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Three-dimensional urban models in complex rural environments. Proposal for automation in the historical centre of Cehegín.

Urban modelling processes are the basis for the management of Smart Cities. Automated workflows are typically used to model large portions of cities with homogeneous urban fabrics. These processes result in very simple three-dimensional models with large discrepancies with reality. However, the case of the historic centres of small cities is different due to the complexity of their urban fabric and the heterogeneity of their buildings.

This paper proposes a semi-automatic supervised modelling workflow that allows the elaboration of complex urban fabric models following the CityGML standard and its levels of detail. The case study focuses on the historic centre of Cehegín (Spain).

The advantage of this methodology is the use of downloadable data from public SDIs such as the Digital Cadastre (cadastral polygons) and the National Geographic Institute (LiDAR point clouds with an approximate density of 0.5 pts/m2). These data are geolocated and processed in GIS, and exported to Rhinoceros-Grasshopper3d where modelling algorithms are implemented for each level of detail, supported by statistical filters and automatic classifiers.

This results in richer and more accurate models than those obtained with automatic modellers and can be used for different applications in the field of management and simulation.

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1. INTRODUCTION

One of the first phases in the digitisation processes of cities is the three-dimensional modelling of their morphology, which makes it possible to obtain a digital representation of the city and facilitate its analysis, management and dissemination. Recently, these three-dimensional urban models are being studied as a basis for the management of Smart Cities and are therefore applied to the modelling of large cities with extensive and homogeneous urban fabrics (Jokela, 2016). In these cases, the problem of a three-dimensional survey of large areas of a city is faced with a high degree of volumetric simplification, either because the amount of data does not allow a scale of detail, or because its morphology does not present complex aspects. Nowadays there are web applications which allow an approximation to the automatic modelling of large parts of a city by simply providing their location and the desired extent of modelling.

However, other urban centres present very different problems. This is the case of the historical centres of smaller towns with complex urban fabrics where different periods overlap and which are dotted with catalogued historical elements. (Cecchini, 2019). That is to say, complex and non-uniform urban plots, where, in addition, there are typical characteristics of these settlements, such as an orography with large slopes or irregular street layouts. In these cases, the aforementioned automatic three-dimensional modelling methods are not useful if a certain degree of fidelity with the built reality is to be obtained.

Nowadays, the historical centres of many towns are being affected by increasing depopulation and abandonment processes due to the departure of inhabitants to other towns or to more modern parts of the same town. The management of urban centres is a key task for sustainable development and is included as a goal in the UN Agenda 2030 (UNO, 2015). The availability of informed three-dimensional models of these parts of the city would be of great help for urban management, maintenance and cultural dissemination. Historical centres cannot be left behind in digitisation and it is therefore considered important to address the problems involved in their three-dimensional modelling. In historical centres, the changes in elevation, the irregularity of the layout, the large number of morphological singularities in their roofs and the typological variety of buildings make it extremely complicated to carry out three-dimensional modelling on an urban scale and in a relatively short time.

For these urban models to be useful they must add referenced geospatial information, be interoperable and share information efficiently. It is therefore important that they are produced in a standardised way, under standards such as CityGML, which is an open data model framework of the Open Geospatial Consortium (OGC) within the philosophy of Spatial Data Infrastructures (SDI) (Álvarez et al., 2018). SDIs developed under the INSPIRE directive are an optimal framework for data exchange.


Fig. 1. Historical centre of Cehegin. General view with digital 3d model overlapped. Authors' image.

2. STATE OF THE ART

The initial methods of representing the urban landscape were based on CAD, from the definition of its geometric qualities. It was not until the advent of GIS technologies to provide information related to spatial analysis and data visualisation to assist in planning and design decisions (Guney, 2016). Nowadays, a wide range of modelling and data entry methods are available that take advantage of the potential of surveys (Juan Vidal & Merlo, 2008). Shiode (2000) classifies them according to the degree of reality (the amount of geometric content), types of data input (capturing

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heights, facade and information) and functionality (the degree of utility and analytical features). In 2000, there were more than 60 large-scale projects around the world (Batty et al., 2001). New techniques are currently being developed and refined to make urban processes more transparent and comprehensible. This is the case of The Environmental Simulations Center (ESC) (www.simcenter.org), which is working on the development of urban modelling technologies as tools for management and decision-making. There are platforms such as Cityvis (www.ciyuvis.io) that bring together visualisation projects of urban areas from all over the world and countless applications that allow their visualisation (Biljecki et al., 2016). Some of the most popular automatic urban modelling platforms are Cesium ion, CadMapper, Maps3D, OSM Buildings and MAPAcad, among others.

Regarding the techniques, several papers exist which discuss various methods for creating 3D urban models from LiDAR point clouds in both aerial and terrestrial modalities. Verma et al. (2006) present a method for detecting and modelling complex buildings from aerial LiDAR data using parametric roof shapes. Hernández and Marcotegui (2009) present an automatic method for detecting and classifying artifacts in mobile LiDAR data. Zhou (2012) develops a 2.5D geometry representation for building structures and proposes an automatic algorithm to discover and enforce global regularities resulting in high-quality 2.5D building models. Heo et al. (2013) propose a semi-automatic method for modeling building facades from terrestrial LiDAR data that improves productivity and accuracy compared to manual methods. Jayaraj and Ramiya (2018) develop a workflow for creating 3D building models in CityGML standard from airborne LiDAR point cloud. Finally, Wang et al. (2018) provide a review of the existing urban reconstruction algorithms, prevalent in computer graphics, computer vision and photogrammetry disciplines. While these papers do not directly address the main experiences in 3D urban models from LiDAR point clouds, they provide useful information on different methods for creating such models. Most of them are focusing on city areas with low density or non-complex urban fabrics and are not using cadastral information.

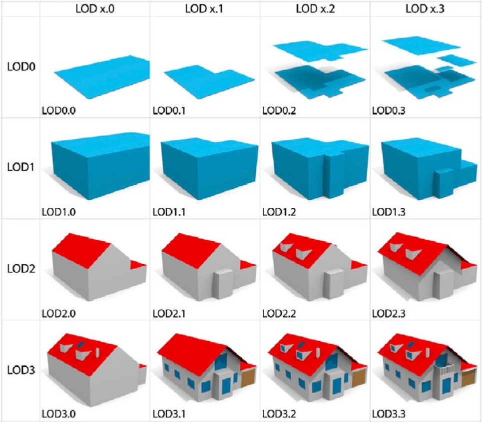

Fig. 2. Different levels of detail (LOD) in residential building (Biljecki et al., 2016).

We found examples of studies similar to the case of our research where the difficulty lies in the complexity of their urban fabric and building volumes. This is the case of the Radici project, applied to the province of Sondrio, Lombardy. In one of its municipalities, Chiuro, a pilot case is being developed for the application of advanced survey and digital representation techniques implemented by the Scuola Superiore di Studi sulla Città e il Territorio of the Alma Mater Studiorum in Bologna. We find similar cases such as those developed by Merlo (2010) in Il Castello di Sorana and Troiano within the research group DiDA (Università degli Studi di Firenze) which has worked in the villages of Aramo, Sorana and Pietrabuona (Tuscany).

3. AIMS AND CASE STUDY

In the case of urban planning, given the size of the city, the modelling procedures to be followed require speed and reliability in obtaining them, and this has led to the development of automatic and semi-automatic methods which seek to improve performance while being able to cover large urban extensions. This makes it impossible to detail the singularities of complex environments such as historical centres.

The aim of this paper is to propose a rapid semi-automatic modelling methodology that, using freely available downloadable data, obtains more detailed and accurate models than those offered by the automatic methods used for homogeneous city areas, always within the levels of detail set by the CityGML standard. For the first levels of detail, the workflow will use data from downloadable databases (Cadastre and LiDAR data -Light Detection and Ranging-), which will be dealt with in this article. For more detailed levels of modelling, data from field work obtained by means of aerial photogrammetry (drone) and terrestrial laser scanning will also be necessary.

This paper describes the workflow from planning, data downloading, processing and automatic modelling using algorithms (visual programming) as well as the results obtained, accuracy levels and difficulties encountered.

The case study where the modelling process is proposed is the historical centre of Cehegín in the Region of Murcia (Spain). The municipality of Cehegín has about 15,000 inhabitants and its historical centre, with an area of approximately 340,000 m2 (34.2 Ha), was declared a Historic-Artistic Site in 1982 by the Spanish Ministry of Culture. Although there are remains of settlements from the Neolithic and Chalcolithic periods, it was in the Iberian period when the population of Begastri arose (Gómez & Lozano, 2019). In the year 713 AD, the Muslims arrived in these lands and the Zenehegian decided to settle on the hill where the historical centre of present-day Cehegín is today, becoming an important Mozarabic community. The urban layout that is still preserved today is basically that generated at this time by topographical growth where the main streets follow the contour lines, and their transversal connections generate roads with large differences in level. After the fall of the Nasrid kingdom of Granada in 1492, the town grew to 3,000 inhabitants in the 15th century and

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5,000 at the end of the 16th century (Rioja, 2021). In the 18th century Cehegín saw its architectural heritage increase with new buildings such as the Palace of the Dukes of Ahumada, the Hospital de la Real Piedad, the Casa Jaspe and the Palace of the Fajardo family, all of which are included in the study area.

The Town Council of Cehegín is currently financing and actively collaborating in the elaboration of this study, interested in obtaining an informed model of the historical centre that will help in management and decision making.

4. MATERIALS AND METHODS

4.1. Materials / Data

In most automated urban modelling methods, the graphical information used for modelling is obtained from the cadastre database. These geometries are extruded vertically with a height obtained from the number of floors of each plot. The volumes thus obtained will always be a very simple approximation because the number of floors is multiplied by an estimated height between floors. It is then a combination of geometric and semantic information.

However, in the proposed case, we always work with geometric data but from different sources. The geometric information is available through open and free downloadable databases, such as the official website of the Cadastre (for the polygons in plan of the plots) and the Download Centre of the National Geographic Institute (IGN) from where digital elevation models (DEM) can be obtained in point cloud files taken from LiDAR flights (for orthometric altimetries) (Suarez et al., 2011). The data downloaded from the cadastre are CAD files in '.dxf' format with several layers, but the most useful is the one called 'building'. The downloaded point clouds were obtained by public LiDAR sensor flights from 2015 onwards, are provided in '.laz' format (compression of '.las'), coloured in RGB, georeferenced in ETRS89 and with a minimum point density of 0.5 points/m2.

All of these sources are resources which are updated by the agencies that hold them.

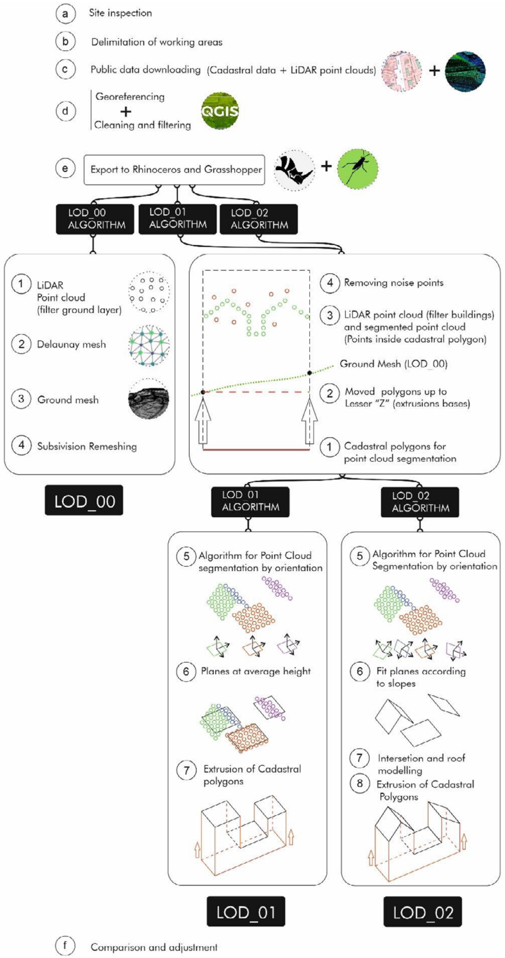

Fig. 3 Workflow

4.2. Methods

The creation of a model can be divided into several stages: data collection, geometry and semantics. In the proposed case we will focus only on data collection and geometry, without dealing with semantic information. The quality of the results obtained in each of these stages leads to the accuracy of the model, creating a more or less faithful representation of reality.

One of the most important initiatives for city modelling was the creation of the CityGML (City Geography Markup Language) standard. This is an open standard for urban modelling. It was developed by the Open Geospatial Consortium (OGC) for the exchange of complex models between different applications and software platforms, facilitating analysis and visualisation by standardising all aspects of the models.

One of the most important aspects of CityGML is the ability to support different Levels Of Detail (LOD) in modelling. The standard sets LOD 0 to represent the terrain, LOD 1 for simplified cubic buildings (up to eaves height or medium height), LOD 2 includes roof shape and orientation, and LOD 03 and LOD 04 for a higher level of detail with façade openings and interior spaces (Fig. 2). Each of these levels can have different applications. Biljecki et al. (2016) have identified more than 30 uses, such as: presentation and exploration of the city; analysis and simulation of data and physical situations; collaboration with other types of applications; management of infrastructures and services at different scales or help in decision-making for emergency situations. These levels of detail (LOD 0, LOD 1 and LOD 2) will be the objective to be achieved with the starting data and the methods proposed below.

The general procedure applied consists of six main phases:

a.- Site inspection of the working area; b.- Delimitation of zones; c.- Download of public data; d.- Georeferencing, filtering and refining of the starting data; e.- Design and application of the modelling algorithms for LOD 0, 1 and 2; f.- Comparison and adjustment. Assessment of the obtained modelling and comparison with point clouds and reality (Fig. 3).

4.2.1. Site inspection and delimitation

When undertaking the urban modelling of complex areas, it is first necessary to carry out a phase of

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Fig. 4. Maps of planning areas. Left: Historical Centre with zones. Right: Pilot area (ZP) with building blocks.

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Fig. 5. Lidar point cloud of the historical centre and cadastral data overlapped and geo-referenced in QGis.

reconnaissance and photography in order to know the urban fabric, the scale of buildings, the types of roofs, as well as the extension of the area to be treated. The historical centre is then delimited (in this case, it is taken from the General Urban Development Plan) and subdivided into different zones according to preferences, difficulty or areas of interest. Each of these zones, in turn, is further divided into blocks to facilitate the location and management of the whole process. It is important that, at the geometric level, these delimitations are carried out by means of closed contiguous polylines, as this will help the subsequent segmentation of the data and the orderly production of the model (Fig. 4). For the final segmentation of the point clouds and the detection of the buildings, the closed polygons of the buildings downloaded from the cadastre will be used.

4.2.2. Downloading, filtering and refining of input data.

Once the working areas have been defined, the geometric data is downloaded. In the case of the polygons of the constructions, from the website of the Digital Cadastre (https://www.sedecatastro.gob.es) and for the download of the LiDAR point clouds, the website of the National Geographic Institute is used in the section of Digital Elevation Models (https://centrodedescargas.cnig.es/CentroDescargas/index.jsp). All of this geometric data must be perfectly geolocated and for this purpose it is downloaded in the same official reference system ETRS89, in UTM projection zone 30, with EPSG 25830, which allows us to open it in GIS in order to process and position it. (Fig. 5).

For this purpose, the free software QGis (v3.28) has been used, which allows on the one hand the direct download of cadastral data and the loading of point cloud layers in '.las' or '.laz' formats. In addition, a layer with the aerial orthoimage of the Google Maps service is loaded as background, as a basis for orientation and checking.

If the modelling algorithms were applied directly to these data, the survey obtained would differ greatly from reality. In order to improve accuracy, some adjustments are necessary. The first of these is to contrast the cadastral plan and its plots with real aerial photographs, as these cadastral plans are often out of date or contain errors. In this sense, updated CAD maps from the technical services of the town hall are of great help. Within the cadastral data, the most useful layer is the one called 'building' or 'building part'.

Next, it is also necessary to filter the point clouds obtained from LiDAR flights that are classified according to different layers with different numbering. These files may contain unidentified points, overlapping points, noise or simply data that are of no interest for urban modelling. The most useful layers are the so-called 'ground' (2) and 'buildings' (6). In addition, it is also convenient to trim the extent of the downloaded clouds to fit the study area and thus optimise the workflow. In the proposed case, the point clouds are divided according to the previously delimited zones (Fig. 6). There are different add-ons to perform these tasks such as LAStools from Rapidlasso GmbH.

4.2.3. Design and implementation of modelling algorithms for LOD 0, 1 and 2.

These filtered and geolocated data are exported to the Rhinoceros software to proceed to the design of the modelling algorithms with the Grasshopper3D plug-in. In order to optimise the work, it was decided to carry out no more than two algorithms for each level of detail (LOD) of which only the general procedure will be described here.

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Fig. 6 Left: Lidar point cloud filtered (layers 2 and 6) and segmented to Pilot Area. Right: Density of Lidar point cloud.

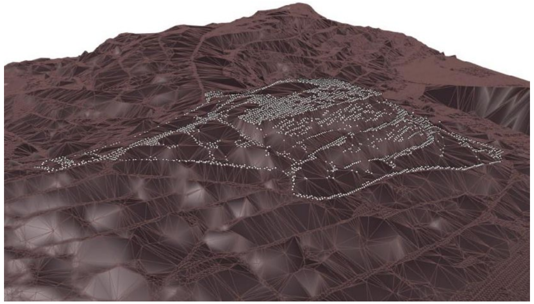

Fig. 8. Delaunay mesh of historical centre with ground point cloud of pilot area overlapped.

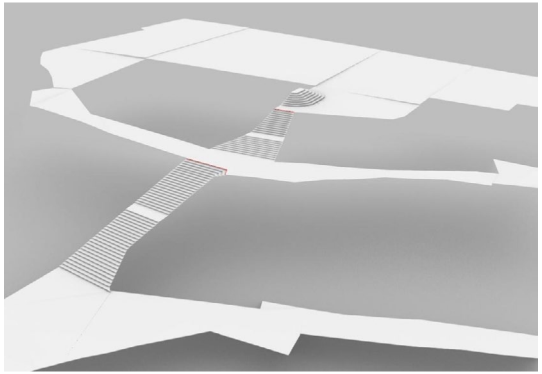

Fig. 9. Model with street pavement and stairs.

For the conformation of the whole terrain (LOD 0) it was decided not to work directly with a DTM but to use a DEM (LiDAR point cloud) of the whole historical centre but discarding all point layers except layer 2 'ground' (Fig. 7).

With this point cloud, a Delaunay-type mesh is obtained by triangulation, generating a modelling that includes the urbanised orography of streets and squares and not only the areas of bare ground (undeveloped areas) (Fig. 8). This three-dimensional grid is already positioned at the corresponding altitude above sea level. In the case presented, there is a relative difference in altitude of 76 metres between the highest and the lowest point. These large differences in altitude, which are so common in these urban areas, will introduce additional difficulties in the automatic modelling and will have to be considered. On the one hand, the mesh obtained has very pronounced triangulations that can deform the appearance of the model, and on the other hand, it does not allow the projection of points or polygons from the cadastre that will be used as a reference for the modelling. In order to solve these two disadvantages, a polysurface is superimposed that allows these projections while smoothing the triangulations of the original mesh.

Due to the steep gradients, it is very common to find streets with stairs. For this purpose, another algorithm has been prepared to model them, starting from the vectorised steps, their perimeter and the difference in height covered by the staircase (Fig. 9). Likewise, courtyard walls and slopes are automatically modelled if their traces are incorporated into a given layer and their height and thickness are specified in the modelling algorithm.

For the automated modelling at LOD 1 level (buildings simplified to flat roof polyhedra) the general procedural strategy is based on using the cadastre polygons as regions that segment the point cloud. In this way, each building is only able to hold the set of LiDAR points that impacted on it. Depending

Fig. 7. Left: Lidar point cloud filtered (layer 2 'ground'). Right: 3D Lidar point cloud of pilot area exported to Rhinoceros.

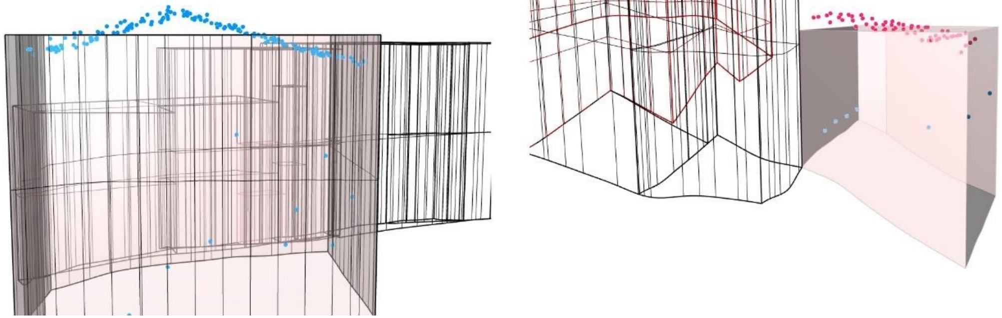

Fig. 10. LOD 01 models with flat roof at an average height of the point cloud, and ground adapting.

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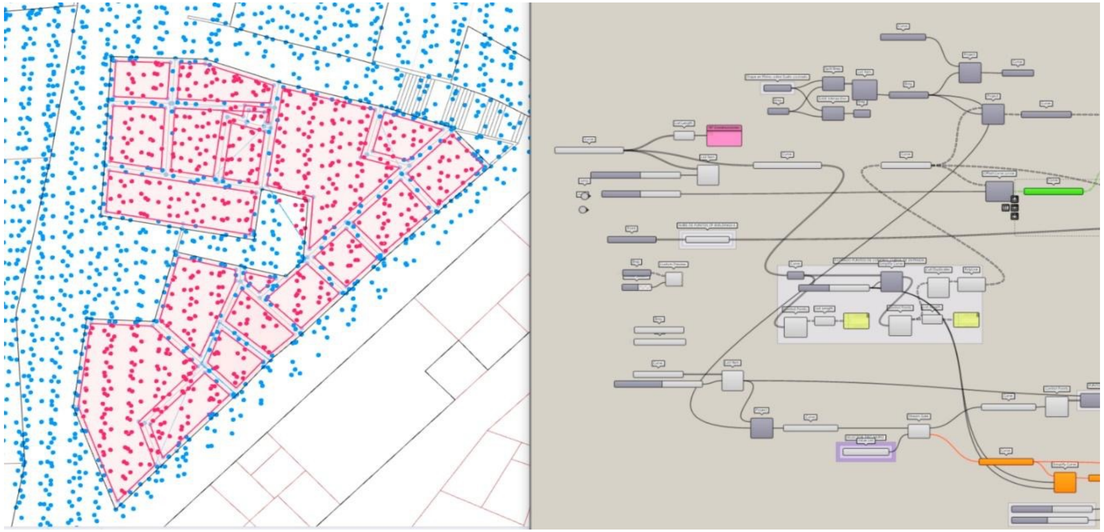


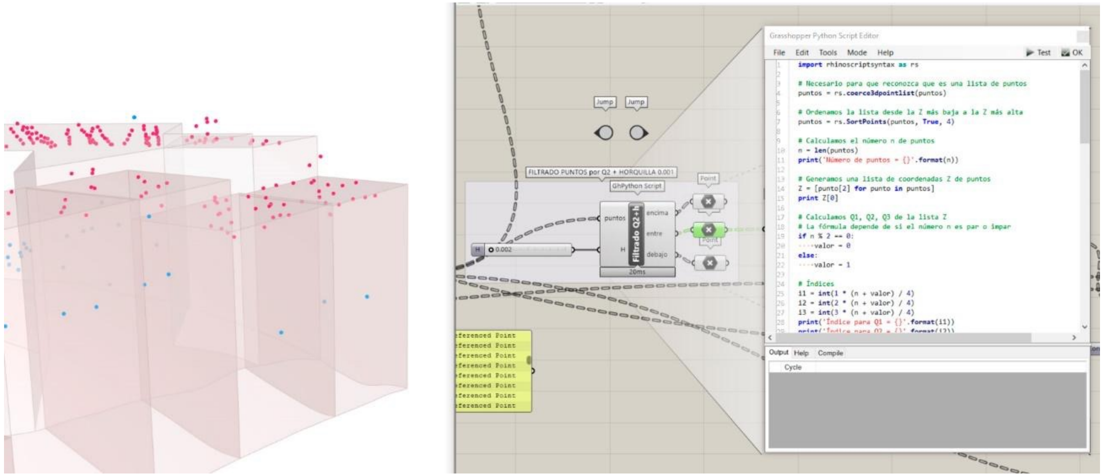
Fig. 11. First point cloud filtering and segmentation. Cadastral polygons with offset areas. Red points included; blue points excluded.

on the density of the DEM and the size of the buildings in these urban areas, between 5 and 45 points (samples) can be counted within each parcel. The algorithm then generates a horizontal plane at the average height of these points where it will project the modelled flat roof. To form the rest of the constructed model, it is sufficient to extrude the edges of the roof (eaves) until they intersect with the terrain model generated in the previous phase (Fig. 10).

This algorithm can be quickly extended to the rest of the cadastral polygons to model large areas in a short time. However, this general procedure has to be refined by two processes. The first one is based on not taking all the points that fall inside the cadastral delimitation, as sometimes the points located on the perimeter are erroneous or not descriptive of the built-upenvelope. To discard these edge points, it is sufficient to make a similar interior polygon (offset) at a certain distance from the perimeter (Fig. 11).

Once only the points inside the perimeter have been selected, it is necessary to program a second statistical filtering of the height of the points (z coordinate) to discard those erroneous points that may not belong to the roof (a balcony, a chimney, an antenna, etc.) and that may deform the plan obtained later. To do this, the points are sorted by their 'z' coordinate and classified into quartiles. This allows us to keep only those points that are within certain limits in height (Q2 (median) + range). This procedure has been programmed by means of a script in a single GhPython component (Fig. 12).

The same modelling algorithm described for LOD level 1 can be adapted to generate the shape of the pitched roofs to produce the LOD 2 model. In contrast to other procedures found (Miranda Martínez et al., 2021) in which a prior classification of the roofs by the number of gables (one, two, three or four-gabled roofs) is proposed, in the present work we have worked with two options. On one hand, it considers the modelling of isolated sloping skirts that have no relationship with each other, and on



```
import rhinoscriptsyntax as rs

# Necesario para que reconozca que es una lista de puntos
puntos = rs.coerce3dpointlist(puntos)

# Ordenamos la lista desde la Z más baja a la Z más alta
puntos = rs.SortPoints(puntos, True, 4)

# Calculamos el número n de puntos
n = len(puntos)
print('Número de puntos = {}'.format(n))

# Generamos una lista de coordenadas Z de puntos
Z = [punto[2] for punto in puntos]
print Z[0]

# Calculamos Q1, Q2, Q3 de la lista Z
# La fórmula depende de si el número n es par o impar
if n % 2 == 0:
    valor = 0
else:
    valor = 1

# Índices
i1 = int(1 * (n + valor) / 4)
i2 = int(2 * (n + valor) / 4)
i3 = int(3 * (n + valor) / 4)
print('Índice para Q1 = {}'.format(i1))
```

Fig. 12. Second statistical filtering of points by quartiles of the z-coordinates. Red points included; blue points discarded. Right: GhPython filtering script in Grasshopper.

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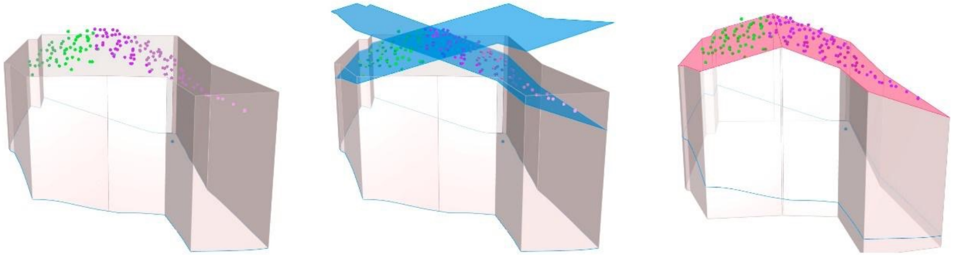
Fig. 13. LOD 02 Roof modelling. Step 1: Points clustering; Step 2: Planes adjustment; Step 3: Intersection and roof formation.

the other hand, it considers the case in which the skirts have a topological relationship, intersect and generate ridge, ridge tiles and valley tiles very similar to the one used by Verma et al. (2006). In our case it is possible thanks to the use of an unsupervised classification algorithm (clustering) called Gaussian Mixture that is applied to the set of selected and filtered points for each building and groups them according to their orientation or slope. Once the points have been classified, the planes are adjusted by least squares method and are used to project the floor plan of the buildings, thus generating the different roof surfaces (Fig. 13). It is necessary to clarify that each of the algorithms used has adjustable values that can be varied depending on the result obtained in real time, such as the offset distance at which the perimeter points are filtered, the threshold for calculating the median Q2 or the working values of the classifier.

4.2.4. Comparison and adjustment. Assessment of the modelling obtained.

Once the modelling algorithms have been run, supervision is needed to check for possible fuzzy areas due to the high complexity of the topography and the heterogeneity of the buildings.
There are several ways to perform these tasks. On the one hand, at the same time as the modelling is being carried out, the model is monitored with the basic aerial photographs downloaded from the Google Maps service. In addition, when there are singular areas, these are visited by members of the team. To evaluate the level of the results, certain areas are modelled with commercially available automated viewers and compared. Finally, point clouds have also been obtained by means of terrestrial laser scanning and aerial photogrammetry of some areas that allow the models to be superimposed and the results compared.

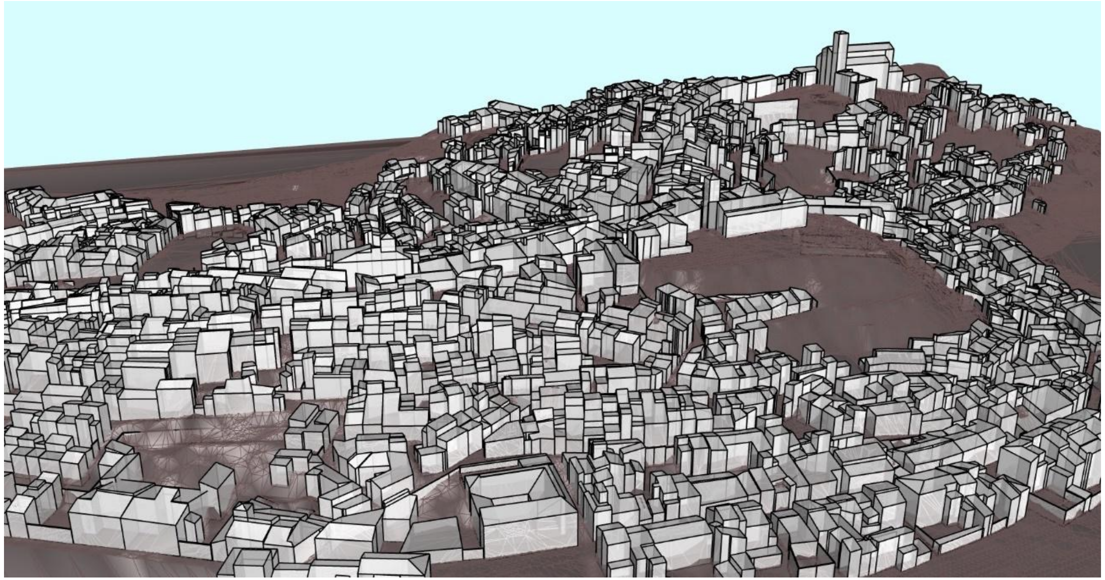
Fig. 14. LOD 02 Model of the historical centre of Cehegín. General View.

5. DISCUSSION OF RESULTS

With the procedure described above, the simplified volumes of the buildings in the historical centre have been obtained in the form of polysurfaces. These objects have all their points georeferenced and can therefore be subsequently translated into GML format. The heights represented in the three-dimensional model come from altimetric elevations (LiDAR) and are true to reality in that they are not derived from an approximation of semantic data. The model adapts to the orography and preserves the complexity of the urban fabric and its roofs. On the other hand, with the levels of detail worked on, minor details such as façade openings, chimneys or small dormers are obviated, and can be considered a level LOD 2.1 according to figure 2. With this methodology, a surface area of 34.02 Ha has been modelled, including 1403 buildings for each level of detail LOD 01 and LOD 02 (2806 in total) (Fig. 14).

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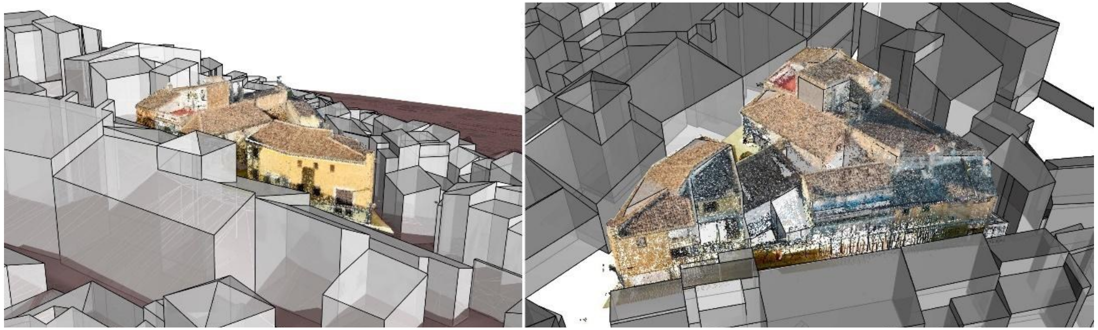
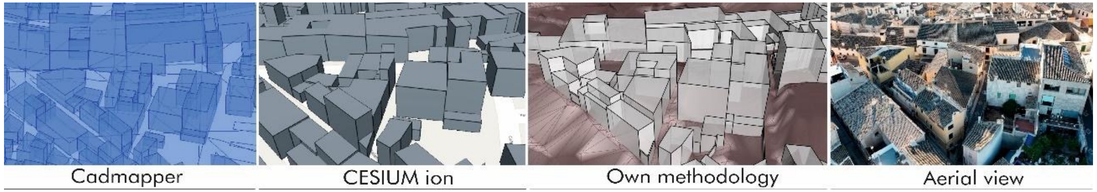


Fig. 15. Point cloud of Block nº11 inserted into LOD 02 model for assessment purposes

	LOD0	LOD1	LOD2	LOD3	LOD4
Model scale description	regional, landscape	city, region	city districts, projects	architectural models (outside), landmark	architectural models (interior)
Class of accuracy	lowest	low	middle	high	very high
Absolute 3D point accuracy (position / height)	lower than LOD1	5/5m	2/2m	0.5/0.5m	0.2/0.2m
Generalisation	maximal generalisation (classification of land use)	object blocks as generalised features; > 6*6m/3m	objects as generalised features; > 4*4m/2m	object as real features; > 2*2m/1m	constructive elements and openings are represented
Building installations	-	-	-	representative exterior effects	real object form
Roof form/structure	no	flat	roof type and orientation	real object form	real object form
Roof overhanging parts	-	-	n.a.	n.a.	Yes
CityFurniture	-	important objects	prototypes	real object form	real object form
SolitaryVegetationObject	-	important objects	prototypes, higher 6m	prototypes, higher 2m	prototypes, real object form
PlantCover	-	>50*50m	>5*5m	< LOD2	<LOD2
… to be continued for the other feature themes					

Table 1. LOD 0-4 of CityGML standard with its accuracy requirements in Gröger et al. (2012).



Cadmapper CESIUM ion Own methodology Aerial view

Fig. 16. Comparison between the proposed model and other automatic viewers.

The first mode of evaluation of the proposed procedure is the comparison with aerial orthophotography, in order to verify general aspects such as the shape of the roofs, their slopes, whether the openings in the courtyards are respected, etc. For more specific aspects, block nº11 of the Pilot Zone has been used. For this block, two point clouds have been obtained, one using a terrestrial laser scanner (façades) and the other using aerial photogrammetry by drone (roofs and interior courtyards) and superimposed on the model generated (Fig. 15). This allows measurements to be made between the resulting model and these point clouds, obtaining a maximum error of 0.40 metres in the most distant areas. This is due to errors in the adjustment of inclined planes in areas with few points. The CityGML standard requires a minimum accuracy for LOD 02 models of 2 metres and must represent objects with a footprint of 4x4 (Table 1). In any case, the method presented here far exceeds the minimum standard.

In all cases (LOD 0, LOD 1 and LOD 2) models are generated with a higher degree of approximation to reality and accuracy than those generated automatically with semantic information of built heights. The example chosen for Block 11 within the pilot area shows this difference compared to other automated urban modelling viewers (Fig. 16).

According to the CityGML standard, higher levels of detail (LOD 3 and 4) imply having geometric information of the interior of the buildings, which is beyond the scope of large-scale urban works. However, the models obtained through this semi-automatic supervised modelling process can be complemented and increased in detail with 3D scanning by terrestrial laser-scanning for façades and pavements, and with aerial photogrammetry by drone for roofs and interior areas not visible from the outside. The availability of various levels of detail greatly expands the uses and applications of these three-dimensional urban models (Biljecki et al., 2016; Jayaraj & Ramiya, 2018). Figure 17 shows the different levels in the modelling of block number 11.

In addition to the different levels of detail, it is necessary to consider the degree of updating of the public databases being used, as the city is a living entity.

With regard to the automation of the processes, the following aspects need to be taken into account. On

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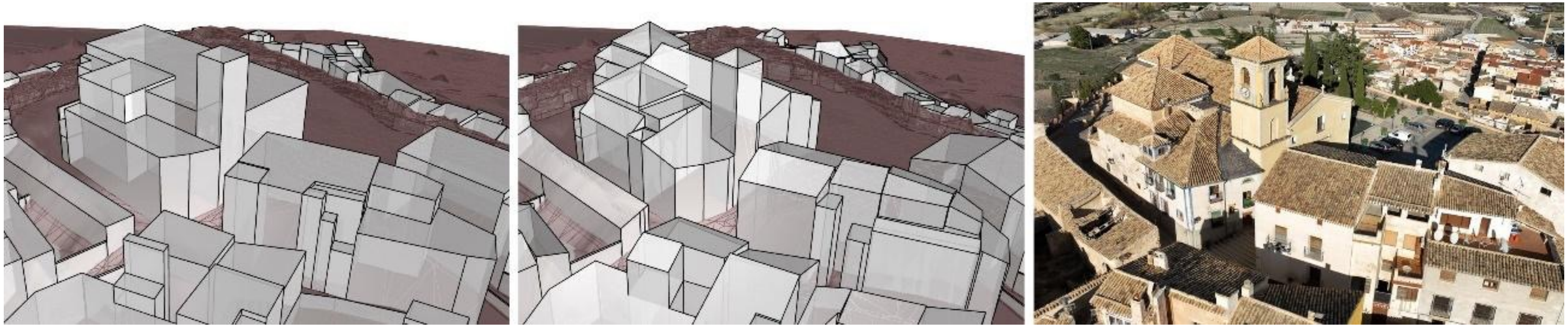

Fig. 17. LOD1, LOD2 and aerial photography.

one hand, when working with data from public LiDAR flights, whose density of points is very low, and when dealing with plots of small surface area, it may happen that the position of the points does not always coincide with the position of the cadastre polygons, or that a polygon contains very few points. These difficulties mean that the values of the modelling algorithm are not always the same for all curves, which sometimes slows down automation. These aspects could be improved in the future if the algorithm itself could decide the values depending on each case.

6. CONCLUSION

The free and public data used from the different SDIs for the generation of the LOD 0, 1 and 2 of the historical centre of Cehegín, allow the models to be obtained with its own workflow that optimises the result of other unsupervised automated methods and without the need to pay for specific LiDAR flights for the desired areas. It is important to note that the models coincide with the cadastral records by using these polygons as point cloud segmentation tools. This results in very useful models for municipal management.

A LOD1 has been obtained with a supervised method of higher quality than the automatically extracted models. The LOD2 model includes a distinction of roof types taking into account the topological relationships and applying different algorithms for courtyards, walls, streets, etc.

The low resolution of the downloaded data compared to the small size of the plots in historical centres sometimes leads to modelling errors. These could be remedied in the future by applying the same modelling algorithms to denser point clouds obtained by aerial photogrammetry covering large areas at low cost and in short times.

Thus, LOD 1 will be used for urban management of the municipality and LOD 2 for physical simulations such as energy efficiency, sunshine or flood control among others. These models are live and can be updated as regularly as the data from which they are derived.

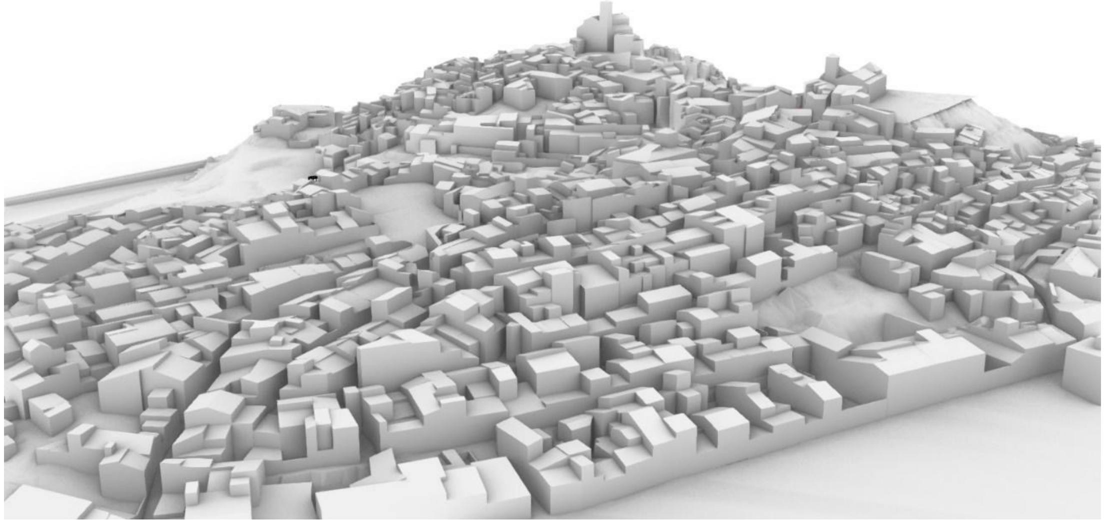

Fig. 18. Render of LOD2 model. General view.

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