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Enhancing Offshore Wind Farm Development Through Advanced 3D Ground Modelling

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ABSTRACT: The rapid growth of the offshore wind industry in the global energy market requires reliable ground modelling to optimise project timelines and costs, with one key aspect being data visualisation. Displaying site conditions using 3D ground models is becoming more common and the use of a GIS-based method facilitates their development and implementation without the need for additional specialist software. The 3D environment allows for a comprehensive presentation of seabed and sub-seabed data, including outputs from geophysical, geotechnical, and environmental surveys, facilitating decision-making during the planning and installation phases. The model should be accessible to project stakeholders, ideally with minimum software requirements. 3D model data representation engages both technical and non-technical stakeholders and broadens the understanding of the ground conditions and geohazards present at the site. In addition to providing a visualisation tool, the GIS model acts as a data repository reflecting project updates and allowing stakeholders to follow project progress. A central data repository ensures that all project team members have access to the most current and accurate information. This paper explores the implementation of a GIS-based 3D modelling technique and showcases it in a case study of a recent offshore wind farm project. The applications of 3D ground models for offshore wind farm development are also discussed.

Keywords: Offshore wind farm; integrated ground model; 3D model; GIS

1 INTRODUCTION

Energy costs have become a growing topical problem globally due to climate change and other factors influencing the energy supply. As a result, national administrations are adapting their approaches to energy generation and increasingly turning to renewable energy sources. By 2030, several countries have engaged themselves to transform their energy mix, with a transition to include a higher portion of offshore renewable energy. One of the most sustainable and efficient sources for increasing renewable energy production towards a resilient and decarbonised energy supply is offshore wind energy. Ground models can often be overlooked by developers but represent a crucial tool to assess seabed and sub-seabed conditions required for a successful offshore wind farm (OWF) site development. Integrating complex datasets into ground models provides essential information for the identification of data gaps and uncertainties across the site. The resulting ground models provide support in understanding suitable foundation options, undertaking conceptual designs based on soil zonations, classification of soils/rocks and their geotechnical parameters, and developing risk registers. This detailed site characterisation with identification of the associated geohazards is a key element to minimise risks and costs and it is often best examined in a three-dimensional environment.

3D models have been extensively developed to support geo-modelling (e.g., Sauvin et al., 2022; Peng et al., 2024); these have also been used as data and results repositories, and as visualisation tools, allowing a better overview of the project; and providing clarity and precision in the different stages of project development.

The aim of this paper is to provide insights into the utilisation of 3D ground models primarily as integrated data repositories and visualisation tools for OWF projects. The paper proposes a GIS-based method for 3D model development, supported by a case study example, as well as applications of such 3D models.

2 METHOD

A common process used to prepare and publish 3D models relies on GIS software and the seamless integration of GIS objects into a 3D environment.

The model can be produced at any phase of the OWF project and a direct connection between the master GIS project and the 3D model allows for continuous updates. Vector and raster files from the GIS-based model can be visualised in a 3D environment and be accessible to all OWF project stakeholders.

2.1 Data Requirements

There are no minimum data requirements to generate a 3D ground model. However, for an OWF 3D ground model the following GIS elements can be considered as a baseline:

- the bathymetry of the site;
- the interpreted subsurface interfaces;
- boreholes (BHs) and cone penetration testing (CPT) data.

In addition to these, and during the later stages of the projects, the model can also include additional layers with interpreted seabed features, geohazards, geotechnical zonations, survey tracklines, wind turbine generator layouts, etc.

Some of these layers result from the interpretation of data in specialist software, such as subsurface interfaces interpreted from geophysical data or geotechnical zonations interpreted from site investigations. For geophysical data in particular, the depth information is usually recorded in signal travel time, so-called "time domain" (with time units in seconds or milliseconds). To be displayed against geotechnical information acquired in "depth domain" (depth units in metres), a data transformation from time to depth domain is required. This transformation is supported by the implementation of velocity models in specialised software.

While minor modifications can be made to GIS layers during the 3D model development, a thorough quality control should be performed before their integration into the 3D model to prevent the incorporation of errors or the propagation of uncertainties.

By using GIS, files in any compatible formats can be integrated into the model. However, following industry recommendations and standards, the shapefile format should be considered for vector type layers (Open Geospatial Consortium, 2018). For raster type data, GeoTiffs or XYZ formats are most used and accepted as a norm (Open Geospatial Consortium, 2019). Discrete data, such as ground investigations, can be integrated into GIS projects as text delimited ASCII files or CSVs.

2.2 Data Preparation

Data can be loaded into the 3D model at any stage of the OWF project development. However, the GIS elements have to undergo a data preparation and reformatting step to ensure they are displayed properly in the final model.

The use of a GIS for the development of a 3D model can come with limitations. Depending on the software used, the data might require prior processing before being included in the 3D model. This might include de-spiking, clipping, simplifying or utilising other algorithms with the ultimate goal being clear data display and increased model performance.

In addition, an adequate visualisation of the BHs and CPT data might require reformatting of the input CSV files to include a minimum sequence of columns. The following can be considered as a base example:

- location ID;
- X and Y coordinates;
- lithology description (only for BHs);
- CPT parameters (only for CPTs);
- elevation of unit tops;
- thickness of units (only for BHs).

CPT data can also be simplified prior to inclusion in the 3D model in order to decrease the amount of data displayed and enhance the model performance.

2.3 Data Display

Once formatted, the data can be displayed in a 3D viewer in a flexible manner, depending on client preferences.

All elements can be symbolised as per GIS standards or end user preference. For a clear data visualisation, rasters can be customised, for example by calibrating their resampling levels and adjusting elements such as symbology, materials, opacity, shading. Guides and publications for improving scientific data visualisation (e.g., Crameri et al., 2020; HeiGIT gGmbH, 2023) are available and can be consulted at this stage. This step ensures that the raster morphology is clearly captured and that all elements can be displayed simultaneously with minimum impact on model intelligibility and performance. The lithological intervals and log values from BHs and CPTs can also be customised based on end user preference. Custom 3D meshes from external sources can also be used for elements such as wind turbine locations, shipwrecks, etc.

General adjustments (e.g., vertical exaggeration, background colour, etc.) can further improve the overall appearance of the model. The vertical exaggeration is defined based on the level of detail required and the depth of interest captured in the model and can be chosen based on trial and error, aiming to keep the distortion of the overall geometry to a minimum while ensuring individual elements in the model are easily discernible. A higher vertical exaggeration can help with the visualisation of models focused on the shallowest section of the subsurface (e.g., models for export cable routes and inter-array cables).

2.4 3D Model Publication

Many of the GIS software offering 3D model development have dedicated viewer tools, allowing the end users to access the model. Alternatively, models can be published as an HTML file, either online or distributed locally, which can be viewed in a web browser.

Ideally, the model should be accessible to anyone without the necessity to acquire specialist software licenses. The main benefit of publishing the 3D model as an HTML file is to overcome software and licence requirements, which could increase project costs or limit sharing capabilities.

To maximize the model value and usability, it is crucial to implement a robust publication and sharing strategy. The model must be stored in a secure location, either on a reliable online platform or as local files distributed among the provisioned users.

A cloud-based solution offers several advantages for storing the 3D model. Authorised users can freely access the model from any device and from anywhere in the world, which facilitates collaboration in international teams. Updating the online model takes immediate effect for all the end users at the same time, which ensures consistency between all stakeholders. Additionally, the cloud storage offers seamless scalability by easily accommodating basic to large and complex models.

When the online publication of the model is not feasible, a local file distribution can be implemented. Encrypted file transfers and simultaneous updates for all users are crucial in this scenario.

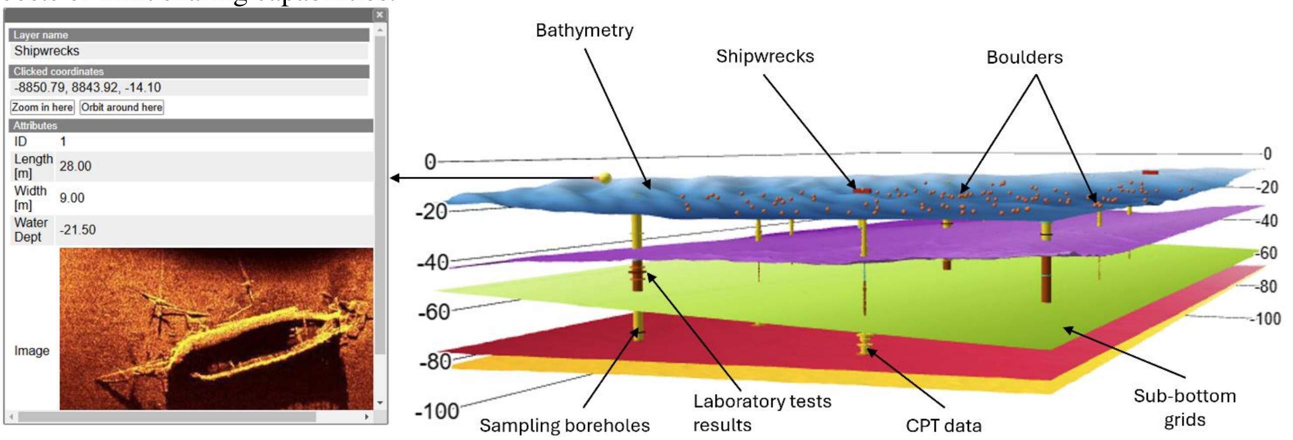

Figure 1 – An example of a 3D ground model prepared for an offshore wind farm project.

3 CASE STUDY EXAMPLE

Figure 1 presents an example case study model that integrates data acquired as part of preliminary geophysical and geotechnical campaigns.

In this case, the main line spacing utilised during the geophysical campaign was 70 m. The dataset acquired included multibeam echosounder, side-scan sonar, magnetometer, sub-bottom profiler, and single-channel seismic data. The bathymetry data collected for the site was used to illustrate the seabed topography, highlighting sediment waves and hard sediment outcrops. Sub-bottom data interpretation in the form of grids was incorporated into the model to provide insights into the subsurface ground conditions.

The model also integrates results from a preliminary field geotechnical campaign, including sampling boreholes, CPTs, and the results from subsequent laboratory testing. Sampling boreholes and CPTs were colour-coded based on their geological classification. While the radius of the sampling boreholes was kept constant, CPT radii were varied according to the displayed parameter value at each depth. Cone tip resistance (q_c) and normalized friction ratio (F_r) were included in the example model, allowing for visual inspection of the material strength and the alignment between the geophysical and geotechnical interpretations. CPT data, originally available in 2 cm increments, were processed by applying a 10 cm rolling average, which greatly decreased the number of 3D elements displayed and improved the model performance. Laboratory test results were added to the model as discs along the boreholes. Test results together with hyperlinks to the relevant reports were included in attribute tables.

Additionally, the model contains seabed interpretation results, including sediment classification and seabed contacts such as boulders, shipwrecks, seabed infrastructure, and more. For larger contacts, the model incorporates preview images of the side-scan sonar mosaic within their respective attribute tables.

4 APPLICATIONS

Overall, 3D ground models are becoming increasingly important to the offshore wind industry. They can be used to enhance the understanding of subsurface conditions, to support OWF site spatial analysis and data repositories, but also for marketing and communication purposes.

In addition to the visual representation they provide, 3D models play a crucial role in identifying and mitigating geohazards and anthropogenic constraints (Velenturf et al., 2021; Sauvin et al., 2022; Peng et al., 2024). By providing an integrated representation of those risks, they enable offshore wind developers to make informed decisions during survey planning and wind turbine layout optimization.

The models can also serve as a central repository of project data. They combine data from multiple sources, including geophysical and geotechnical surveys, and provide a centralised and convenient platform for accessing and querying the data, which can be continuously updated as the project progresses. Furthermore, when published as HTML, 3D models can be accessed by any users, including non-specialists, for minimal costs and without the need for specialist software.

3D ground models also play a role in marketing and communication as they represent products which are visually appealing, often providing additional selling points to commercial projects. Moreover, 3D models have been often used during public consultations, increasing public engagement with more transparent and collaborative processes.

5 CONCLUSION

Although 3D ground models can often be overlooked by offshore wind farm developers, they can provide significant advantages when it comes to centralising, visualising, and sharing project data. A GIS-based solution can facilitate the efficient implementation of such models, without the requirement of additional specialist software.

Seabed and sub-seabed data, including outputs from geophysical, geotechnical, and environmental surveys, can be included in the model. The data must undergo a preparation step to ensure adequate data display and model performance. The resulting 3D ground model should be made available to project stakeholders, ideally with minimum software requirements.

A GIS-based 3D model provides a straightforward way of displaying the ground conditions and potential geohazards within an offshore windfarm site. This can facilitate communication between various stakeholders and support the developers during the survey planning, design, and installation phases. The model can also act as a central data repository that ensures all project members have access to the most up to date site information. Lastly, 3D ground models can also play a key role in marketing and both technical and non-technical communications.

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