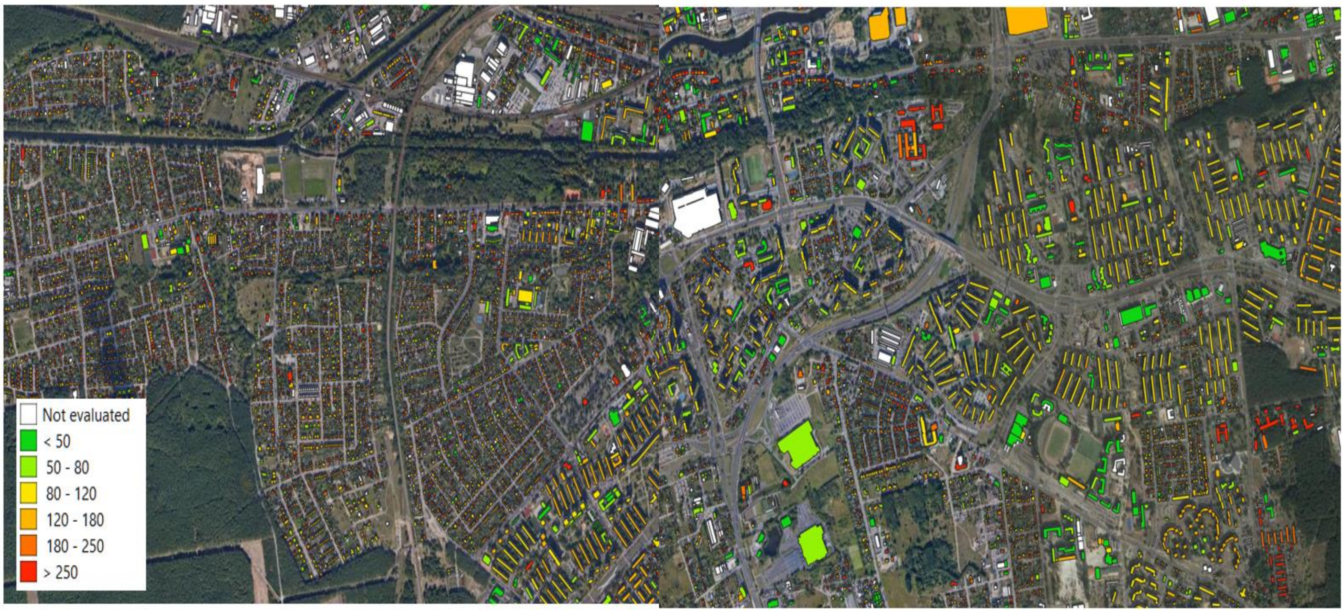

Figure 67 Heating demand (kWh/m^2) of other areas of Bydgoszcz (the analysis has been carried out for the entire city of Bydgoszcz)

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8. Conclusions

This deliverable includes a description of the work carried out in mySMARTLife project related to the energy analysis of the three follower cities which integrates as a basis the processing of the information available in the 3D model of each city. It has been observed that depending on the level of information available in each city there have been different requisites and results.

In contrast with the situation with the lighthouse cities, in this case it has been possible to generate the City-GML of the entire city for the three follower cities; Palencia, Rijeka and Bydgoszcz. However, the level of detail and the information included the City-GML of each city has been different. In the case of the city of Palencia and Bydgoszcz all the parameters defined as mandatory in the methodology have been included. But in the case of the city of Rijeka, the lack of information regarding the age of buildings and the difficulties faced for the processing of the height of buildings has limited the information included in the City-GML.

Regarding the energy modelling carried out, following the same procedure as in the case of the lighthouse cities, the results obtained have been adjusted as much as possible to the most realistic values. This phase has also been different for each city although in all the cases a similar process has been followed. Each model has been adjusted according to the information that was available in each city. In this regard the calibration, or the contrast done for each district, needs to be carefully interpreted because in most of the cases there was no actual monitoring data related to the energy consumptions of the buildings and the differences shown in the tables correspond to the variations obtained respect to other modelling results and energy labels. In any case, it is considered that good results have been obtained for all the models.

It is also remarkable that in for those cities which had all the required information available, the energy modelling developed in the first step for the district selected, has been scaled-up to the entire city. Therefore, the energy characterization of the buildings of the entire cities of Palencia and Bydgoszcz have been generated in this subtask although this was out of the scope of the project. However, in the case of Rijeka, this has not been possible. Although the problems with the height of buildings were finally solved, due to the lack of the parameter of the age (which is mandatory for the energy modelling), it was not possible to provide the energy characterization of the entire city, and only the area of study was evaluated. In any case, all the information available including the pre-processed height of the buildings has been included in the City-GML developed in a way that will be useful for future energy characterization studies that can be carried out in the city.

Besides, the results obtained in the Subtask 6.2.1 (described in this deliverable) have also contributed to a better understanding of the energy performance of the built environment of the area selected for each follower city. Besides, the scale-up analysis of the cases study to a larger area of the cities has resulted also really useful for the subtasks ST6.2.2 of the mySMARTLife project related to the energy scenario analysis of the following 10-20 years considering that it allows the generation of reliable scenarios for the deployment of different interventions that will be implemented in the cities as part of the project.

Finally, it needs to be mentioned that apart of this deliverable many files have been generated and provided specifically to each city. These files provide information to the municipalities that can be used in different ways depending on their necessities and capabilities.

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