

**Wildland-Urban Interface Virtual Essays
Workbench**

WUIVIEW

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Procedure for WUI scenarios 3D modelling

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Abstract	This document D5.2 provides a brief insight into 3D scenarios modelling and suggests a practical workflow for the data gathering, objects and scenarios generation to be used in FDS fire simulations. Several approaches and involved technologies are presented and discussed. Some preliminary examples of application are also included. The resulting method will be further tested and fine-tuned in the selected study cases in WP7.
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Table of Contents

1. About this deliverable	7
2. Introduction	7
2.1 What is a 3D WUI scenario?	7
2.2 Suggested approaches	8
2.3 Setting spatial boundaries, resolution and scale	9
3. Description of idealized scenarios by catalogue entries	10
3.1 Use of catalogue entries	10
3.2 Placing and orienting objects. Creating idealised 3D scenarios	11
4. Description of real scenarios by 3D data gathering	14
4.1 Use of high-resolution LIDAR	14
Selecting LAS data sets	14
Processing	15
Results and discussion	17
4.2 Photogrammetry	18
4.3 Airborne photogrammetry. Use of RPAS	20
Advantages of airborne photogrammetry	20
Adequacy of RPAS for WUI microscale	21
Design of flight patterns	22
Systematic grids	23
Orbital patterns	23
Geo-referencing	29
Photographs processing	30
Placing and simplification of the 3D obtained scenarios	32
Observed limitations and discussion	34
5. Spatial segmentation and FDS parsing	35
5.1 Voxelization	35
5.2 Assigning properties and cleaning	38
5.3 Parsing voxels into FDS files	40
Parsing OBJ format	40
Mesh size and resolution	40

Obstructions	41
Bounding surfaces	41
6. Concluding remarks	41
7. References	42

Acronyms used in this document

CFD	Computational Fluid Dynamics
DTM	Digital Terrain Model
FDS	Fire Dynamics Simulator
FOV	Field Of View
GPU	Graphics Processing Unit
GPS	Global Positioning System
HFOV	Horizontal field of view
HRRPUA	Heat Release Rate Per Unit Area
LIDAR	Light Detection And Ranging
MTOW	Maximum Take-Off Weight
PBD	Performance Based Design
RPAS	Remotely Piloted Aircraft System
SDK	Software Development Kit
SFM	Structure From Motion
SIFT	Scale-Invariant Feature Transform
VFOV	Vertical Field Of View
VLOS	Visual Line Of Sight
WUI	Wildland-Urban Interface

File formats

FBX	Used to provide interoperability between digital content creation applications.
FDS	Used by fire dynamics simulator as input, includes information on geometry, material properties and combustion characteristics.
LAS	Used for the interchange and archiving of LIDAR point cloud data.
OBJ	Used for the easy interchange of the geometry of 3D models.

1. About this deliverable

WUIVIEW stands for Wildland-Urban Interface Virtual Essays Workbench, and it is a project funded by the Directorate General for European Civil Protection and Humanitarian Aid Operations (DG ECHO) and coordinated by the Universitat Politècnica de Catalunya (Spain). The project objective is to develop a ‘virtual laboratory’ based on Performance Based Design (PBD) and Computational Fluid Dynamics (CFD) models for the analysis and assessment of the processes and factors driving structure damage in forest fires. The results will serve as guidelines and recommendations of good practices for the protection and prevention of forest fires in European communities inserted in forested lands. The project is divided into 8 work packages, out of which work package 5 is devoted to the definition, design and setting of WUI fire microscale scenarios typical of European WUI realities.

This document D5.2 provides a brief insight into 3D scenarios modelling and suggests and explores a practical workflow for the data gathering, objects and scenarios generation to be used in FDS fire simulations. Several approaches and involved technologies are presented, tested and discussed. Some preliminary examples of application are also included. The resulting method will be further used and fine-tuned in the selected study cases in WP07.

2. Introduction

2.1 What is a 3D WUI scenario?

Lessons learnt in recent forest fires affecting WUI areas show the importance of the type and the spatial arrangement of the elements involved, particularly in the immediate environment surrounding the houses.

A 3D WUI scenario is a digital instance of the geometry and materials of the different objects present in the WUI microscale, including buildings and their constructive elements, vegetation, other installations, garden furniture, secondary structures such as garages, warehouses and sheds, and other materials and elements which may eventually participate in the combustion and damage in a forest fire. This scenario is composed, therefore, by objects digitally represented by 3D meshes at a given degree of detail, placed in a spatial region delimited by a bounding box. Each object maybe compound of elements, each one with different material properties and, in general, of different colours and other surface parameters. Colour is relevant as it may be used as a key parameter for the identification of objects and materials in the real world, so the management of colour (capture, processing, and identification) is duly considered.

In existing approaches and solutions for the risk assessment in the WUI microscale, little focus has been given to the spatial dimension of the factors and processes involved. Indeed, in such detailed scales, the vertical dimension (Z) is relevant and so it must be considered in the data gathering, scenarios description and modelling. Vegetation structure, understood as a set of interrelated layers (grass, shrubs, young trees, trees canopy etc.), strongly conditions the way the fire starts and builds up; besides, the three-

dimensional relationship between vegetation and nearby structures (houses, installations etc.), that is the relative spatial distances and orientations, conditions the way the heat sources affect the building elements.

Today there is a good number of software applications which provide functionality for the gathering of 3D data sets, the building of 3D digital objects, the design, manipulation and arrangement of such objects into 3D scenarios, the assignment of object surface properties and, finally, the generation of the files including 3D information for the simulation into FDS fire simulation model.

2.2 Suggested approaches

This document explores and describes approaches for the data capture, setting and modelling of 3D WUI scenarios, giving particular focus on the approaches of gathering information from real world and obtaining a 3D digital instance to be used in FDS fire simulator. The two suggested lines of work differ in the way the 3D representation of objects and their arrangement into 3D scenarios is achieved.

On one hand, the use of catalogue entries of the different existing objects is suggested. This is possible thanks to the pleiade of existing repositories of digitized 3D objects in common universal exchange formats (OBJ, FBX etc.), mainly due to their use in the game and advertisement industries, but also the existing CAD datasets of buildings and installations widely used in engineering and architecture. The obtained objects can then be arranged in 3D scenarios in some of the existing 3D editors (Maya, Blender, 3DS Max just to mention a few), according to position and orientation observed in the real world. This is a rather straightforward process and interestingly cheap and fast (detailed 3D modelling of new objects is well known to be a time-consuming process). A main drawback is that these objects, particularly buildings, do not represent in detail the existing reality of specific locations, instead they just give a general representation of average models.

On the other hand an approach for the elaboration of accurate, realistic 3D scenarios is presented. This approach is strongly based on procedures and solutions for 3D data gathering, as existing today in the market, such as photogrammetry and LIDAR-based modelling. While the first one will render 3D digital instances of all objects surveyed over a 3D micro scale WUI scenario, including colour of their surfaces, the second one will provide a point cloud which will serve as baseline for the 3D spatial segmentation of objects occupation. Both techniques are adequate to quickly and relatively accurately gather the position, orientation and type of objects present in a WUI micro scale scenario. As seen in the next points, the photogrammetry approach provides a more flexible, simple and cheap workflow to gather 3D information at different levels, while LIDAR approach is more adequate for large extensions. Both of them are explored and discussed in this document.

The main workflow which is presented has the following general steps:

- Data gathering (catalogues, photography, LIDAR)
- 3D objects modelling (meshes of triangular facets)

- Spatial segmentation (voxelization)
- Surface properties assignment
- Parsing voxels and properties into FDS scenarios

Some of the steps of this workflow may be skipped depending on the approach selected, in particular:

Approach 1. From catalogue 3D objects (no modelling needed), based on aerial orthophotography, placing elements in an idealised 3D scenario, assignment of surface properties, then proceed with voxelization and parsing into FDS files.

Approach 2. From airborne and ground photo sets, proceed with photogrammetric modelling of 3D objects and scenarios, including simplification and cleaning of the obtained objects, assignment of surface properties (based on the observed colour), proceed with voxelization and finally parsing into FDS files.

Approach 3. From LIDAR datasets, proceed with a spatial segmentation of the obtained returns, including the observed colour, assignment of surface properties (based on colour) and proceed to parsing FDS files. In this case no extra voxelization is required.

As seen, a type or other of spatial segmentation of properties is needed at a certain degree of detail, depending on the spatial scope and resolution of the simulation. In all three cases, a spatial segmentation is obtained, in terms of occupation of each of the discrete x,y,z positions within the spatial region considered (voxels). Out of this voxelization, obstruction nodes (OBST) are automatically obtained, so to be used in FDS model, each one with its correspondent surface properties.

2.3 Setting spatial boundaries, resolution and scale

The first step in describing a 3D scenario is to identify the spatial boundaries (bounding box) in which all elements will be included and in which all the processes to be simulated will take place. This must be consistent with the bounding box and mesh division finally used in the FDS simulations. In order to ensure consistency, the 3D scenarios in WUIVIEW include two small objects (cubes) located precisely in the initial (x_i, y_i, z_i) and final (x_f, y_f, z_f) coordinates defining the bounding box. In doing so all the processes described in this document will refer to that bounding box and the spatial segmentation will take place along such dimensions in a robust way (divisions of the same size, regardless of the dimensions of the scene).

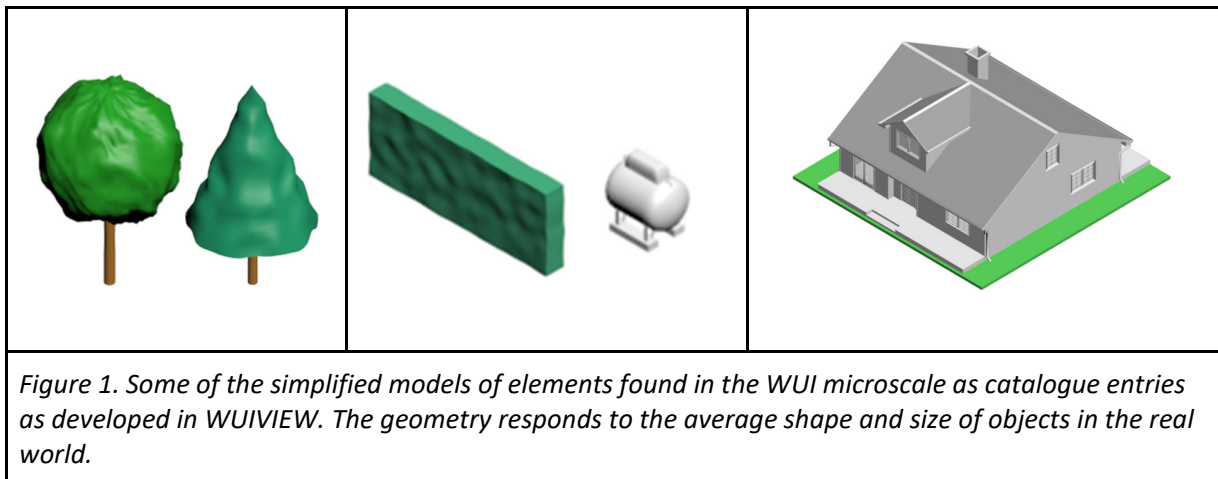
The second step is setting the resolution and level of detail required in the objects to properly describe the phenomena which is subject of simulation, which is directly related to the scale of the scenario. Indeed, most of the described scenarios in deliverable D5.1 take place in a spatial region of a few meters; while some others, in particular those referring to glazing and gutters or roofing, take place along a few centimetres. In the description of 3D scenarios in this document, the procedures, techniques and tools will be mostly focusing on the first class, typically happening in the area corresponding to the garden and the immediate surroundings of an average size house. For these scenario sizes (of around 100 to 400 m² of layout surface) a resolution of 20 cm is suggested as reference (thus, a scenario spanning 20 m in a given axis will give 1000 divisions). As discussed in the following sections, this resolution will determine

the maximum distance of data gathering (i.e. photograph) according to the capacities of the sensors used (i.e. photographic sensor resolution), hence the design of the mission (i.e. RPAS flight pattern).

3. Description of idealized scenarios by catalogue entries

3.1 Use of catalogue entries

The first and perhaps the most straightforward method for a quick setup of a 3D scenario is the use of existing 3D models which reflect the objects and elements present in the WUI microscale. There are several repositories of 3D models in several interchange formats (OBJ, FBX etc.) classified by types. Amongst them it is of particular interest the structures (houses, installations, other buildings), LPG tanks, the garden furniture, vehicles and garden vegetation (Figure 1). However many of these models refer to the reality in other countries outside Europe which is particularly relevant when using house models. For these cases it is recommended to organize and populate a proprietary catalogue with simplified versions of the most common houses found in our countries. For such an endeavour, the TABULA (<http://webtool.building-typology.eu>) classification of housing structures is a good starting point.



In regards to vegetation, a good collection of realistic models is available in several repositories, classified by tree type and size (age), including garden ornamental plants and other species found in forested lands. However they normally add a large amount of polygons as they mimic leaves, twigs and branches. For these cases it is suggested to work on simplifications of the geometry by considering the enveloping volume instead (see Figure 2).

Using catalogue entries facilitates and speeds up the process of describing idealized scenarios for quick simulations, as they include the geometry and the properties of the surface components (materials). As new types of objects are studied (particularly their physical properties, geometry and combustibility descriptors, such as burning rate or heat release rate) they may be added to the catalogue for its general use in idealised scenarios.

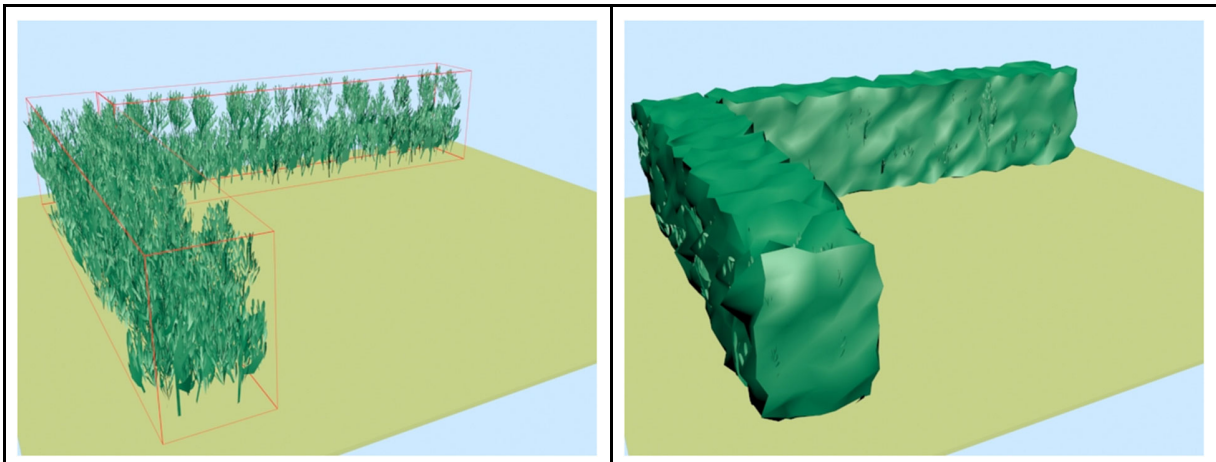


Figure 2. An example of a detailed model of a green hedge (left) and the simplified version of it (right) as a polyhedric shell around the bulk volume.

3.2 Placing and orienting objects. Creating idealised 3D scenarios

Idealised scenarios represent simplified versions of object arrangements present in the real WUI microscale. The relative position (distances), orientation and size of the elements are described based on templates or patterns observed in the real world. The process of describing a 3D scenario is performed in 3D model edition platforms, such as 3D Studio Max, Maya or Blender (Figure 3). For the WUIVIEW project the preferred software is Autodesk 3D Studio Max 2019.

The interface of this type of programs allows to perform intuitive but precise designs and arrangements of objects in a 3D environment, assign properties (materials) and transform the elements (position, rotation and scale). The 3D models are made of triangular facets connected by vertices and edges. The 3D editing programs allow the manipulation, grouping and transformation of objects and their components. This is particularly useful when determining components in a complex object with different materials.

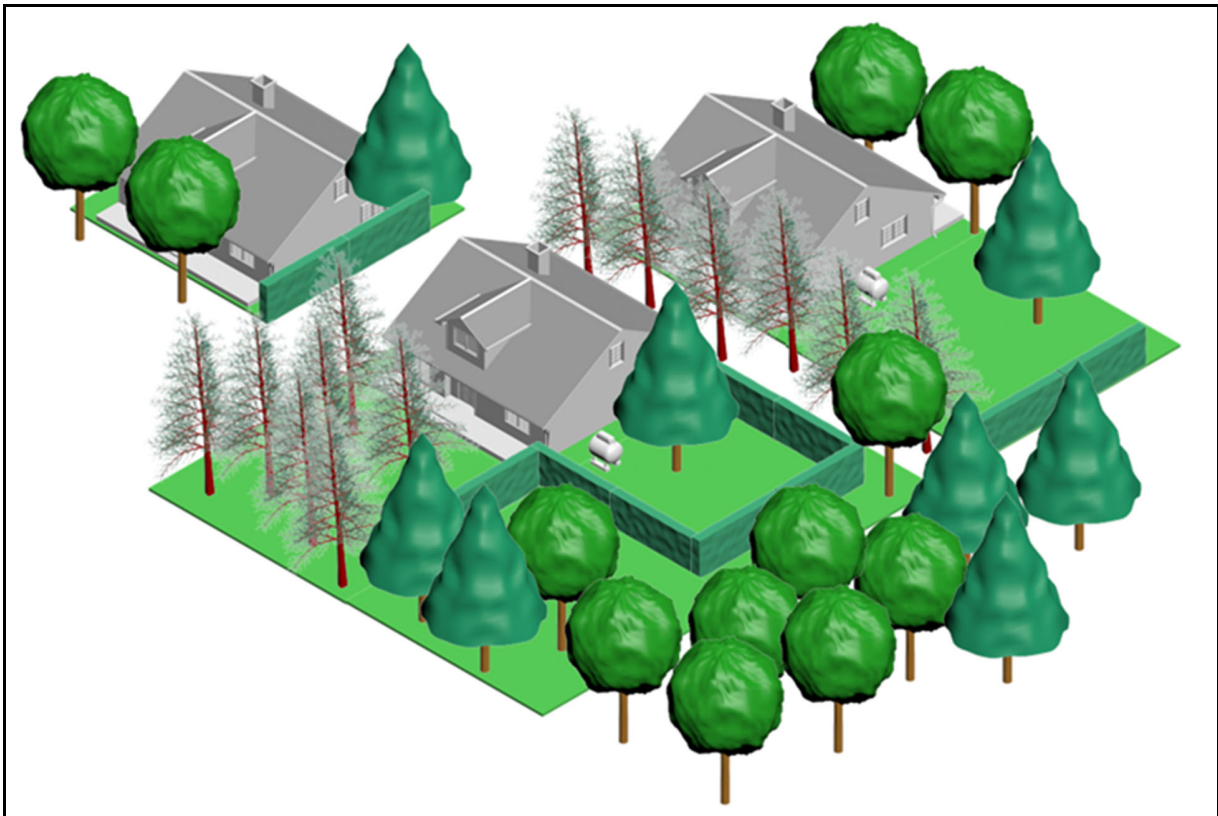


Figure 3. A simplified scenario in which several instances of the object catalogue are placed in the position and relative orientation according to what is observed in the real world. A 3D modelling platform is used for this purpose, such as 3DSMax, Blender, Maya etc.

One strategy explored in this project is the use of orthophotos as templates for the location of the identified objects (structures, vegetation, gardening, furniture, vehicles etc.). To achieve this, reference points must be set in advance so to precisely give metrics and reference to the objects inserted. The orthophoto can then be displayed in the background of the top view or alternatively be projected onto a plane object. As a rule, coordinate system relates to geographical coordinates by assigning X to 'East', Y to 'North' and Z to 'up'.

In WUIVIEW project, the use of LIDAR data for the automatic positioning of numerous catalogue objects (for example trees) has been also explored and tested, thanks to the development of a parsing application (VEG2OBJ) which interprets vegetation occupation and tree height into 3D objects position and size in the 3D scenario (see figures 4 and 5). This helps in the preparation of more realistic scenarios while consuming a fraction of modelling time. The application renders instances of objects (trees) in OBJ format placed at predefined positions in a regular grid of a certain size (for example, 1 m). To achieve this, the pivot of each instance, located at the bottom centre, is used. The same approach can be followed for the automatic placing of buildings and other elements identified in the LIDAR file.

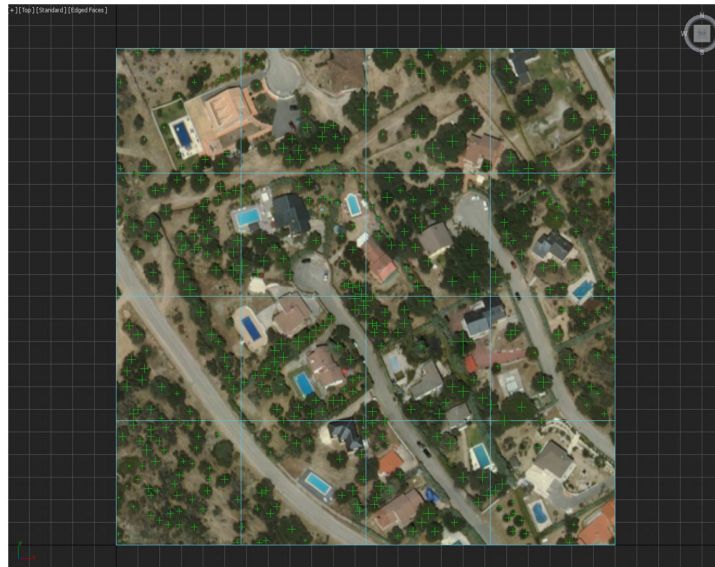


Figure 4. A simple parsing application (VEG2OBJ) has been developed in order to insert objects (idealised trees) in a 3D scenario according to LIDAR data (occupation and vegetation height) over a prescribed grid of 1x1 m. The resulting scenario can be edited in a 3D edition program as 3DS Max (in the image). This corresponds to study case 2 in Madrid Autonomous Region.

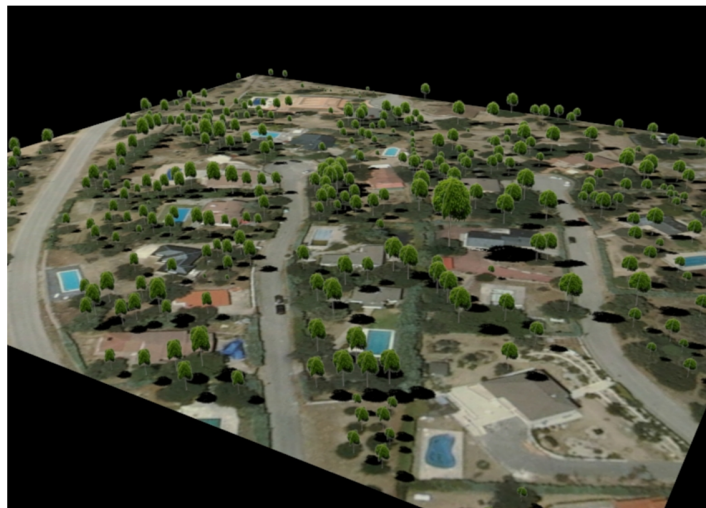


Figure 5. Idealised 3D scenario which includes catalogue 3D objects (trees) automatically placed over a grid of 1x1 m and scaled according to vegetation height observed by LIDAR data. Study case 2 in Madrid Autonomous Region.

4. Description of real scenarios by 3D data gathering

Besides to idealised versions of the real world, the interest in WUIVIEW project gravitates mostly towards the description of 3D scenarios which reflect accurately what is actually in the territory, particularly in the WUI microscales. To achieve this, two strategies are presented and explored: the use of LIDAR data and the application of photogrammetric techniques.

4.1 Use of high-resolution LIDAR

One of the most interesting data sources for 3D WUI scenarios modelling is the telemetry provided by LIDAR sensors. These include one or several returns of a laser beam indicating the heights of the terrain, vegetation and structures. Initially designed for the extraction of digital terrain models (DTM), this product gained popularity in other domains, particularly for the applications in forestry management. In Spain, as well in other EU countries, official LIDAR datasets are freely available, under the open data policy and INSPIRE directives. Recently some autonomic regions in Spain have programmed flights with airborne LIDAR sensors, rendering high resolution products. Navarra autonomous region has released this type of products and WUIVIEW project has performed a detailed exploration of its suitability for the purposes presented in this document. To achieve this, a portion of one of the most severe WUI areas has been selected, within the area of Estella city (Figure 6).

Selecting LAS data sets

LIDAR data is generally stored in files under LAS format specification. This format includes information of all returns of each pulse and a generic classification of the land use. Returns provide telemetry about the absolute height. Real heights of objects must be derived by subtracting the corresponding value for the terrain (DTM). For the purposes of WUI microscale modelling, a resolution has to be established in advance. One limitation is that official LIDAR LAS datasets provide between 0.5 to 2 pulses per square meter, which is way below what is needed for a detailed 3D modelling. For this reason, an exploration of one of the datasets is performed, and a methodology applied to test to which extent the results are usable within WUIVIEW scope is developed.

The mentioned dataset includes a classification of the land uses, based on the returned colour of each pulse. Out of the classes described in the LAS specification, the class 2 (ground), 4 (medium vegetation), 5 (high vegetation) and 6 (buildings) are used. In order to avoid too much noise in the statistic calculations, just the first and second returns of each pulse are considered. With these considerations, a collection of x,y,z are obtained, expressing the spatial occupation of vegetation, buildings and terrain. The selected LIDAR dataset has been downloaded from the SDI service for Navarra (SITNA) with LAS 1.4 specification and ETRS89/ UTM 30N coordinate system. Given that many of the processes presented here are performed under LAS1.2 specification, a conversion is needed.

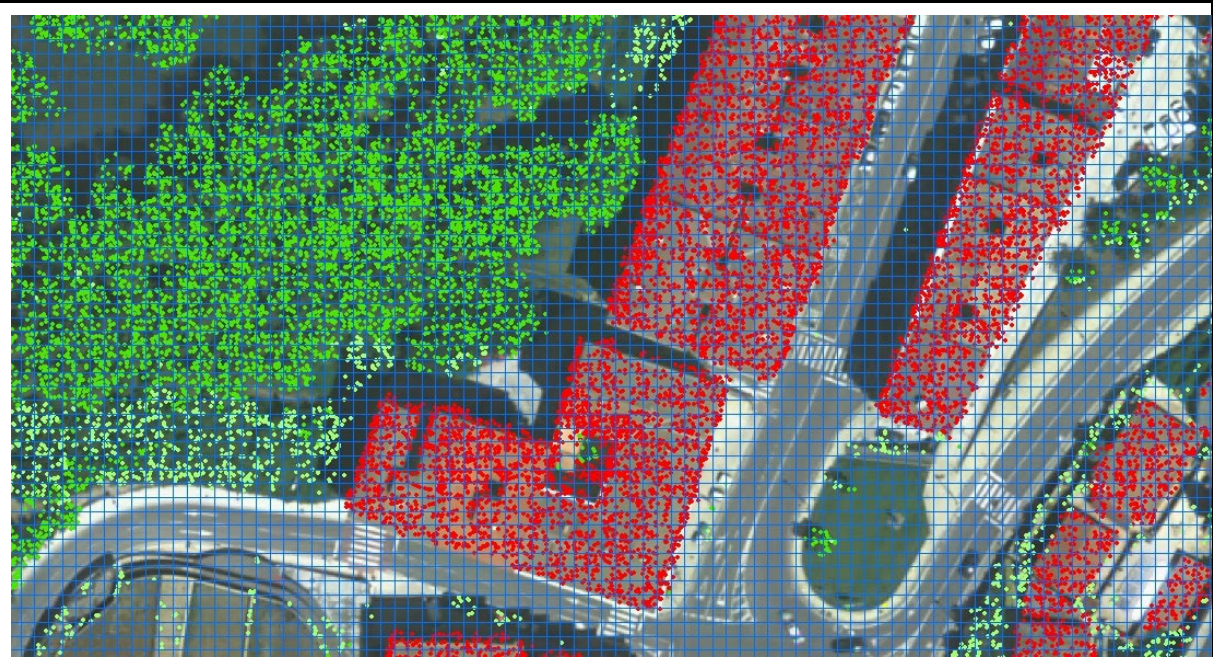


Figure 6. A portion of the LAS file in Estella, in Autonomous Region of Navarra, Spain, showing the returns 1 and 2 for class 4 (medium vegetation), 5 (high vegetation) and 6 (buildings). Overimposed a grid of 2x2 m so to check available data density for classification.

Processing

All the processing of the LAS file has been performed with LasTools, a set of freeware applications for the manipulation, transformation, calculation and display of LIDAR datasets. The conversion into LAS1.2 specification took place with the modifier:

```
-set_version_minor 2
```

To select specific returns (1 and 2) and classes (4, 5 and 6), the following modifiers are used:

```
-keep_return 1  
-keep_return 2  
-keep_classification 4  
-keep_classification 5  
-keep_classification 6
```

LasTools allows to directly generate a voxelization of the selected points, with the command 'LasVoxel'. The size of the voxels (in meters) is then specified with the modifiers `-stepxy` and `-stepz`, both of them have been set to 2 meters in this example. For the purposes of 3D modelling it is required to have the occupation of each x,y,z position (voxel centroid), and LasTools allows the generation of such coordinates with the modifier 'voxels as points'. Given that further processing is performed in other platforms (such

as ArcGIS), the modifier ‘output format txt’ is used, to have the list of voxels and attributes in ASCII format easily readable by other platforms.

Once generated, the segmented LAS file into voxelized space, it can be imported into ArcGIS or other geographical information platform. In ArcGIS, the generated x,y,z list in ASCII format is loaded as table. Then the command Display XY Data is used over the generated table. Finally, a conversion of the generated point features (one per voxel) can be converted into a raster file with the option Conversion Tools/To Raster/Feature to Raster.



Figure 7. Segmentation of returns 1 and 2 of classes 4, 5 and 6 into 2D space using a 2x2 regular grid, showing the occupancy by vegetation (in green) and buildings (in red). This is a raster map generated in ArcGIS from the x,y,z list of voxels containing the LIDAR data.

The resulting map (a 2-dimension space) provides a first insight of the expected friction between buildings and vegetation (see Figure 7), and evaluates the adequacy of the point density at the referred resolution (2 m in this case) to explain the land use occupancy.

However, the real use of the generated list of x,y,z, occupancy is the generation of 3D objects. A simple parsing application, which generates cubic objects from the voxel centroids identified in LasTools and stores it in OBJ interchange format, has been developed. The resulting 3D voxels can then be inserted in the following steps of the general workflow.

A quick way to visualise the resulting voxel dataset is performed using the scientific visualising package Paraview. To achieve this, the x,y,z ASCII file is loaded in Paraview. A filter ‘TableToPoints’ is then applied,

specifying which of the fields correspond to coordinates and which one to scalar values (type of occupation, whether it is terrain, vegetation or building). For a better representation, occupation points are displayed as cubic voxels using the 'Glyph' filter and selecting 'cube' as glyph shape (Figure 8). The field containing the value of occupation type is then associated to the scalar value using 'Active Attributes/Scalars' pointing at that field, and setting 'Scaling Mode/Scalar' with 'Scale Factor 1'.

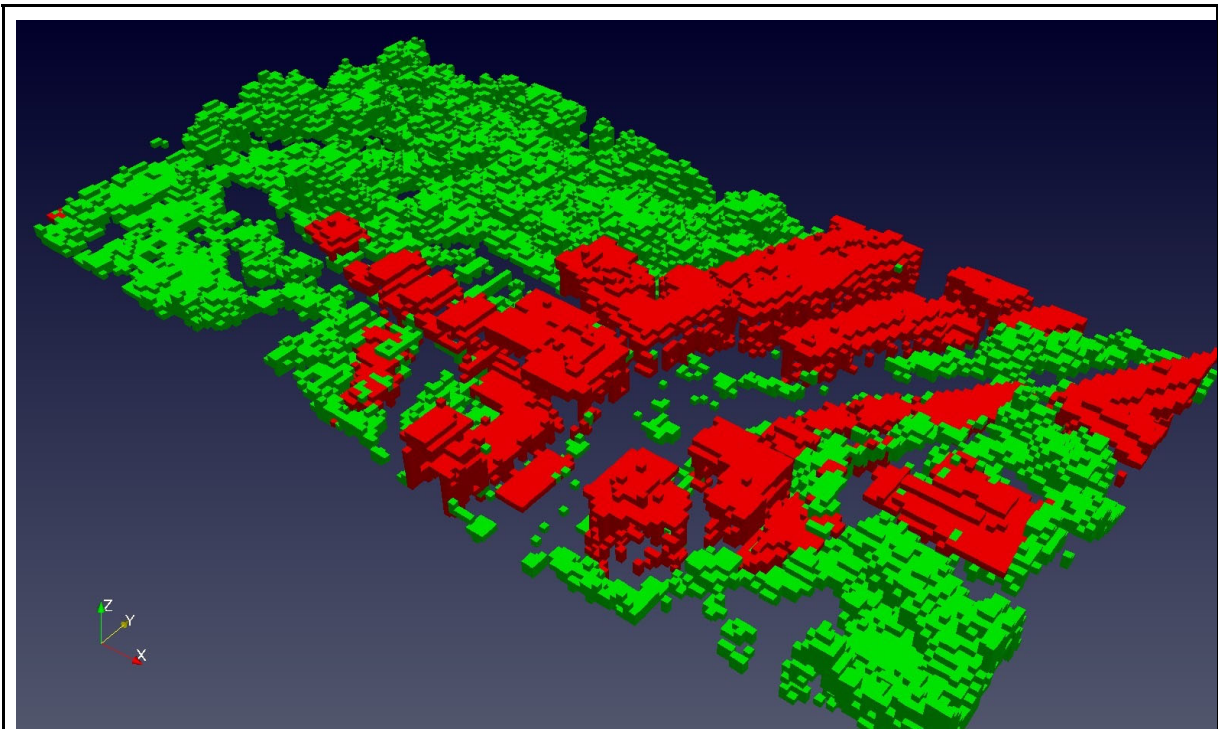


Figure 8. Spatial segmentation of the returns 1 and 2 of classes 4,5 and 6 using a regular 3D grid of 2x2x2 m rendering voxels occupied by vegetation (in green) and buildings (in red). Some inconsistencies of classification are found when compared with the orthophoto. Render is done in Paraview visualisation software.

Results and discussion

LIDAR datasets are very useful to obtain a general overview of the 3D space occupation and the spatial relationship between vegetation and buildings, but at the scale and resolutions required for WUI microscale modelling generic LIDAR data is insufficient. Nevertheless, the principles of 3D modelling and FDS simulation are pretty valid, considering that what is simulated is the progression of the fire in the mesoscale and the potential affectation to buildings as coarse bodies, not considering elements and associated materials. To achieve this, much more detailed LIDAR is required (for example, LIDAR sensors mounted on RPAS flying at low altitude). Alternatively, photogrammetric techniques are preferred.

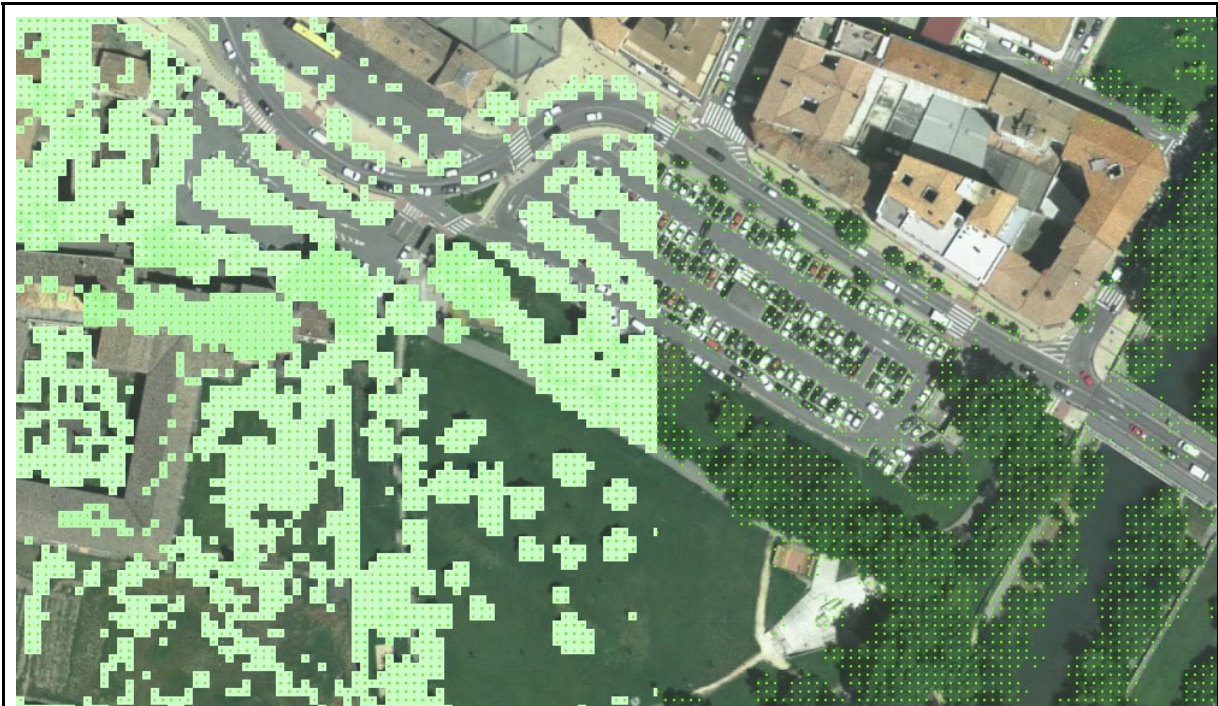


Fig.9. Some errors in the classification of LIDAR returns, as in the LAS files obtained from official sources. In this case a parking lot is classified as vegetation.

In addition to what has been said, another relevant limitation is the land use classification ability of LIDAR datasets. In fact LIDAR purpose was initially to obtain digital terrain models, and in this sense the classification of ground points is very accurate. In regard to vegetation, and more particularly when vegetation and buildings mix together, some inconsistencies have been found, in particular buildings classified as vegetation and vice versa, generating confusing occupation arrays and generally exaggerating the friction between houses and vegetation. Other very evident classification errors are observed in streets and installations, for example parking lots and cars classified as medium vegetation (see Figure 9). To improve classification of points and avoid such problems, other sources of information are required, such as orthophoto or satellite images.

4.2 Photogrammetry

The modelling of 3D objects from a set of photographs is a technique widely used in several fields of engineering but also in the gaming and advertising industries. Today several applications to help in the survey and assessment of field works, construction areas, real estate, mineral extraction, archaeological sites, cultural heritage are commonplace, and have increased the accuracy of model generation and the calculation speeds thanks to the parallelisation of processes and the use of GPUs.

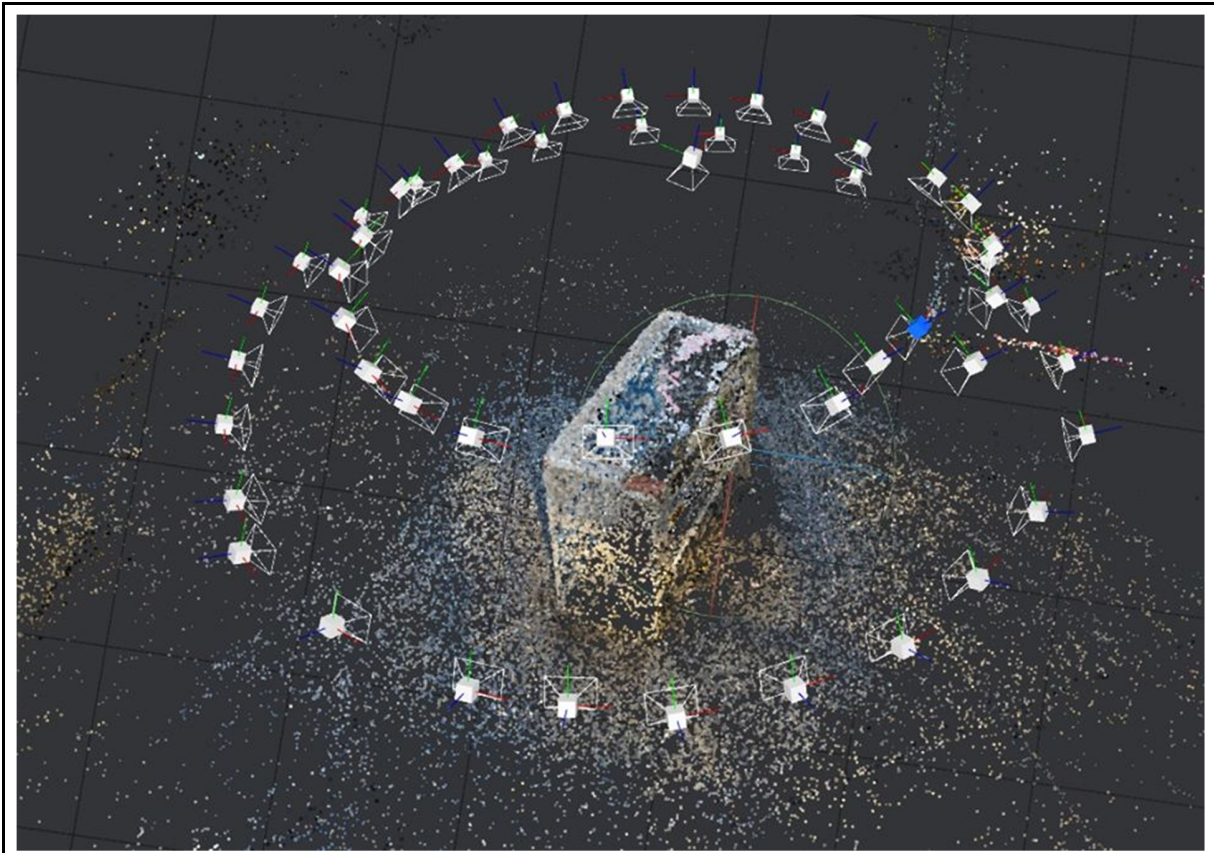


Fig.10. An example of generation of a point cloud in MeshRoom corresponding to common features identified in a set of photographs taken around the object, mimicking what is done in airborne missions (a nadir take and several orbits with an overlapping of 80%). From the point cloud a 3D model made of triangular facets is obtained. The colour information of the vertices is then mapped into the resulting 3D object.

Photogrammetry techniques are preferred for the purpose of detailed 3D modelling of WUI microscales and its elements. This approach requires affordable equipment, such as photographic cameras, action cameras or even cameras in mobile phones, is more flexible as it can be applied literally to any scale and with any desired resolution, and the existing software is free or relatively cheap. Besides, some of the packages include full integration with RPAS, incorporating not only the video or pictures taken airborne but also the GPS position for the generation of geo-referenced scenarios. Several solutions have been tested, namely:

MeshRoom. This is an open source suite of applications for general photogrammetry aimed at the generation of 3D models from photographs. It is modular, configurable and programmable, allowing many adjustments and fine-tuning to obtain optimal results. The calculation process, however, is rather time consuming.

Pix4D. This is a commercial package, slightly pricey, but very robust and fast. This application integrates seamlessly with RPAS navigation and gathered data, whether it is video or photography, and generates

3D models in several interchange formats and digital terrains and maps. Works much better with a generous photo overlapping or 4K videos.

Autocad Recap. This is a generic purpose application for 3D models generation from photographs or map mosaic production from airborne data. This application sits and operates in the cloud, making use of its calculation potential. Photos must be uploaded and the process queued for calculation. The educational license has the limitation of 100 pictures per project.

Zephyr. This is another robust application at a reasonable price (particularly the license admitting up to 500 pictures per project) and fast in processing images. Renders results in several interchange formats such as OBJ.

In WUIVIEW project, several tests have been made and the software packages evaluated, as part of the service workflow in the future. All of the solutions follow a similar approach for the identification of features, the calculation of camera positions, the pairing of photographs and the derivation of coordinates of intermediate 3D points, and the generation of the 3D meshes out of the point cloud. In all of them some artefacts are unavoidable generated and has been observed that a large number of pictures, with generous overlapping (over 80%) diminishes the presence of these artefacts and model errors. Preliminary tests were made in ground with photo cameras and mobile phones, mimicking the orbits of an airborne survey. The same procedure has been completed for the generation of 3D models of common objects found in the WUI microscale. Handheld, ground photo gathering is rather easy and straightforward process, some of which can be taken in the photo studio. Position and camera consistency render a robust point cloud and hence a realistic 3D model (see Figure 10). Generally speaking, photogrammetry for 3D model generation is based on a widely accepted method called Structure From Motion (SFM), which identifies objects from photographs. The general process is based in finding matching features (corners, edges, patterns etc.) based on Scale-Invariant Feature Transform (SIFT) algorithms. This is a globally used method for the detection of features in an image and widely used in artificial vision. The SIFT key points are extracted from a series of reference images and stored in a database. Given a new image, the features are compared with those existing in the database, so creating a list of pairing photos based on the Euclidean distance calculated for the vectors associated to the identified features. In this way, SFM finds matching features in sequential images (video frames or photos), for which is very important to keep consistency in the camera properties (same camera for all pictures) and camera movement (continuous trajectory, such as orbits). This SFM approach was originally designed to work with video streaming in real time for artificial vision and object recognition.

4.3 Airborne photogrammetry. Use of RPAS

Advantages of airborne photogrammetry

Airborne photogrammetry is specially suitable for the modelling of geographical features, such as structures and buildings. A camera mounted in an aircraft provides the advantage of an oblique view from above under different angles, which strongly completes the on-ground images for photogrammetric restitution. The idea underlying airborne photogrammetry is designing flights in such a way that it covers a large area, ensures images overlapping and provides different angles of observation, ideally at different

heights. This can be hardly achieved in the case of houses and other buildings just by taking on ground photographs, which is why airborne cameras are a good solution. Today the use of drones (RPAS) allow to take airborne photos with built-in cameras mounted in stabilisers and gimbals, or action cameras attached to the drone body. These are cheap and portable solutions, allowing a broad range of applications in a wide number of situations. In the case of WUI microscale, drones are particularly useful, due to their flight flexibility (they sneak through narrow spaces), their portability, the short deployment and flight preparation time (just minutes), the lack of intrusiveness (they are tiny and quiet) and the less restrictive regulations on aeronautics safety and operation.

Adequacy of RPAS for WUI microscale

Today there exists a massive offer of all types of RPAS, ranging from the nano-drones of a few grams to the 25 kg plus, autonomous large professional RPAS. Particularly interesting are the smaller drones (up to 2 kg MTOW) such as DJI Mavic, DJI Phantom and, more recently, DJI Mavic Mini, with a mere 249 g MTOW. Several of these models are equipped with safety sensors to avoid unwanted collisions, perform autonomous flights over prescribed flight patterns and count on a return-to-home function which prevents them to be lost in case of problems. Some of these aircrafts are classified as ‘toys’, but they perform greatly carrying action cameras, such as SYMA X8HG, an inexpensive RPAS capable of doing so (Figure11).

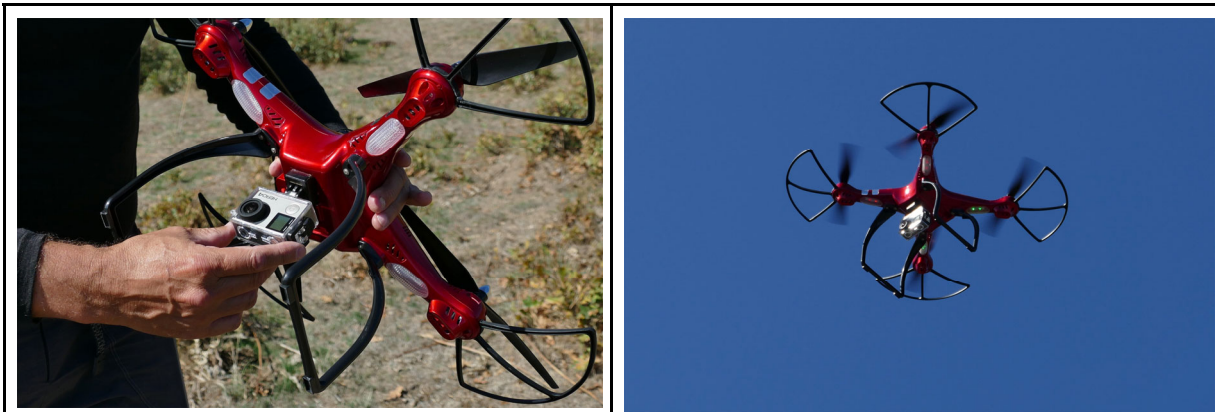


Figure 11. A SYMA X8HG is an inexpensive drone capable of lifting a GoPro Hero4 camera which delivers 12 Mpx images (4000x3000). In the image, the first test flights with this RPAS in the selected WUVIEW study cases in Madrid Autonomous Region.

Most of these RPAS allow manual control of the position and evolution in the air, under visual conditions (VLOS) at different heights. This flexibility in positioning the aircraft in such small spaces, as the immediate surroundings of a building, makes them particularly suitable for this type of work. Figure 12 shows the potential of these techniques with a completed 3D model as the result of photogrammetric restitution from airborne photographs in a preliminary WUVIEW exercise in Madrid Autonomous Region.

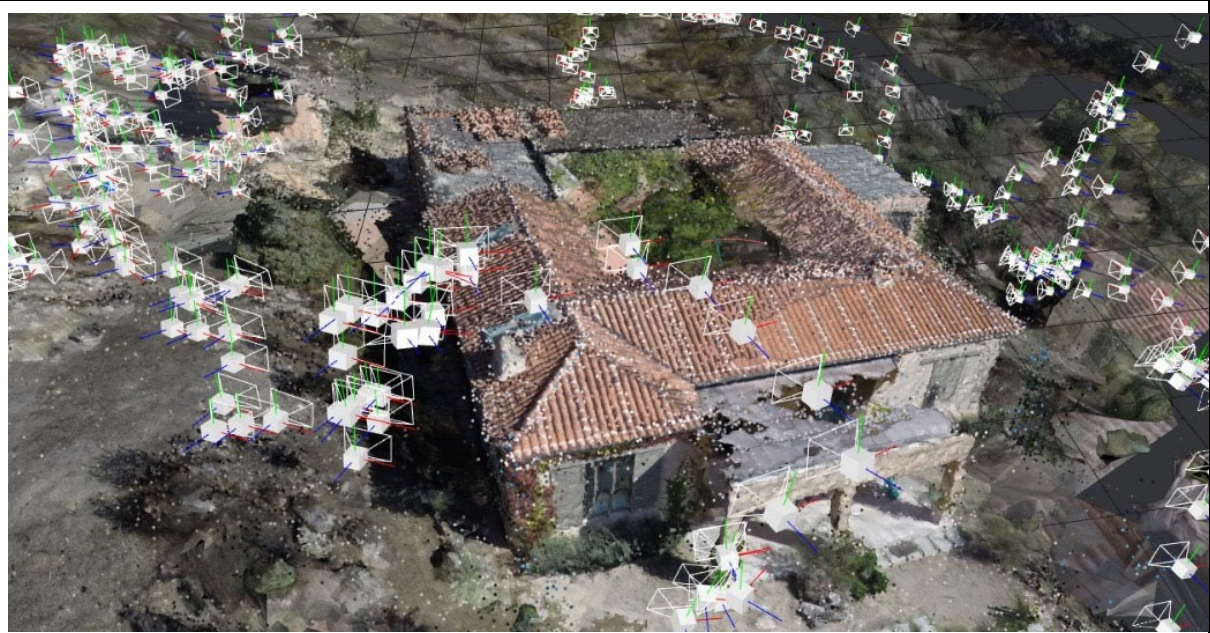


Figure 12. A first completed 3D model with textures of study case 1 in Madrid Autonomous Region, as the result of photogrammetric restitution from airborne photographs. For this preliminary exercise a SYMA X8HG drone was used with a GoPro camera attached to it, rendering 12Mpx images. The positions of the drone are represented as white icons, as well as the projection FOV. To achieve such degree of detail, a total of 492 images were used.

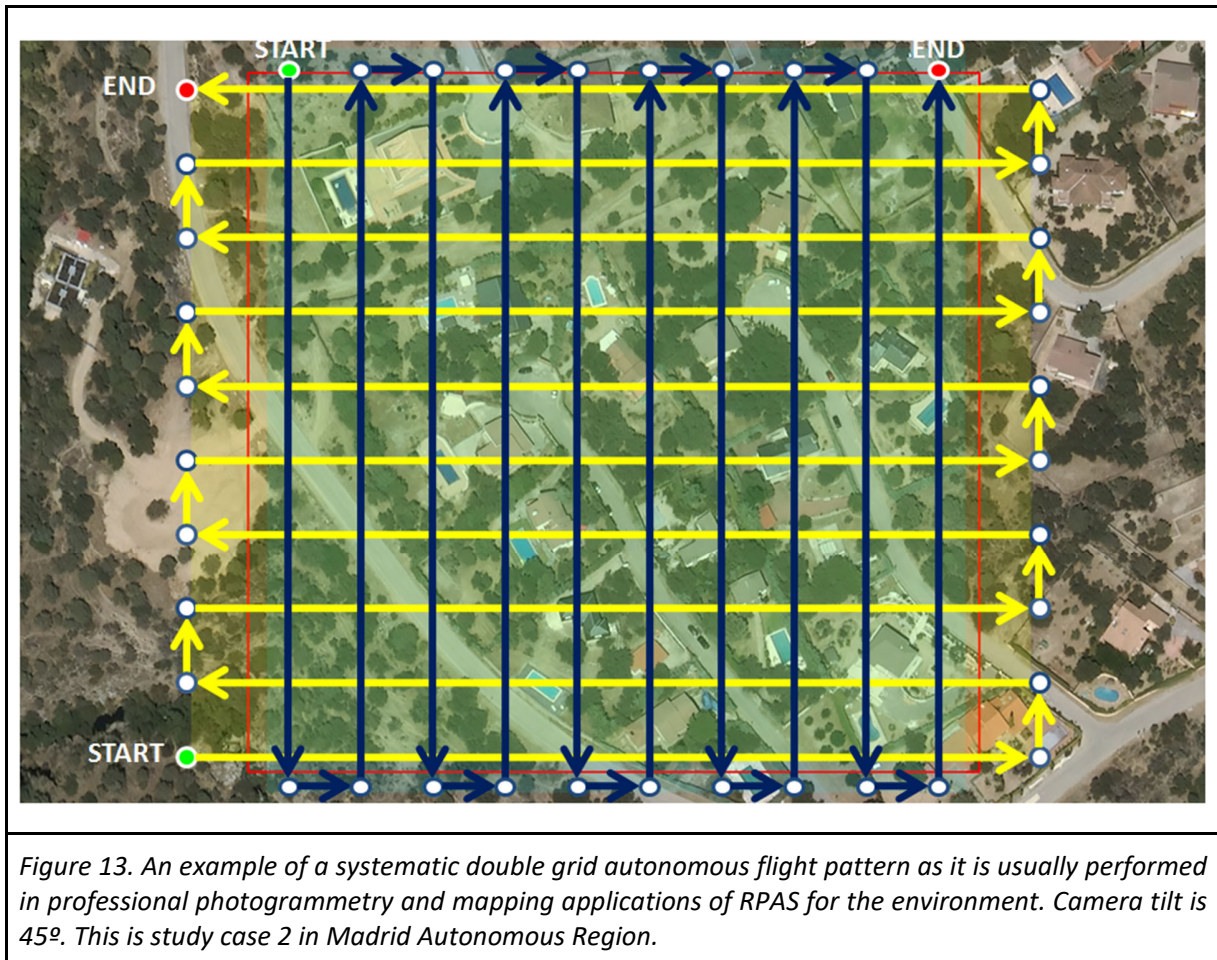
Safety is another positive point to consider when evaluating RPAS as platforms for airborne photography in the WUI microscale. Given their relative reduced weight (normally under 2 kg, but frequently under 1 kg and the last models even below 249 g of MTOW) and that they are equipped with proximity sensors, they offer a minimum risk for people and properties in the flight area, in case of failure. The smaller versions of RPAS are suitable for indoor flights as well.

Design of flight patterns

Using RPAS for 3D WUI scenarios modelling implies a systematic approach to the flight missions, in order to ensure maximum coverage with the minimum number of photos, thus optimising the process of data gathering. Today several autonomous flight solutions are available in the market, which allow accurate flight control of position, heading and camera tilt, rendering faster and consistent sets of photographs which are preferred by the photogrammetry applications. These can be programmed beforehand according to the mission objectives, the type of aircraft operated and required level of detail. Professional use of RPAS for photogrammetry and mapping deal with such applications for medium to large territory extensions, but little has been developed for photogrammetry at the micro-scale, in the order of just a few meters. In this sense, two approaches are suggested, the widely used multi-pass systematic grids and the newly method, tailored for this project, of orbital patterns.

Systematic grids

The most generalised flight pattern aimed at photogrammetry is the double grid pattern, in which a drone flies autonomously from a start point, following a straight line, turning back at a certain distance to allow lateral overlapping, and continues zigzagging in such a way to cover the desired area. The process is repeated in a pattern crossing 90° to the previous one. Camera tilt angle is typically set to 45°. Fly height is kept constant (Figure 13).



These systematic flight patterns are commonly used for photogrammetry works over large areas, for which autonomous flight and photography is needed, given the surface covered and the large number of pictures. As there is no variation in flight height, limited detail is given of the lower part of the buildings, which are hidden for the airborne view. This is why a different approach and flight pattern has been designed in WUIVIEW project, presented in the next point.

Orbital patterns

For small scenarios, such as those found in most WUI microscale in Europe, it is much more efficient to design flight patterns based on orbits around the targeted building. These imply a smaller fly space and

generally optimise the time of photo gathering. Following, the principles for orbital flight design, based on the characteristics of the used RPAS in WUIVIEW project, is presented.

For such a smaller spaces, consequently smaller RPAS are preferred, due to their flexibility, reduced legal restrictions (particularly with MTOW below 250 g), ease of use and better safety flight conditions. In WUIVIEW project, the recently released DJI Mavic Mini (Figure 14) has been selected and used in preliminary test flights, and the orbital pattern has been designed according to its camera characteristics.

DJI Mavic Mini is a nano-drone which main characteristic is its maximum take-off weight (MTOW) of 249 gr, which implies a much less restricted flight due to regulations in most of EU countries, which makes it particularly suitable for missions in populated urban areas and much safer flight conditions. This RPAS is foldable and extremely portable, and also reduces noticeably the intrusivity due to its size and quietness flying. However, no SDK has been freed from manufacturer, and consequently no autonomous flight can be programmed as in other models. The preliminary test performed with this drone were performed under VLOS and manual navigation, so the orbital flight pattern was established as a reference only.



Figure 14. The RPAS DJI Mavic Mini unit used in WUIVIEW project microscale test flights.

DJI Mavic Mini has camera with a horizontal field of view (HFOV) of 83°, and a vertical field of view (VFOV) of 62.25°, with a horizontal resolution (HRES) of 4000 pixels and a vertical resolution (VRES) of 3000 pixels. These are the basic parameters to design the orbital patterns so to ensure maximum coverage with the minimum number of photos, as a reference example. Another parameter considered is the radius R of the half dome in which the flight takes place. This distance is set according to the camera resolution and the required degree of detail in the final model. In particular, the horizontal angle covered by every pixel is:

$$\alpha_H = HFOV/HRES = 0.02075^\circ$$

According to this, the object resolution at a distance of R meters is approximately:

$$d \simeq R \cdot \alpha_H = 1000 \cdot 0.02075 = 20.75 \text{ cm}$$

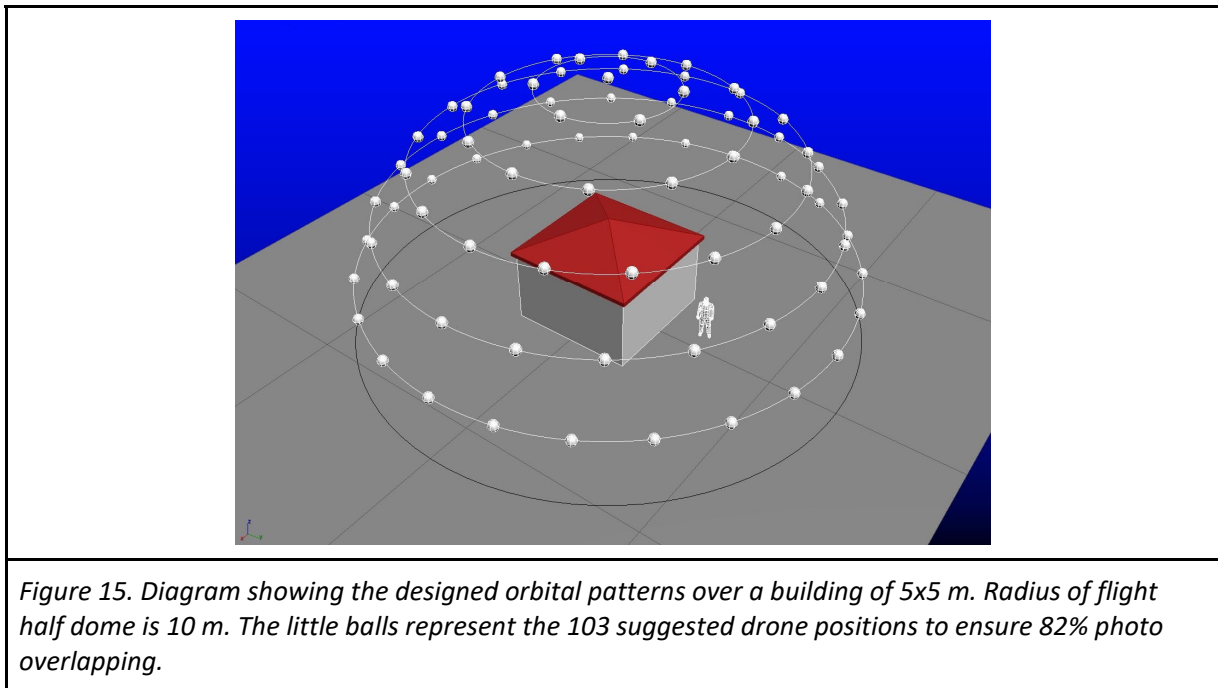
Given that it is preferred to include the whole building in each of the photos, the distance R is to some extent subject to the size of the building to be modelled. This also implies that the obtained object resolution is subject to the size of the building, in particular for R equal 10 m and a HRES of 4000 pixels, a maximum of 20.75 cm of object resolution is obtained. For larger buildings it is preferred to use the systematic grids as presented in the previous points, but consequently coarser object resolutions will be obtained as distances are larger.

In professional fora of photogrammetry, it is strongly suggested to keep a constant and generous overlapping, both horizontally and vertically, between consecutive photos, ranging between 60 and 80%. Taking as a reference a 80% overlapping, let's find the angle increment to optimally cover the whole orbits, and hence derive the design of the orbital pattern. In fact, to ensure an 80% overlapping over a HRES 4000 means displacing the next take position just 800 pixels, meaning 16.6° (at $0.02075^\circ/\text{pixel}$) of horizontal displacement between consecutive photos. This implies taking $36/16.6=21.68$ photos to cover a full orbit of radius R.

To facilitate the understanding and use of this orbital pattern, nominal values (based on the calculated ones) are used instead. In fact, if a photo is taken every 15° (similar to the 16.6° obtained), a total of 24 photos are needed to cover a full orbit of radius R. These 15° are equivalent to 722.89 pixels which means 81.92% overlapping. Nominal values (15° and 24 photos) are the reference to design the full set of orbits, each one at a vertical distance of 15° from each other, so to complete half dome with six orbits and a nadir photo in the very top. To obtain the radius of each orbit, the associated angle to the orbit is considered. In order to obtain consistent results, the number of photos in every orbit (at different radius) is such that the overlapping of 81.92% is ensured. That means that the RPAS, in every orbit, will move the same arc length which is approximately $R/4$.

These are simplified rules that establish a semi-spherical mesh of locations from which the RPAS will take photos. Camera tilt angle is set in every orbit in such a way that the centre of the image is looking at the centre of the half dome in which the building is inserted. That means that in nadir take the camera tilt angle is 90° (looking downwards); in the first orbit the angle will be $90-15=75^\circ$; in the second $90-30=60^\circ$; in the third $90-45=45^\circ$, and so on. The last one will be at ground level with an angle of 0° for which it is suggested to perform photo taking just walking around the house with the drone handheld (same camera) to ensure photography consistency. This is preferred to fly the drone so close to the ground with the potential danger of crashing the aircraft. The following table summarizes the values obtained for the design of each orbit with R set at 10 m, and the following illustrations (Figures 15-17) show the visual look of the proposed pattern:

Orbit	Angle °	Radius m	Height m	Camera tilt °	Nº of takes
0	0 (nadir)	0	10	90	1
1	15	2.58	9.65	75	6
2	30	5	8.66	60	12
3	45	7	7	45	17
4	60	8.66	5	30	20
5	75	9.65	2.58	15	23
6	90 (ground)	10	0	0	24



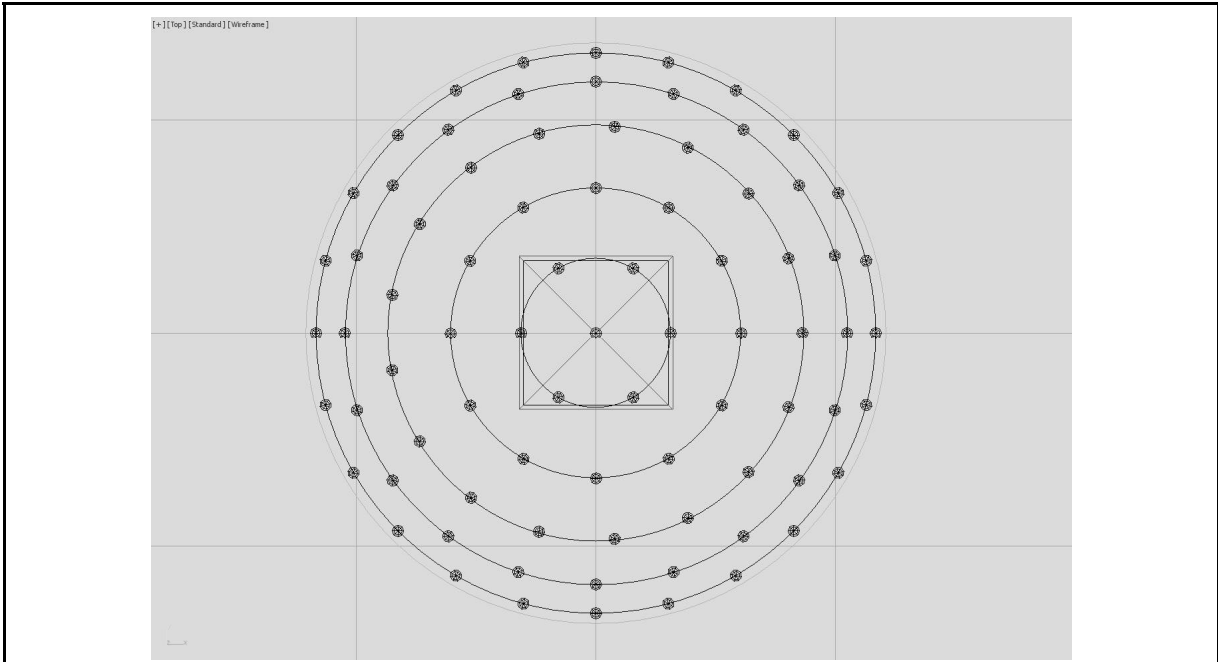


Figure 16. Top view of suggested drone positions. Observe the constant arc increment of $R/4$ m.

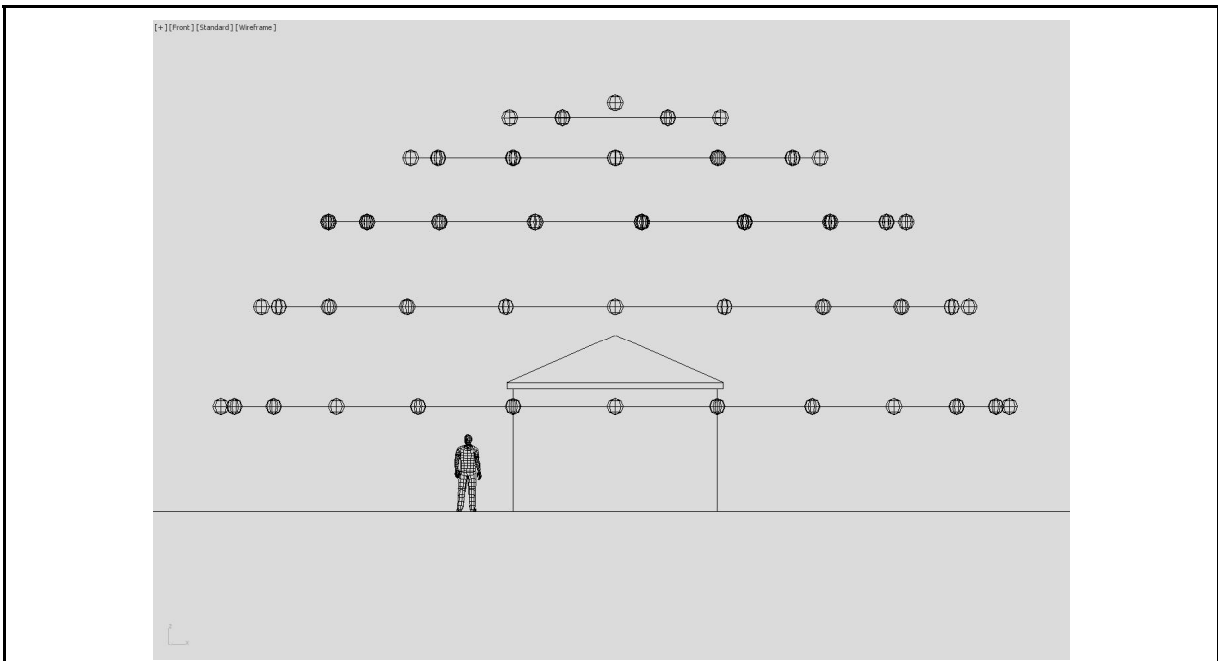


Figure 17. Front view of the suggested drone positions in each of the orbits and the nadir take.

Some preliminary tests have been performed based on this design, in particular a flight over a small structure in Madrid Autonomous Region, which is one of the selected study areas in WUIVIEW project.

The resulting flight track and the drone positions (GPS positions further corrected by photogrammetric measurements) is presented in Figure 18:

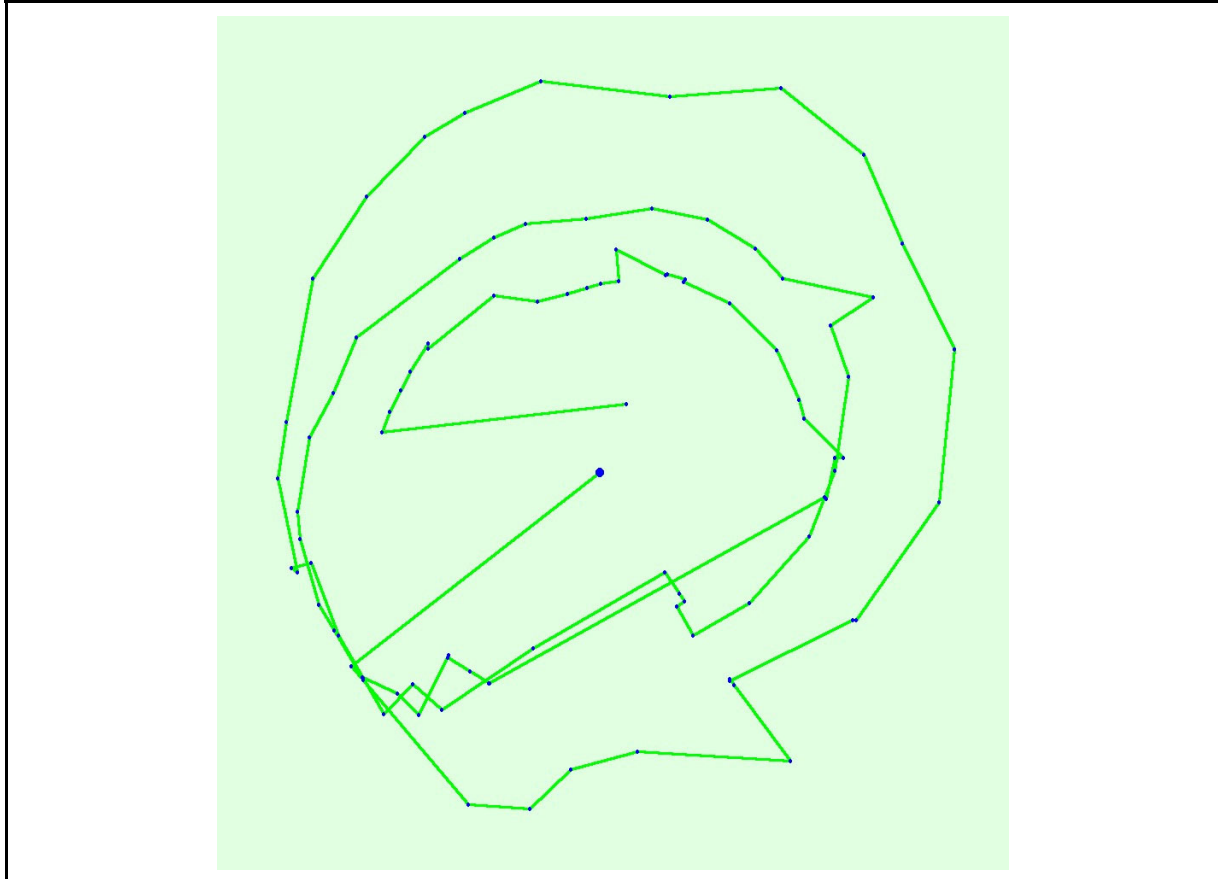


Figure 18. Actual positions of the RPAS (GPS corrected by photogrammetry measurements) in three different orbits and a nadir take in this preliminary test flight in study case 3 of Madrid Autonomous Region. In this case manual flight mode was used. Semi-autonomous flight is achieved with the 'QuickShot/Circular' mode.

A total of 95 photos (Figure 19) were obtained in three different orbits, including a nadir picture. Average maximum flight ceiling was 15 m and the maximum flight distance 20 m. This operation took place under mild-wind conditions (around 2.5 m/s). Cloud overcast helped in removing unwanted shadows and helping in further identification of object features, although colours resulted in a slight washing out. Semi-autonomous flight mode for DJI Mavic Mini can be achieved for circular orbits around a subject making use of the 'QuickShots/Circle', for which a constant height and a distance from the centre are specified.

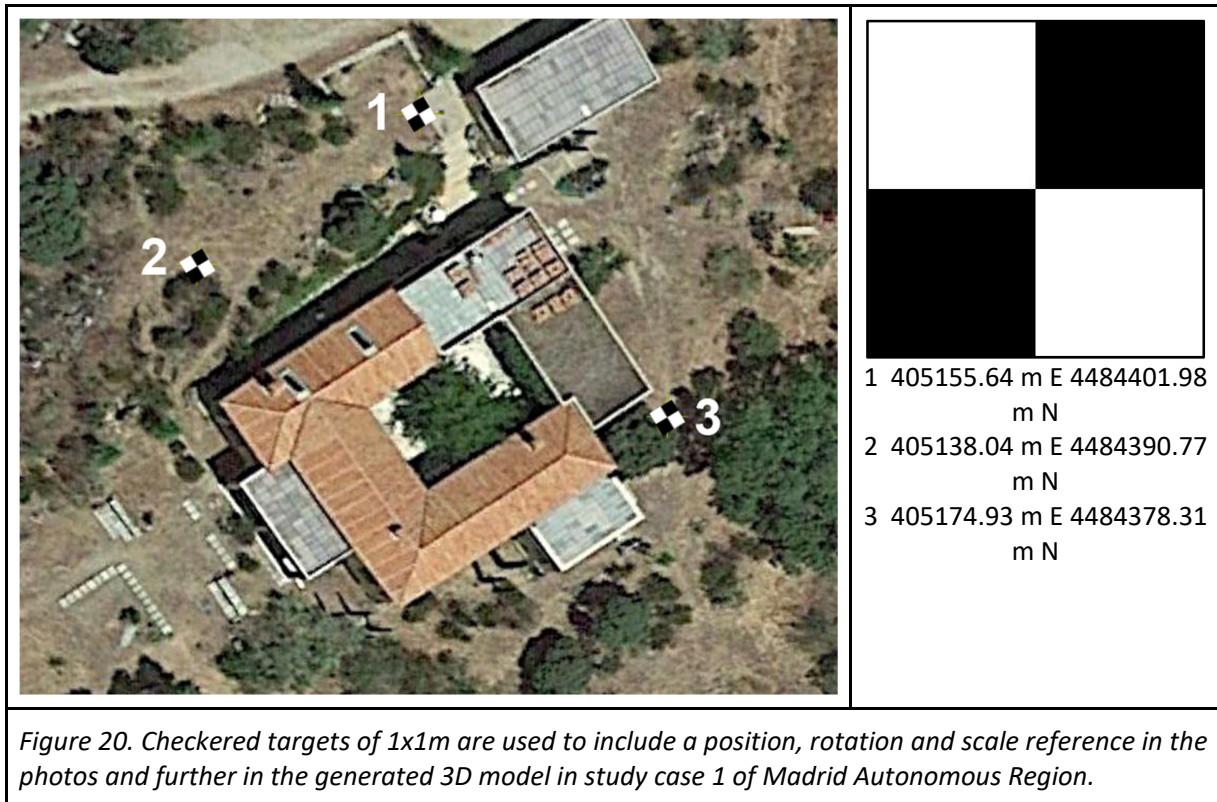


Figure 19. The full collection of the obtained photos in this preliminary test flight in study case 3 in Madrid Autonomous Region. The camera tilt angle was set remotely with 1° accuracy. Observe that the building is seen completely in every frame.

Quite long discussions took place about the use of autonomous pre-programmed flight applications (such as Drone Deploy, Pix4D Capture or Litch) for such reduced spaces as the WUI micro scales are, which frequently are populated with objects and obstacles of all sizes (electric poles, trees, wires, fences, beams, verandas etc.), complicating enormously the completion of a safe flight. For such missions proximity sensors are required and in such constrained spaces manual flight to avoid collisions and ensure flight safety. Besides, and for the same reason, small drones and manual flight, operated by certified pilots with the assistance of complementary observers, are preferred. However, manual operation of RPAS normally reduce positioning accuracy and require more time to perform than autonomous flight. These aspects must be considered in the final design of the data gathering services.

Geo-referencing

In order to have exact position, dimension and orientation of the obtained objects, thus helping in the composition of complex scenarios, some kind of geographical references have to be included in the photos. To achieve this, regularly professional photogrammetry jobs set a number of targets (at least three) in the area to be scanned, in specific positions which coordinates are obtained from GPS readings or from a detailed scale map. In the preliminary tests, three checkered targets of 1x1 m were placed in the approximate corners of the designated area (Figure 20). Further, these serve as reference in the obtained 3D model to precisely set the position, rotation and scale of the object in consonance of the real world, by means of linear transformations in the 3D editing software (in this case 3DS Max).



When using a RPAS with a GPS receiver, this approach is redundant, as all the GPS drone positions are registered within an error of 1.4 m (according to manufacturer specifications), which are further corrected by using the calculated camera positions from photogrammetry, as explained in the following points. On top of the two referencing approaches, it is suggested to double check dimensions of known features in the scenario (such as certain parts of the building which can be measured in field or over an orthophoto), as accuracy of relative distances and orientation between objects is paramount for FDS simulation.

Photographs processing

A generic photogrammetric process workflow is followed in WUIVIEW for the generation of a 3D model from a set of photographs, namely:

1. Camera initiation
2. Feature extraction
3. Image matching
4. Feature matching
5. Structure from motion
6. Densification of point cloud
7. Calculation of depth map
8. Filtering of depth map
9. Mesh generation

10. Mesh filtering

11. Texturing

The photogrammetric procedure first extracts the information from the EXIF data in each image, to gather the camera properties (focal length, type etc.) and geographic position (GPS data if available). The second process is the identification of features in each of the photos. For this reason, contrasted pictures with details in the surfaces are preferred to uniform, flat materials. A list of features is created for each image. After, the process orders images and creates a list of candidates for pairing, so to identify consecutive photos which overlap. The process continues with the identification of common features in consecutive photos (feature matching) and exclude those features which cannot be found in several.

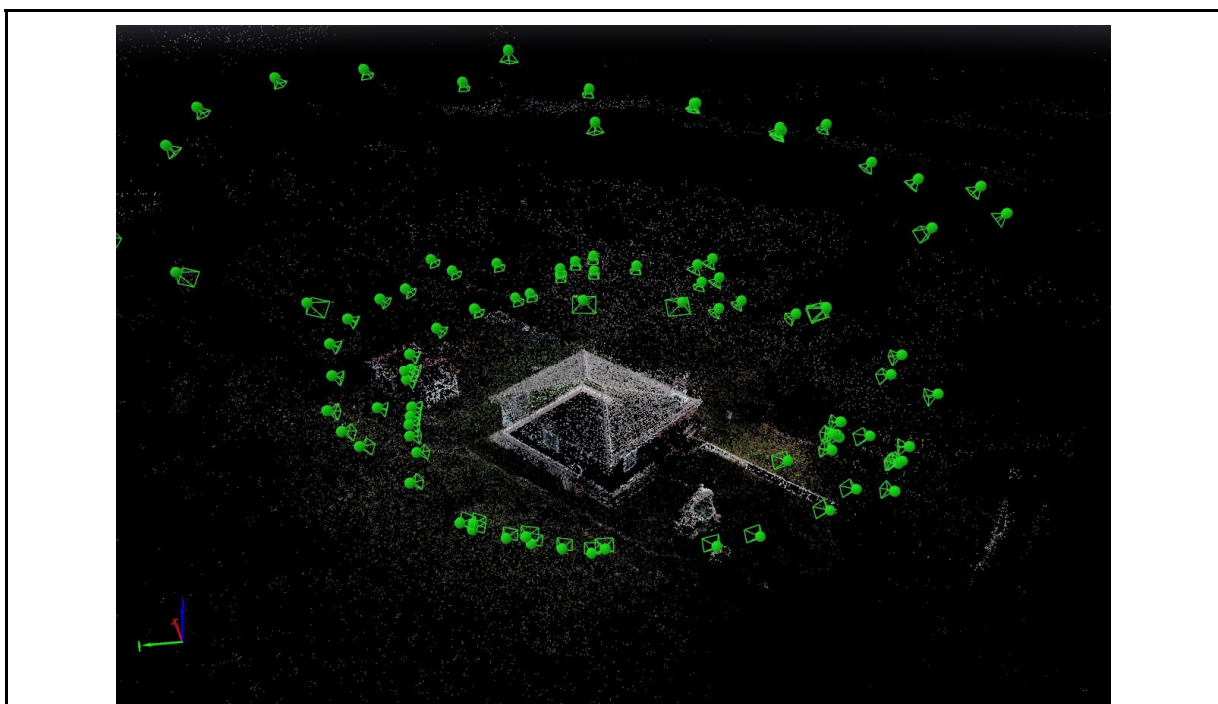


Figure 21. Obtained camera positions based upon GPS coordinates and further correction by pairing photographs with matching identified features in the study case 3. The different orbits performed by the RPAS are also depicted.

The main process of photogrammetry is the application of SFM routines, for the calculation of camera positions and the triangulation of matching features in coupled images. This is the part of the process which is more time consuming and renders an intermediate point cloud which is further densified with more of the identified features (see Figure 21).

In order to consistently generate a 3D mesh, the process orders and filters the points according to a depth map, so to ensure continuity in the identified surfaces. Once the points are ordered and filtered, a triangulation takes place between triplets of points, so generating triangular faces of the 3D model, this

is the mesh generation step. Further filtering of the generated triangular facets is applied so to discard inconsistencies and non-continuity of generated surfaces. The last step is to assign a colour code to each of the vertices, generate texture mapping coordinates and generate the corresponding texture map. This last part adds a great value in the 3D generation of WUI microscale, as colour is a parameter used for the identification of materials of objects and their components (Figure 22).

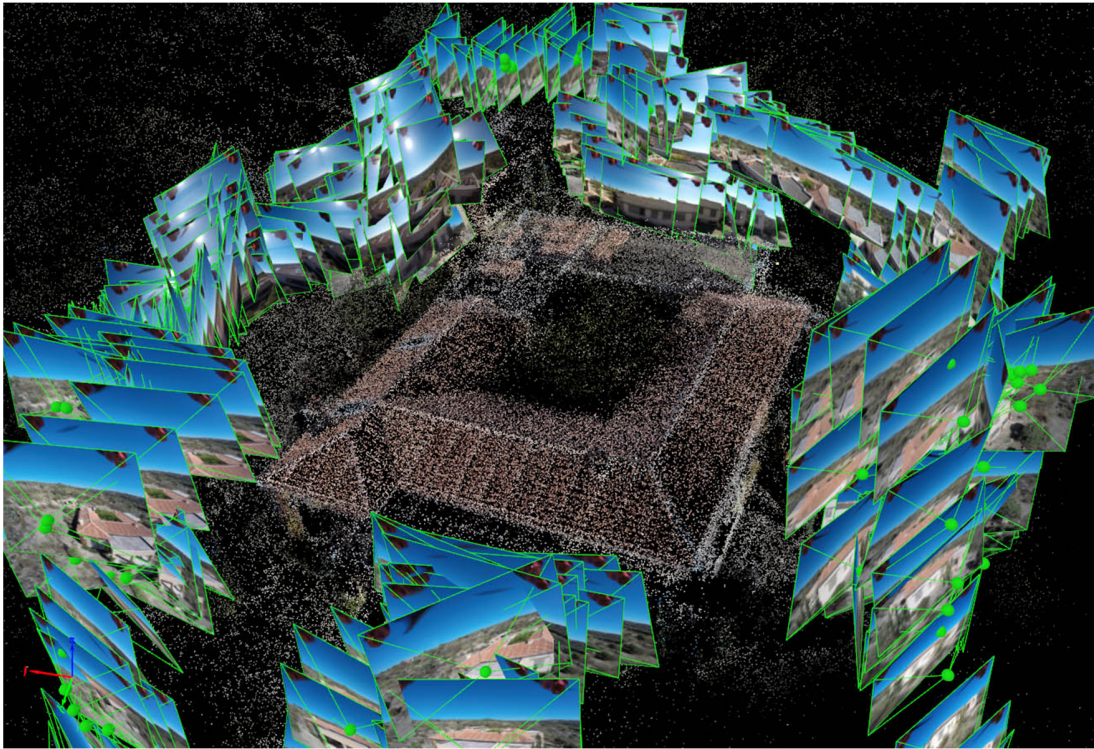


Figure 22. Obtained intermediate point cloud with the associated colour as observed in the photos and camera positions with the projection orientation of the corresponding photos in the study case 1 in Madrid Autonomous Region. Unmatched pairs of photos are discarded for further SFM calculations. In this case all the 95 pictures were used.

Placing and simplification of the 3D obtained scenarios

Best results are achieved with a generous overlapping between consecutive photos (between 60 and 80%). In study case 1 a total of 492 images were used, rendering a great detail. However, the lack of nadir pictures and some complementary takes in the interior patio resulted in some inconsistency and artifacts. These were further cleaned in the 3D editing program (3DSMax). Using photogrammetry for 3D objects modelling normally renders extraordinarily big number of triangular facets (several millions for the current study cases); a simplification process is applied to minimize redundant information of unwanted micro details by using decimation algorithms, preserving general details and geometry (Figures 23 and 24).

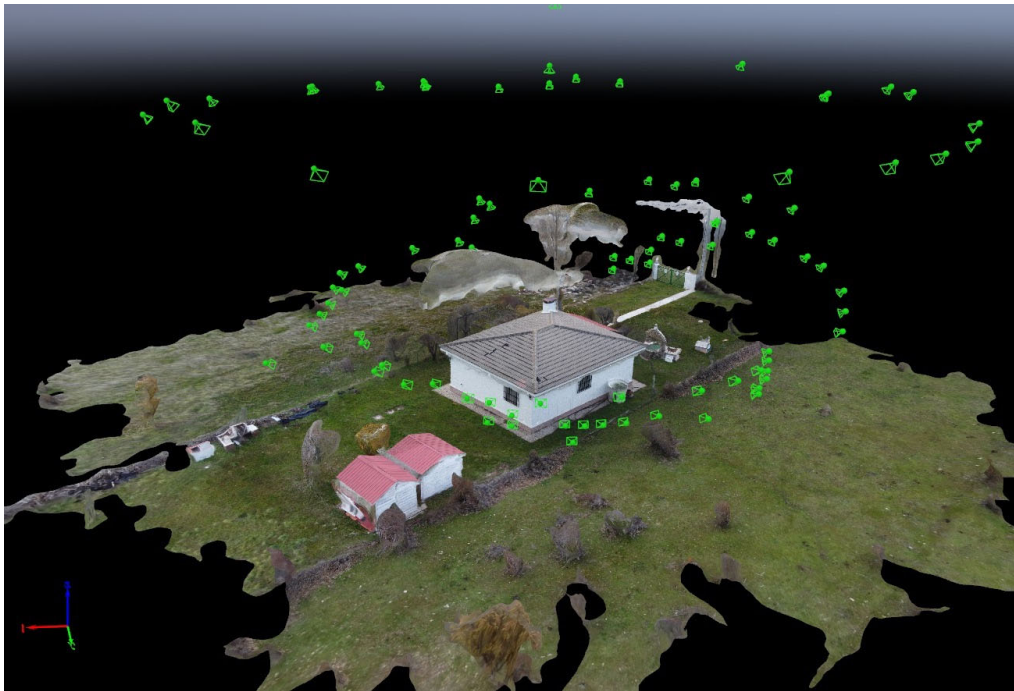


Figure 23. Completed version of textured 3D mesh of study case 3, prior to simplification and cleaning.



Figure 24. A high level of detail was achieved with just 95 images in the study case 3. However, some artifacts and inconsistencies are observed. These were edited in the 3D editing platform 3DSMax.

Using the reference targets as control points, a routine of placing, rotating and scaling the obtained 3D model is performed. To achieve this, target coordinates acquired by GPS are used to draw simple objects in the 3D editor which serve as reference. In this case, small boxes are used. The next step is to displace the observed target in the 3D object to the centre of the reference box; this can be done by using snap to vertex function for a precise movement. Using a second target as reference, a 3D rotation vector is defined to perform an exact rotation of the 3D object. Finally, using the third target, a uniform 3D scaling vector is defined to match exactly the dimensions of the object in the real world. A fourth target point can be used for checking and fine tuning the placing, rotation and scaling (Figure 25).

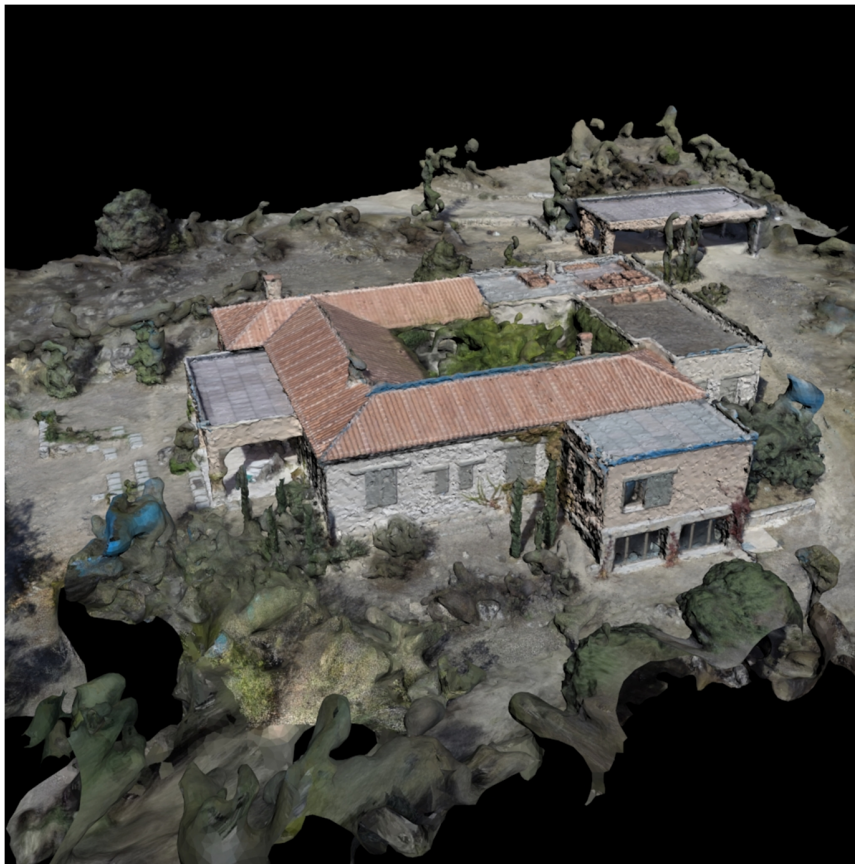


Figure 25. 3D model of the study case 1 in Madrid Autonomous Region, with the exact position, location and scale. This ensures that distances and dimensions are accurately reflecting the relative position of objects, as in the real world. Artifacts and inconsistencies are also removed in the 3D editor. A rectangular region has been clipped out to discard distant polygons.

Observed limitations and discussion

Photogrammetry renders high level of detail with a minimum time invested in generating the model. In the presented cases, half an hour was invested in the RPAS flight in average; about two to four hours of computer calculation; another two to four hours for 3D editing and material assignment and another hour to parse into FDS format, totalling a day work. However the obtained objects are not perfect, which

require further editing and refining. Uniform light conditions in the acquisition process normally render worse results. Cloud overcast, nevertheless, avoid casting hard shadows and helps obtaining more uniform textures. The process presented is not very effective in modelling trees and other plants, particularly if the leaves are not in place. Under wind conditions, leaves and branches move between takes, rendering poorer results as they do not refer to the same locations. Clouds and other distant objects appear as artifacts that need to be removed. Concave spaces, particularly below terraces and porches, are difficult to acquire, and ground photography is needed to complement the data gathering. Large buildings and installations (several hundreds of meters) need to be acquired in sections and then integrated in the 3D editor.

5. Spatial segmentation and FDS parsing

5.1 Voxelization

The next step in the workflow is the segmentation of the 3D scenario into small cubic regions referred to as voxels (from volumetric elements, or volumetric pixels). Each of the voxels contains information about the average type of occupation according to what is found in each of the x,y,z locations in the grid. Consequently, the scene bounding box is divided regularly in each of the coordinate axes, resulting in the final voxel resolution (Figure 26).

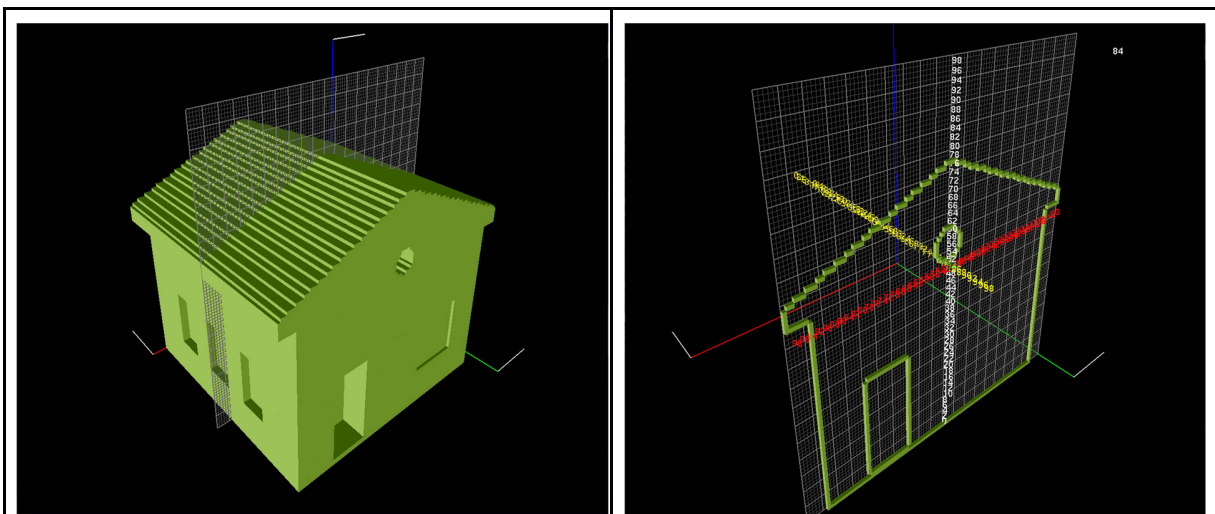


Figure 26. A voxelized version of a simplified house (left) and a slice of the same object (right), showing that only the external shell is transformed for simulation. Voxelization performed with binvox algorithm and displayed in Viewvox application.

The voxelization method adopted in the WUIVIEW project follows the strategy reported in Haumont and Warzée (2012) and Karabassi et al., (2012). A 3D discrete space Z^3 is a set of integer grid points in a 3D Euclidean space denoted by Σ . A 3D grid point is a zero dimensional object defined by its Cartesian coordinate (x,y,z) . The Voronoi neighborhood of grid point p is the set of all points in the Euclidean space

that are closer to p than to any other grid point. The Voronoi neighborhood of a 3D grid point is a unit cube around it, known also as a voxel. The aggregate of all voxels is a tessellation of 3D Euclidean space. A voxel's value is mapped into the set $\{0,1\}$: voxels assigned the value '1' are called 'black' or 'non-empty' voxels, while those assigned the value '0' are called 'white' or 'empty' voxels. Two voxels are 26-adjacent if they share a vertex or an edge or a face. Every voxel has 26 such neighbours. Eight of the 26 neighbours share a vertex (corner) with the centre voxel, twelve of the 26 neighbours share an edge with the centre voxel, and six of the 26 neighbours share a face with the centre voxel. Accordingly, the face-sharing voxels are defined as 6-adjacent, and the voxels that are both edge-sharing and face-sharing are defined as 18-adjacent.

Binvox is a straight-forward program that reads a 3D model file, rasterizes it into a binary 3D voxel grid, and writes the resulting voxel file. binvox uses the parity count method and (a slight variation of) the ray stabbing method described by Nooruddin and Turk (2003). To speed up the parity counting, a hardware z-buffer 'slicing' method is used (Figure 27).

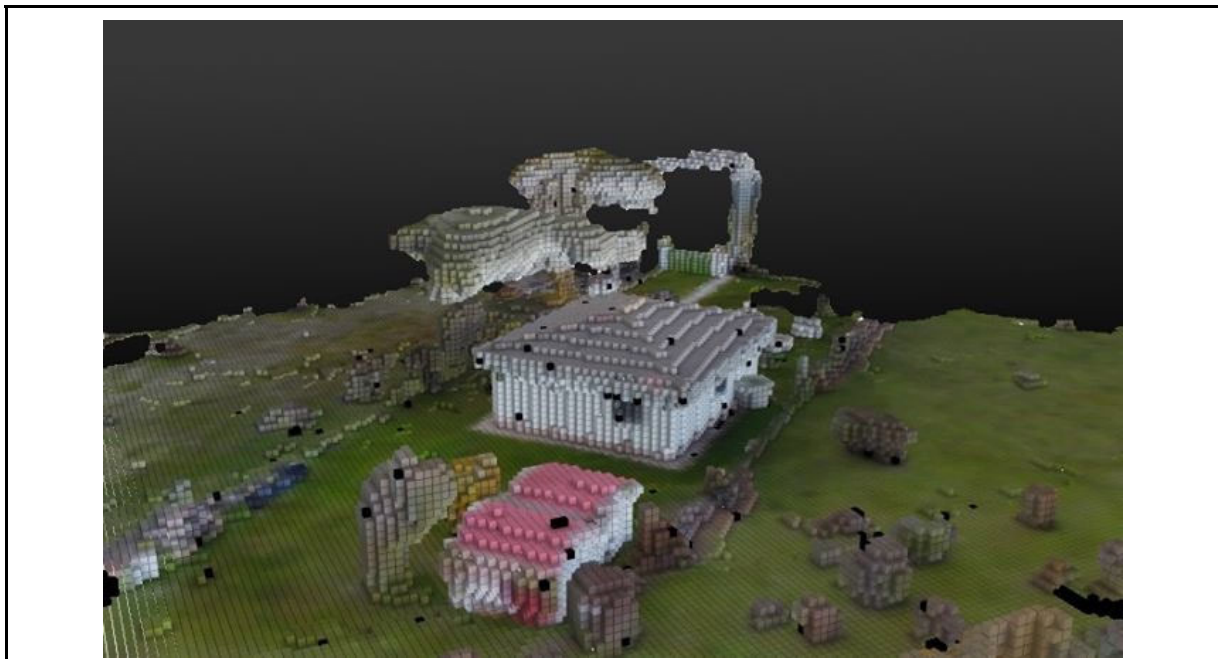


Figure 27. A voxelized version of the scenario corresponding to the study case 3 in Madrid Autonomous Region. In this model the voxel resolution is 30 cm. Colour information is averaged from the vertices falling in the same voxel.

A specific voxelizing program has been offered by researcher Anestis Koutsoudis (IPET) to be tested in the selected WUIVIEW study cases. The implemented voxelizing algorithm is similar to that found in Binvox application (Figure 28).



Figure 28. A voxelized version of study case 3 in Madrid Autonomous Region, with a voxel size of 10 cm, rendering a large number of objects. Colour gathered from pictures is used as reference for material assignment in further steps.

Voxelization of 3D meshes based on triangular facets is using the principle of cubic volume intersection with the associated planes. To easily achieve this, the external shell of 3D object is divided into slices in each of the spatial axes, resulting in intersections of planes and the object surface; for each of the resulting curves, the intersections of the cubic mesh, of a given cell size, are calculated and the obtained points sorted. The neighbouring voxels which describe contiguous points are then interpolated. In this way, space occupation of the object is translated into this three-dimensional grid. Properties of each facet (i.e. colour) is transferred to the x,y,z position of the grid. This can further be used as an indicator of different materials. Voxelization is not free of inconveniences and drawbacks. The first and more notorious is the spatial aliasing effect when objects have planes (for example, building façades) which are not aligned with coordinate axes; for these cases aliasing effect is observed, for which straight lines and planes appear to be formed by discretized steps. Another problem is the generation of a large set of objects, normally counting several millions. Voxel size must be selected in such a way that the desired level of detail is retained while do not increasing enormously the number of objects. For the examples presented a compromise resolution of 20 cm is selected. Finally, several facets with different properties (colour) may be falling within the same voxel region so rendering confusing results; a statistical method is applied (i.e. mean) to assign a unique but meaningful value to the voxel.

5.2 Assigning properties and cleaning

The generated voxelized scenario can be easily edited in a 3D editor such as 3DSMax or Blender. This includes the removal of unwanted voxels, the inclusion of missing ones, the correction of artifact which may be generated in the voxelizing process and the association of material properties to the objects and the components in the scenario.

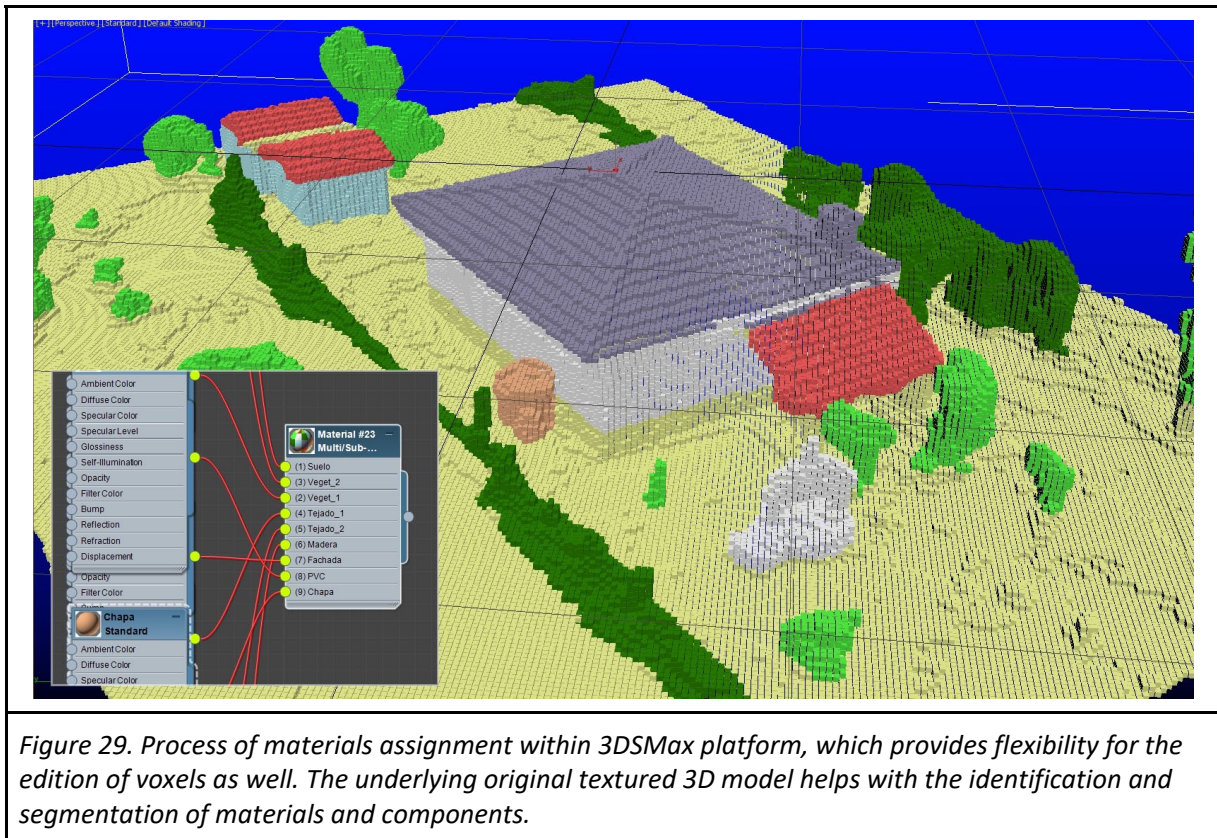


Figure 29. Process of materials assignment within 3DSMax platform, which provides flexibility for the edition of voxels as well. The underlying original textured 3D model helps with the identification and segmentation of materials and components.

Two approaches have been followed for the identification of objects and their components and the association of the corresponding materials:

By region: selecting regions as observed in the original 3D model, overlaid on the voxelized version, and creating groups which are further associated to material entries (see figure 29). This is a time-consuming process but, on the other hand, the most accurate results are obtained. Given the easiness of 3D edition of single voxels, a detailed selection of voxels can be done (see Figure 30). For small scenarios this is the method preferred.

By objects: making use of the spatial region defined by the original objects, and based on the acquired colour (texture map, as seen in figures 27 and 28), an automatic assignment of materials is performed. Although this is much more efficient in terms of time consumption, a large list of materials is generated, as each slight variation of the RGB colour triplet is considered a different one.

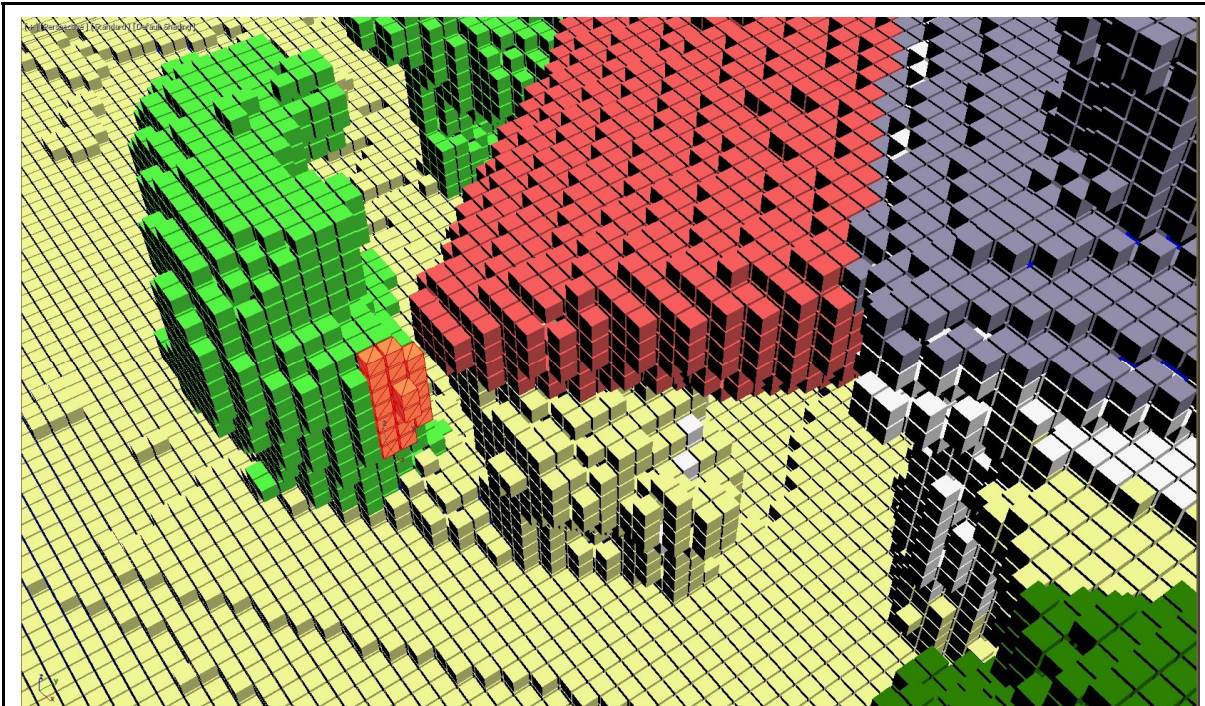


Figure 30. Process of editing voxels, removing unwanted ones, adding missing elements and grouping them into batches with same material characteristics. All the process is done intuitively in 3DSMax editing platform.



Figure 31. Resulting clean 3D microscale scenario of study case 3 of Madrid Autonomous Region,

voxelized at 20 cm of resolution, with materials assigned and ready for its conversion into FDS files for simulation.

5.3 Parsing voxels into FDS files

Parsing OBJ format

The last step in the proposed methods for WUI microscale scenarios 3D modelling is the association of geometry and properties of 3D voxelized objects (written in OBJ file format) into model characteristics to be used in the fire dynamics simulator FDS. To achieve this, first is needed the understanding of an FDS file and the simulation software. The parsing or translation of a generated 3D voxelized scene into FDS is done through the automatic generation of an FDS format input file. This avoids or reduces the time-consuming process of describing detailed geometries of an scenario; all the editing, finetuning and material associations are done in the user-friendly interface of a 3D model editor such as 3DS Max or Blender.

Mesh size and resolution

All FDS calculations must be performed within a domain that is made up of rectilinear volumes called meshes. Each mesh is divided into rectangular cells, the number of which depends on the desired resolution of the flow dynamics. As a general rule in this process, an exact geometric equivalence exists between generated voxels and the FDS rectangular cells. FDS computational mesh size for the selected scenario is automatically generated from the maximum and minimum x,y,z, values found in the OBJ file, which describe the bounding box of the region. Given that a procedure has been suggested to consistently keep the same bounding box spatial region over the several steps (image acquisition, 3D model generation and voxelization) by setting two small boxes in each of the describing corners, the resulting spatial region will exactly match with the size of the FDS mesh. The size of the voxels d (as described in the voxelizing process) is used to deduce the number of divisions of the computational mesh in each of the coordinate axes. The coordinate system consistently matches the used in FDS (right hand rule).

So, given x_i, y_i, z_i and x_f, y_f, z_f the extreme coordinates of the 3D scenario bounding box, and given d the size of the unitary voxels, the number of divisions in each axis is:

$$\begin{aligned} N_x &= (x_f - x_i) / d \\ N_y &= (y_f - y_i) / d \\ N_z &= (z_f - z_i) / d \end{aligned}$$

Thus, the generated line in the FDS file for the computational mesh description is:

```
&MESH IJK=Nx,Ny,Nz, XB=xi,xf,yi,yf,zi,zf /
```


Obstructions

The entire geometry of an FDS model is described using rectangular solids within the flow domain called obstructions (OBST). It is defined by two points (x_1, y_1, z_1) and (x_2, y_2, z_2) as the opposite vertices in the parallelepiped. The translation of the obtained voxels (in the OBJ file), of uniform size and regular spacing, into obstructions is immediate, generating as many obstructions as occupied voxels in the simulation space. To achieve this, given that in the OBJ file the vertex list is generated sequentially so every 8 lines a voxel is described, the first and last vertices of each group of 8 corresponds to the extreme vertices (x_1, y_1, z_1) and (x_2, y_2, z_2) of the cubic voxels. Thus, reading these, the generated line in the FDS file for every voxel is:

```
&OBST XB=x1,x2,y1,y2,z1,z2, SUF_ID='MATj' /
```

Where MAT_j refers to the associated voxel material which is described in the corresponding line in the SURF namelist group of bounding surfaces as described below.

Bounding surfaces

In FDS simulations, definition of the structure of all solid surfaces is required and specified through the SURF identifier for each obstruction in the corresponding SURF line. The assignment of surface properties for each voxel surface is performed using the material file (MTL) associated to the OBJ file. In this, each facet compounding each of the voxels has a unique material assigned, in such a way that every voxel has only a material value associated. This simplifies the translation into surface properties in FDS, as just one surface ID is used for every voxel (SURF_ID, for all facets in a voxel), as seen in the previous point. In the OBJ file each material is specified, first, by the name (MAT_j) and the red, green, blue triplet (RGB) of the associated colour, following other parameters such as texture and reflection map which are not used. The material name used in the previous step is inherited in the corresponding SURF section of the FDS file, so to explicitly refer to real materials which properties are tabulated. Besides, the colour RGB triplet, as described in OBJ file, is directly used in FDS format to ensure consistency in the representation of the scenario. The corresponding line in the FDS file is:

```
&SURF ID='MATj'
```

6. Concluding remarks

This document describe the procedure to obtain WUI microscale scenarios using existing 3D data gathering and 3D modelling tools that will feed FDS scenarios in WUIVIEW study cases. The proposed method is based on airborne photogrammetry and includes several key steps: design of flight patterns, geo-referencing, photo-processing to obtain an initial 3D model. Following, the 3D model is converted into FDS compatible data through a process of voxelization, properties assignment and cleaning.

The methodology has successfully been developed and tested in one of the WUIVIEW preselected study areas of Madrid Autonomous Region. The final steps of 3D model transferring and adaptation to FDS compatible scenarios will be further detailed in future WP7 deliverables.

7. References

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