

Capturing, processing and analysing 3D Data in a National Mapping Agency

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Abstract

National Mapping Agencies (NMAs) have traditionally mapped their respective countries in two dimensions, taking inherently three-dimensional information and generalizing it into a flat projection plane. While some NMAs have moved completely to a three dimensional data model, many are still working in 2D, often augmented by height attributes which bring the data slightly closer to a 3D model of the world. As data capture, data processing and data analytics systems and software have evolved, it is now easier than it has ever been to collect, view and process 3D data. National Mapping Agencies have acknowledged this by moving towards 3D geospatial data models, although the approach taken, and the type of 3D data provided to users, varies between different countries. This paper describes the current position of Ordnance Survey, Britain's national mapping agency, as it develops prototype 3D products. It describes the technical methods used to create a 3D product together with the business methods used to test the market, understand the customer, and provide a product that is both technically feasible to produce and financially viable to create and market to customers.

1. Introduction

1.1 Historical context

The role of a national mapping agency has changed significantly over the past few decades. For the Ordnance Survey (OS) in Great Britain, this change has included the move from paper-based maps to digital geospatial data and from a department of government, via a government executive agency, to a government owned company. During these changes, the sources of the geospatial data, and the nature of the data that is captured, has not dramatically changed. While sketching cases and theodolites have given way to tablet computers and GNSS kits, the data itself still consists largely of two-dimensional points, lines and polygons, together with attributes which convey semantic information to the geometric features.

At Ordnance Survey, the 3D aspect of geospatial data has been represented by contours, manually traced using photogrammetric processes; and digital terrain models, originally derived from contours and now generated using image-matching software and multi-overlapping aerial images. In recent times, building height attributes have been introduced to its National Geographic Database, representing the top-height of each building, akin to an LOD 1 building model (Open Geospatial Consortium, 2021). While this gives an impression of a 3D model of buildings, it does not apply to other features such as vegetation, walls or street furniture.

This paper describes the product development process undertaken by Ordnance Survey to determine the most appropriate 3D product for its users, taking into account the costs and resources needed to produce it and the demand for such products from its customers.

1.2 Research into 3D data

Many research projects have been undertaken at OS to investigate the capture of 3D information. This has taken several different forms, including CityGML building models, 3D point clouds and various types of mesh model. In most cases, these projects have been restricted to small geographical areas, often as part of larger projects relating to digital twins or 3D simulations. For example, Holland *et al.* (2020) described the OmniCAV project, which developed a simulation of part of the road network in Oxfordshire, used to test autonomous vehicle software. The 3D data in this project included LOD2 buildings, road and kerb surfaces, vegetation and streetside furniture such as traffic lights and road signs. As with many similar past projects, much of the data collection process involved manual feature extraction, requiring several months of work. This work included the crafting of bespoke 3D models of roadside features, the extraction of detailed surface models of the road surface and the capture of the surrounding urban and rural scenery. For this project the models were crafted in Blender, while the finished 3D objects were converted to fbx file format, to allow it to be read by the simulation software used by the OmniCAV partners.

Previous research projects at OS have investigated the use of both point clouds and building object models, but all have remained within a research context, rather than being taken into an operational production process.

1.3 3D data in other countries

Several National Mapping Agencies in Europe have embraced the concept of 3D geospatial data and are now supplying 3D products to their users. One of the earliest examples of this was SwissTopo, the NMA in Switzerland, which embarked on the journey from 2D to 3D in the early years of the 21st century (O'Sullivan *et al.* 2008). In the Swiss case, the production

system within the national mapping agency was transformed from a cartographic mapping process to a 3D data capture process, with staff being re-trained to capture 3D data using photogrammetric systems. The underlying data model in the SwissTopo system is now a 3D model, holding buildings, roads, ground surface and vegetation objects. The 3D database, together with a single editing system, acts as the single source for all geospatial data products supplied by the mapping agency.

The Swiss data model is different to many other 3D geospatial models in that it holds the roof structures of each of the buildings, rather than the footprints. These roof structures are extruded downwards to intersect with the underlying terrain, to form 3D building objects.

A second country which has been working with 3D data for a long time is the Netherlands. The Dutch Kadaster, working alongside the Technical University of Delft, maintains a 3D cadastre for the registration of 3D land rights and restrictions in the Netherlands (Stoter *et al.* 2013). In addition to datasets distributed by the Kadaster, TU Delft also produces its own data, including 3DBAG (2024), a 3D dataset of all the buildings in the Netherlands, available in various formats including CityJSON, GeoPackage and Wavefront OBJ (Peters *et al.*, 2022). The software developed for the production of the various 3D products is openly available via the GitHub repositories of the 3D geoinformation research group at TU Delft.

Other European countries have taken different approaches to 3D data. BKG, the national mapping agency in Germany, for example, is engaged in a multi-year programme to capture a 3D point cloud of the entire country, at the resolution of 40 points per square metre, using airborne lidar. This data will form the basis of a digital twin of Germany, sufficient to answer many different use cases, from civil protection in the event of flooding to the monitoring of invasive species (BKG, 2025). The Danish mapping agency (part of the Agency for Climate Change) is also building a digital twin, creating 3D building objects using a combination of height data from the Danish elevation model, building footprints from the national mapping database and aerial imagery. LOD 2 building models are created, together with individual trees and tree-groups, and an underlying terrain surface mesh model. The Danish 3D model has an innovative feature which drapes image textures onto the buildings on the fly, using oblique aerial imagery.

2. Developing a 3D product

2.1 Different modalities

There are several different ways in which 3D data can be portrayed, including 3D point clouds, 3D meshes, voxel models, and 3D object models at various levels of detail. Each of these has its advantages and disadvantages and the choice of which mode to use often depends on the use case to which it will be applied.

It is natural that a mapping agency, accustomed to the creation of attributed polygons representing real world features, would look to a 3D equivalent model, such as a CityGML or CityJSON 3D city model. As mentioned above, other European mapping agencies have already taken this approach, including the Dutch Kadaster with its 3DBAG data (Peters *et al.*, 2022). Ordnance Survey has undertaken previous work on 3D city models, including 3D road simulations, smart city digital twin models and telecommunications planning models. Although

such models are ideal for many use cases, they can be expensive to create and to maintain. Moreover, there can be a steep learning curve when moving to complex 3D object models, which often do not easily fit into the systems that users are familiar with. At a recent EuroSDR meeting on 3D mapping (EuroSDR, 2026) it was noted by some of the European mapping agencies that “everyone wants CityGML”. In the UK, we have not found this to be the case, with many users of geospatial data being unaware of CityGML and its associated Open Geospatial Consortium standards.

In a project undertaken over the last few years, OS has taken a pragmatic approach to the choice of 3D model, working with customers to determine the type of 3D product which would be best suited to as many use cases as possible. 3D object models, points clouds and 3D mesh models were all considered and tested as potential products before settling on a 3D mesh model as the most appropriate 3D product. The geometric accuracy of a 3D product may be slightly influenced by the form of the data (point cloud, mesh or 3D city model) but the main contributor to accuracy is the underlying geometric accuracy of the source data. As the source data was the same for each of the potential products, it was not deemed necessary to perform a detailed analysis of the geometric accuracy of the different 3D model types, although such work may be undertaken in future.

2.2 Initial research work

The OS 3D mesh product started life as a research project, investigating different methods of creating 3D data products. Part of this work involved the testing of a potential production process at scale. Previous research projects had created 3D meshes of towns or parts of cities, but OS had never attempted to create a 3D dataset covering a large area. In order to test the feasibility of scaling up a 3D product to a national extent, the South West of England was chosen as a test area, covering an area of over 21,000 square kilometres.

The SW England 3D mesh was produced using multi-overlapping aerial imagery collected initially for Ordnance Survey's topographic data capture programme. The image frames from a Vexcel UltraCam Eagle Mark 3 camera, at a nominal resolution of 15 cm ground sample distance, were processed using Skyline PhotoMesh software. In addition to the SW England mesh, several smaller subsets were captured at higher image resolutions and were processed separately. In one of the sub-regions, in the city of Exeter, several different image datasets were captured, from both nadir cameras and an oblique camera system (the Leica Geosystems CityMapper, flown by BlueSky). Although the SW dataset took several months to process on the limited computer systems available to the research team, the computation did eventually complete, resulting in a prototype product which could be explored and tested by existing and potential customers.

Example visualisations of the 3D meshes are shown in Figure 1, depicting various models of Exeter Cathedral. The top image shows the 3D mesh created from standard OS 15 cm imagery, flown with an overlap of 80% along track and 30% across track. As can be seen, the general shape of the cathedral is there, but the detail is missing and the sharp edges of the building appear as if draped in a thick blanket. This has always been a problem with 3D models derived from imagery but the team at OS has noticed that the image matching software has improved over time and even in the short time since these images were created, they have noticed further improvements. The centre image in

Figure 1 shows a 3D model derived from nadir imagery with a higher overlap (80% fore and aft, 60% side) and a smaller GSD (10 cm). There is a noticeable improvement in the model, with more detail in evidence on the façades of the cathedral and crisper edges to the building. The final image in Figure 1 shows a model derived from oblique imagery, with a nominal (nadir) GSD of 5 cm. This model shows further improvement in detail and integrity, exhibiting fewer artefacts than the other models. This of course comes at a considerable cost as it takes much longer to capture data at this high resolution, and the oblique camera system delivers far more images than a nadir sensor, requiring a lot more processing time and higher storage needs.



Figure 1. Three models of Exeter Cathedral produced using imagery from, top: 15 cm nadir, centre: 10 cm nadir and bottom: 5 cm oblique imagery.

2.3 The product development process

Following on from the initial research, a multi-disciplinary team was set up to develop a new potential product, using experts from research, production, marketing and product development. The team worked as a squad, using product development techniques often found in the software industry and in start-up

companies. This process started with a product discovery phase which involved engaging with customers from different market sectors, in order to find out what their business needs were and how 3D data could be used to satisfy their use cases. The markets covered included urban and rural development planning, telecommunications, security services, utility management and monitoring, and disaster planning.

In addition to the customer insight analysis, the team investigated different potential data sources and production processes which could be used to deliver a 3D product. This involved an assessment of the feasibility of creating the product and the viability of such a product in the market. Unlike many other European mapping agencies, Ordnance Survey acts as a commercial company, so the potential return on investment from a 3D product was an important factor in the analysis.

One of the essential considerations when developing a 3D product was to understand what source material was already available to the organisation. For OS, a key aspect of a 3D mesh was that it could be derived from existing data, namely the multi-overlapping aerial imagery used by OS in its national cyclic revision data capture programme. This imagery is used primarily for the update of topographic mapping and is collected on a three-year cycle across the whole of GB. The prototype products developed in the preceding research project (see section 2.2) were used to demonstrate the capabilities of 3D meshes to potential customers.

The product development process culminated in the creation of a 3D mesh beta product, a sample of which was made available for any prospective customers to view and download. This was published on the OS products website (Ordnance Survey, 2024) using an ArcGIS Online interface and is still available at the time of writing.

The source data for the beta product is nadir aerial imagery at a nominal ground sampling distance of 15 cm, overlapping by 80% along-track and 30% across-track. 3D meshes created from such imagery using image-matching software are of course not as detailed as 3D meshes produced from very high-resolution oblique imagery, but they do serve a useful purpose for many use cases. A 3D mesh derived from 15 cm imagery is not suitable for detailed analysis or for engineering surveys, but it was found to meet the needs of many of the potential users consulted by the OS team, especially as a visualization tool. The mesh was also found to be compatible with other OS topographic products and reference datasets. A localized evaluation of the mesh against a high-resolution terrestrial laser scanned point cloud showed a geometric accuracy of 1.1 m RMSE. This figure is affected by transient features in the mesh (e.g. parked vehicles) which are present in different locations in the mesh and the reference data. In parts of the model where there are only permanent features (e.g. buildings) the geometric accuracy is greater. Figure 3 shows an example of the product, both as a wireframe model and a rendered 3D mesh.

2.4 Production process

Several different software packages were used in the creation of the 3D mesh model. The source data consisted of imagery frames, processed by Vexcel UltraMap; a water mask identifying areas of open water; data describing the geometry of the image block; the aerial triangulation results from UltraMap and a set of ground control points, captured using GNSS equipment by Ordnance Survey field surveyors. These datasets were assembled and reformatted by Safe Software's FME,

which then passes the data to Skyline Photomesh. The Photomesh parameters were adjusted to produce the most realistic 3D model. This specifically improved the results in low overlap, nadir projects, by filling in the gaps on the ground surface in areas with low coverage.

The initial 3D models suffered from large positional errors in areas of water, where the image matching process failed to find any correlation between overlapping images. Various methods were proposed to remove these errors, with the early solutions using water masks derived from topographic vector polygons of water bodies to identify the problem areas, together with DTM data to fill in the resulting gaps. Later iterations of the process used newly-implemented features of the UltraMap image processing software to identify areas of water. The flowline from imagery to 3D mesh is highly automated, but does need to be manually checked and, if necessary, edited to remove any blunders which might lessen the usefulness of the mesh. Quality checking and editing is performed using the Skyline TerraExplorer software. The processing flowline is outlined in Figure 2.

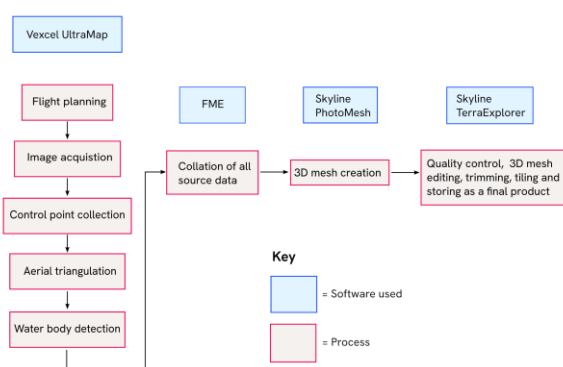


Figure 2. The processing flowline used in 3D mesh production.

3. Uses of a 3D mesh

3.1 Urban planning

Users in several different market sectors have tested the 3D mesh product and used it to fulfil their use cases. One of the main early uses of the 3D mesh was in the planning departments of both local and national government bodies. For these users, the primary use case for the 3D mesh is as a contextual background in urban planning applications. Planners of proposed housing developments may have access to high-resolution imagery and 3D models of their immediate site, often via UAV survey, but the lower-resolution 3D mesh serves to put this into context by showing how the proposed buildings will fit into the surrounding landscape. This can be used to show a visualisation of the development to stakeholders and local citizens, to let them know how the proposal might affect their neighbourhood.

A small number of local authorities in GB, including Nottingham City Council and Bradford City Council, have already embraced 3D models into their planning process. In a report to investigate the return on investment delivered by the use of 3D data by Nottingham City Council, ConsultingWhere (2024) concluded that “the benefits-to-cost ratio in the Nottingham pilot suggests that 3D geospatial data can potentially unlock significant value across many planning

processes and the broader UK economy”. For urban planning applications, the Ordnance Survey 3D mesh product would need to be augmented by higher-resolution 3D data in the immediate area under development, but it could provide the context which links the detailed development site to the surrounding urban and rural landscape.

3.2 Emergency response

A second important use case of a 3D mesh is as an extra dataset in emergency situations such as landslips and flood events, or in the managements of crowds at international sports events. For example, the OS 3D mesh was used by the Devon and Cornwall Police to help them manage a large-scale evacuation of Plymouth after the discovery of an unexploded bomb in a suburban garden in February 2024. The 3D mesh was first used in combination with UAV data and other topographic data to help the Police to determine the potential blast zone, in the event of an explosion. Armed with this information, they then used address data to identify, contact and evacuate all the residents within the potential blast zone. This resulted in one of the largest evacuation operations undertaken in GB since the end of World War Two.

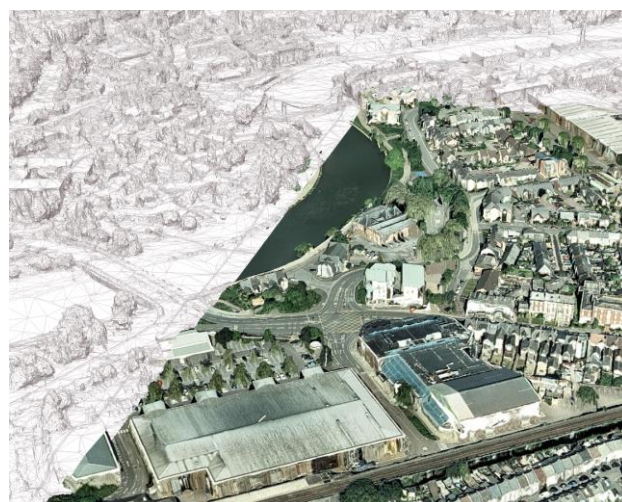


Figure 3. A 3D mesh model of an area of Exeter, UK, generated from standard OS 15 cm imagery.

Having evacuated the area, the police and military personnel used the 3D mesh to help them to plan the most appropriate route for the bomb disposal experts to take in order to safely remove and dispose of the device. Using this approach, bomb disposal experts were able to transport the bomb to a nearby coast where it was towed out to sea and detonated in a controlled explosion. One of the main advantages of the 3D mesh data in this case was the ability to stream the data to browser-based platforms, including mobile phones. This allowed the security services to view the data and plan their operation while on site, as well as from their command centre.

Other uses of 3D meshes by the emergency services have included the monitoring of crowds at large sporting events; the planning of security at international political conferences (such as meetings of the G7) and the assessment of changes to the coastline after a landslip on the Isle of Wight.

3.3 Other use cases

While planning and emergency response applications have been the most common areas of use, there are several other uses to which the 3D mesh data has been applied. These include other types of planning applications, such as the analysis of suitable locations for proposed wind turbine sites or telecommunication mast sites. In these use cases, the analysis of lines of sight, or full 360° viewsheds, is an important consideration. It is therefore important to ensure that the 3D mesh models are of sufficient geometric quality to allow such analysis.

4. Future work

4.1 3D mesh improvements

Since Ordnance Survey first used image matching technologies to create 3D mesh models, the capabilities of the processing software have continued to improve. Early versions of the process produced 3D models of low geometric accuracy, often looking as though the features were draped in a way similar to, but much more pronounced than, the top image of Exeter Cathedral in Figure 1. The use of higher-resolution imagery does of course make a difference, but the improvements to the image matching algorithms and the ability to adjust the parameters of the model to optimise it for the area being processed, have certainly resulted in better-quality 3D mesh models. There is always room for improvement of course. For example, using existing topographic data alongside the image matching process could ensure that edges of features are better delineated and that water bodies are correctly modelled in the mesh. There are also other technologies, such as Neural Radiance Fields (NeRFs) and Gaussian splatting, that can be combined with the more traditional image matching algorithms to produce more realistic-looking 3D meshes.

One drawback of 3D meshes is the continuous nature of the mesh, which essentially means that an entire 3D scene is represented by a single mesh structure. In many applications, this may be a limitation, especially where there is a need to identify individual objects in the model, such as buildings, roads or trees. This may be overcome by segmenting the mesh, with each segment representing a physical object on the ground. Some software systems allow these segments to be given identifiers and attributes, allowing them to be used as objects within a GIS. This approach is not ideal, as it is limited by the nodes and edges of the mesh, which may not align with the corners and edges of the physical objects they represent. As modelling techniques improve, meshes are likely to provide a closer correspondence between the models and the features that they represent, making them more amenable to segmentation techniques and more suitable as frameworks for recording object attributes.

4.2 Other forms of 3D data

The 3D mesh is one of several different forms that a 3D model can take. When Ordnance Survey first started to work with 3D meshes, there was some feedback from other mapping agencies suggesting that the mesh wasn't a real 3D model, and was really just a visualisation system, rather than a useful analytical tool. As this paper has shown, the use of meshes to solve real-world problems indicates that it is not merely a visual product, but it still has its detractors within the domain of traditional photogrammetry. It may also be thought of as a base 3D map, describing features at a coarse level of detail, which can be

augmented by more detailed models based on other forms of 3D representation.

In the field of 2D geospatial data, mapping agencies generally represent objects on the ground as a set of points, lines and polygons, stored as vector objects in a database. The obvious extension of this into 3D space is to represent objects by 3D points, lines and faces, assembled into solid models. Such models have the advantage over meshes that they can represent a one-to-one correspondence between a feature on the Earth and an object in the model. For example, a building can be represented by a unique building object, marked with an identifier and labelled with a set of attributes relating to anything from energy efficiency ratings to property ownership details. Ordnance Survey has, of course, investigated such models in the past, and will continue to do so. Some of the reasons why objects stored as 3D city models have not yet made their way into OS products are the time and resources needed to create them and the return on investment achievable. Automated processes are gradually being introduced into the production systems used to generate such models, while GIS software is improving in its ability to manipulate such data. It may eventually be the case that it becomes cost effective to create national-scale 3D city models, at which point they could remove the need for a separate 2D geospatial dataset, as has happened in Switzerland (O'Sullivan *et al*, 2008).

3D point clouds often form an intermediary role in the creation of 3D products. Digital terrain models, digital surface models and 3D meshes may all start off as massive clouds of unconnected points in space, which are filtered, processed, and joined together to make more coherent 3D products. The 3D point cloud is also of use as a product in itself, especially when used in segmentation tasks to isolate sets of points representing 3D objects. As a national mapping agency, Ordnance Survey is constantly being asked for new products and for new features to be added to existing products. Many of these features are three-dimensional objects, such as lamp-posts, traffic lights, trees, bushes and other vegetation. Point clouds, derived from aerial image matching or from other sensors such as vehicle-based Lidar, could provide a rich source of data from which these new products may be derived.

Dealing with ever-growing datasets has its own demands. Even the low-resolution 3D mesh of the South West of England required the processing of over nine trillion (9,000,000,000,000) pixels. Units of storage are now likely to be measured in multiples of Terabytes rather than Gigabytes (when this author started working at Ordnance Survey, a Megabyte seemed quite a lot!). To move from a 2D vector view of the world to a 3D point cloud or 3D object model would take significant investment in data capture, processing, storage and maintenance so it is not a process that would be undertaken lightly. The OS Research team will continue to investigate and develop new ways of acquiring and manipulating 3D data, so that any future change to a fully 3D data model will be as smooth a process as possible.

5. Conclusions

This paper described how a national mapping agency developed a 3D mesh product, in collaboration with its customers. It showed how a product development methodology, common in the software industry, could be adapted to fit the creation of a geospatial product which is cost-effective to create and meets the needs of a range of different users.

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