Delft University of Technology

Thesis proposal

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# Modelling a military scene using a Discrete Global Grid System

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# Contents

# 1 Introduction

Nowadays, the military parties across the world are focusing on the modernization of the military scene modelling. Concerning this, apart from the standalone military interest actions, the military also engages in situations where close partnership with the civil party is required, such as first response activities, disaster management, hybrid threats and interoperability provision in cross-border crises.

Depending on the need of the situation, a high level of collaboration is needed, requiring effective Civil-Military Interaction (CMI)(Cusumano and Corbe, 2017), to exploit the different resources and model a military scene. Civil-military cooperation (CIMIC) stands as a joint function in the military structure (NATO/OTAN, 2018), aiming to maintain cooperation with non-military actors within an area of operations (NATO/OTAN, 2018). Concerning the geospatial applications, the military frequently operates within areas of coverage. An area of coverage is a ground area, usually a scene, within a planned amount of time, as a part of a Mission Plan (NATOTerm). In military scenes, embedded to the area of coverage concept, the space partitioning is an important aspect, as a base framework for operations.

In many cases, the military resources can be outdated and not conform to modern datasets that the public/private sector can provide, designating the need of an integrated system to analyse geospatial data. The military would foster utilizing multiple types of datasets (vector,raster) provided by civil parties, to achieve the integrated modelling of a military scene. An approach of a Discrete Global Grid (DGGS) system could be applied for this purpose, also assisting on setting a model for geospatial analysis.

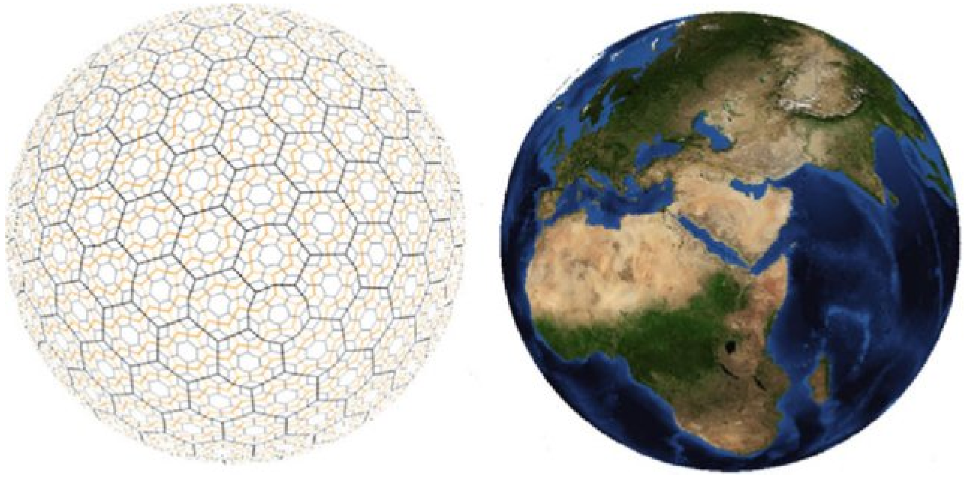


Figure 1: Global-Grid-Systems-ISEA3H-DGGS-W640, image taken from (Alderson et al., 2019)

DGGS are used in several scientific and commercial systems in the recent years (Lu et al., 2012). Mainly, they are utilised as frameworks for information and data and differ from the conventional CRSs that are originally designed for navigation purposes (Purss, 2017). A Discrete Global Grid(DGG) is a spatial structure that comprises a set of regions that partition the surface of the Earth (Sahr et al., 2003). A Discrete Global Grid System (DGGS) comprises different resolution grids (DGG) and forms a hierarchical tessellation of regions/cells used to fit the Earth's surface (Zhou et al., 2020). Multiple examples of the use of DGGS exist, in spatial data management (large-scale), desicion making and analysis (Wang et al., 2021).

# 2 Related work

In recent years, various researches were conducted signifying the potential of the Discrete Global Grid Systems (DGGS) use in the geospatial domain. Several DGGS platforms have emerged and are maintained, offering the implementation of DGG operations defined by the Open Geospatial Consortium (OGC) Abstract Specification (Purss, 2017). The following literature are resourceful aiming to sustain the topic and explore applications of data integration using a DGG.

## 2.1 Geospatial operations of Discrete Global Grid Systems

Li and Stefanakis (2020), compare Discrete Global Grid System and traditional GIS operations. The paper aims to serve as a reference for the development of future DGGS operations. It explores and tests existing proposed DGG implementations. The geospatial operations they provide are evaluated, based on the essential operations defined by the Open Geospatial Consortium (OGC) Abstract Specification, and other potential operations to be provided by a DGG. Those operations are compared with the traditional GIS operations to gain insight over various aspects such as database techniques, data visualisation, pre-processing, manipulation and spatial analysis among others.

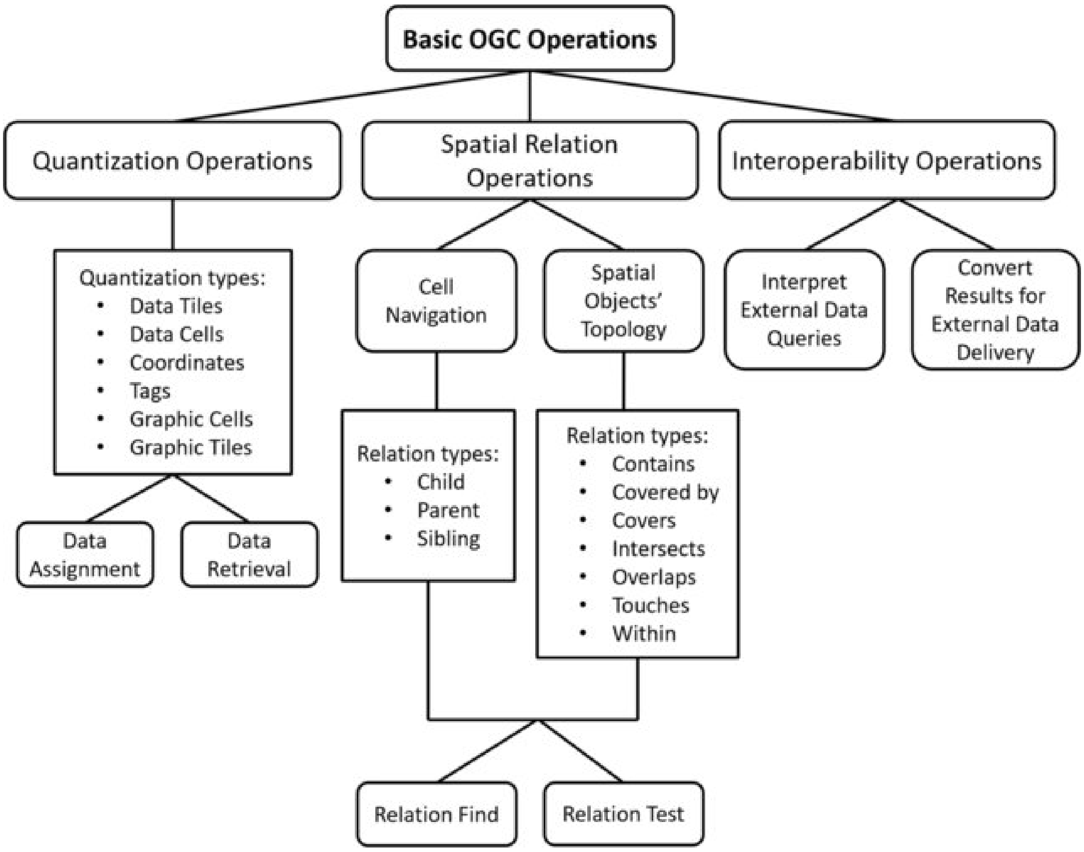


Figure 2: Basic DGGS operations required by the OGC Abstract Specification, (image taken from Li and Stefanakis (2020))

## 2.2 Use of a Discrete Global Grid system in geospatial applications

Recently, the DGG system is utilised for several geospatial applications making use of the different existing state-of-the-art DGG implementations. Researches often use different approaches concerning the intermediate pre-processing, for the integration of different types of datasets in a DGG framework.

Rawson et al. (2021) propose the use of the Discrete Global Grid System (DGGS) as a structure to integrate various maritime datasets predicting the occurrence of ship groundings. The research demonstrates the advantages and efficiency of the DGG structure, using an existing implementation. The datasets are pre-processed, the quantization methods are demonstrated and a spatial maritime risk model is developed based on a DGG.

Bousquin (2021) explores the use of a geospatial framework based on an hexagonal Discrete Global Grid System (DGGS) on a coastal area. This research explores two different DGGS implementations(h3 (`https://h3geo.org/`) and dggridR (`https://www.discreteglobalgrids.org/software/`)) which are compared in terms of data aggregation to scales from other existing frameworks and data integration across different frameworks, among others.

# 3 Research question(s) and Objectives

## 3.1 Objectives

This thesis will attempt to apply a DGG system and integrate different datasets (vector, raster) of military interest, to demonstrate the integration and storage procedure and identify the potential of this approach to model a military scene. The research will attempt to justify for the beneficial use of a DGGS, in comparison with the existing approaches in the military. Based on existing DGG implementations that will be used, the research will gauge the different data quantization approaches for the different datasets and explore their limitations. In parallel, the geospatial insight potential and the visualisation possibilities of the integrated datasets will be explored.

## 3.2 Research question(s)

The main research question that this thesis will attempt to address is:
To what extent can a Discrete Global Grid System assist on modelling a military scene in one integrated way?

This research aims to study the potential of applying a DGG system and integrating different datasets (vector, raster) to model a military scene. To achieve this, the following sub-questions will be relevant:

Subquestion(s):
1) What are the benefits of using a DGGS when modeling a military scene, in comparison with the current state of the art?
2) How to achieve integration and storage of different format 2D geodatasets of military interest (vector, raster) using a DGG?
3) How to prepare DGGS indexed 2D geodatasets stored in a database, for geospatial analysis?
4) What are the different visualisation alternatives of DGG indexed datasets assisting in military analysis?

## 3.3 Research scope

This research will mainly be focused on the procedure of integrating and storing different datasets using a DGG to model a military scene, utilizing an existing implementation. The different approaches of quantization will be explored and gauged for efficiency and quality as well as the ability to assist in performing geospatial military analysis. In parallel, given the data of the case study, the research will attempt to tackle different ways of visualising the integrated datasets to show the potential of the DGGS in geovisualisation of a military scene, focusing in the European region and the members of NATO.

# 4 Methodology

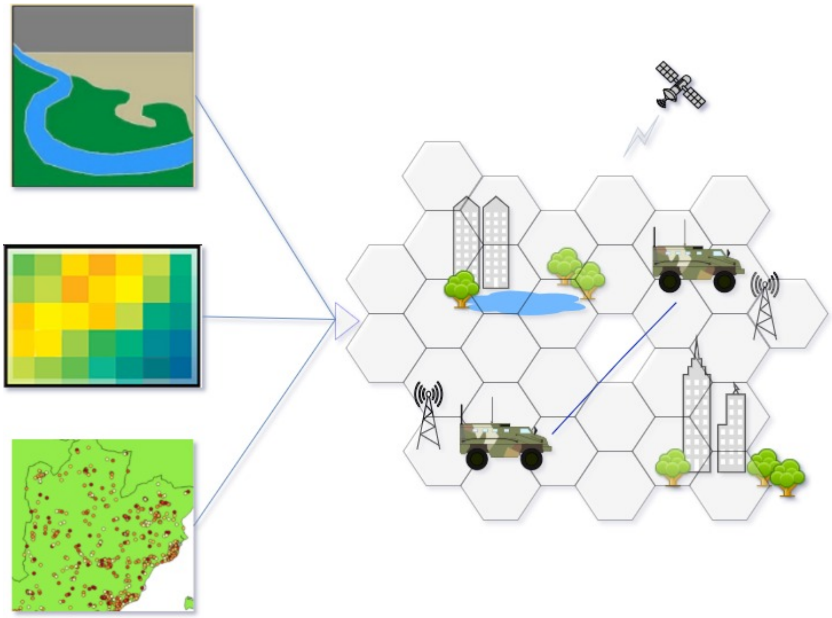


Figure 3: Integration of different data formats under a DGGS framework, modelling a military scene - geo-features are assigned to the corresponding DGGS cell after a quantization operation

## 4.1 DGGS framework to model a military scene

Aiming to identify the potential of using a DGGS framework to model a military scene, the research will firstly explore the DGGS spatial structure definition specifications and its basic properties. The advantages and disadvantages of the different spatial partitioning methods that a DGGS can use, will be explored in terms of their potential in military geospatial analysis compared to the current state of the art. The distributed existing DGGS implementations will be briefly summarized and the one that will be used for the case study will be designated (`https://h3geo.org/`), along with its relevant properties and functions.

Concerning the military geospatial applications, the military frequently operates within areas of coverage. An area of coverage is a ground area, usually a scene, within a planned amount of time, as a part of a Mission Plan (NATOTerm). The research will investigate the added value of using a DGGS framework in a military scene containing areas of coverage, maintaining cooperation with non-military actors within an area of operations (NATO/OTAN, 2018). The benefits of the use of DGGS in relevant military and joint civil-military operations with a geospatial context(shortest path, troop deployment, disaster management, ranges, among others) will be explored. Specifically, the approach of a shortest path operation, a troop deployment and a ranging operation using the DGGS framework integrating the different data formats of the study case will be investigated.

Focusing on the interoperability aspect, the OGC specifications (Purss, 2017) has already started developing standards for the DGGS frameworks. This is critical for connectivity and communication of DGGS infrastructures, but emphasis is given in the usage of a unified model type converting between traditional models and the DGGS model. The DGGS implementations should be capable of converting DGGS cell addresses to traditional (latitude, longitude) graticule or to other DGGS specifications (Mahdavi-Amiri et al., 2015).

To assist on collaboration and interoperability, the existing OGC specifications regarding the DGGS will be explored in proportion with the existing Military geospatial standards (NATO/OTAN, 2016). The military geospatial standards contain various specifications regarding the geodetic datums, projections, grids and grid references, that the military uses. Additionally, specifications concerning different geospatial data formats (i.e rasters) are also included. The level of compliance of a DGGS implementation for military purpose with the existing standards will be investigated, to search for its benefits.

(a)

(b)

Figure 4: Northern Atlantic Treaty Organization - Open Geospatial Consortium

## 4.2 Data integration - Case study

In order to demonstrate the procedure of integrating different data formats and storing them under the same DDGS framework for a military scene (Figure 5), a case study will be conducted. The pipeline can be divided in three main operations: data collection/selection, data integration/quantization and data storage. Military interest datasets provided by civil stakeholders will be utilised, to test the procedure of integration and storage of the data in a military purpose database. Specifically, vector and raster datasets will be used, being the most common and potentially interoperable data formats. The data need to be integrated under the same DGG framework and stored, accompanied by their according properties. For this purpose, an existing implementation of a DGG indexing system will be utilised, also making use of its relevant operations.

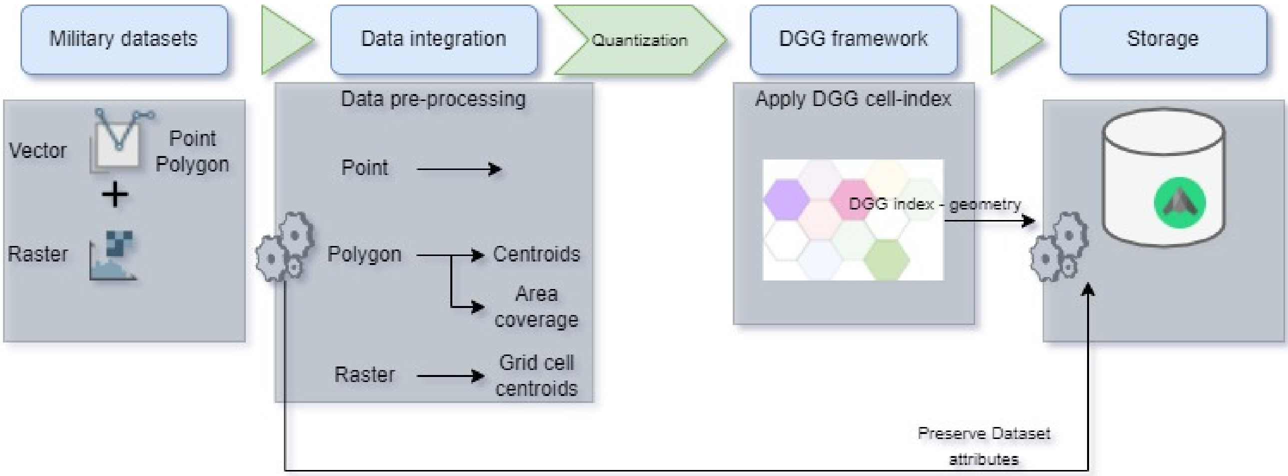


Figure 5: Data integration and storage flowchart

### 4.2.1 Military Spatial Data quantization

Given a DGGS specification, the quantization is the process of digitally assigning data values sampled from other data sources to the DGGS cells (Purss, 2017). Quantization methods to transform raw data to DGGS cells are not limited by the OGC. Regarding the different raw spatial datasets coming from multiple sources, different approaches should be used to translate them into DGGS cells (Li and Stefanakis, 2020).

Regarding the vector datasets, two different are chosen in terms of geometry traits: a point vector dataset and a polygon vector dataset (shapefiles). Different pre-processing should be applied and several quantization strategies will be tested in order to compare the differences and test the limitations that potentially exist when integrating them under a DGGS framework, to model a military scene.

Concerning the point dataset, referring to military interest locations/observations, accompanied with the Coordinate Reference System (CRS) metadata, the quantization strategy is direct. The existing implementation's native indexing operations and the longitude, latitude properties of the dataset will be used, while guaranteeing the correct CRS establishment. In this case, that potentially the DDGS cells represent data cells, the spatial observations are assigned to individual cells based on their geometry (Purss, 2017). An aggregation operation (data binning) can be applied in different resolutions of the hierarchical DGGS tessellation, aiming to visualise the different resolution results to gain spatial insight.

The polygon datasets are more complicated and different approaches can be followed in the preproccessing stage, to integrate their geometry/values under the designated DGGS framework. Based on the selected resolution and different quantization strategy, the results may differ. Two different approaches will be tested, regarding the polygons. On the one hand, each polygon's centroid can be sampled and then using the conventional method, indexed in the DGGS framework. On the other hand, through the existing implementation's functions, using the polygons and the area they cover without overlap, the according cells that partition the same area without overlap will be sampled and indexed. This is relevant with a hierarchical cell rasterization that is used to store vector features in a DGGS using for instance, quadtrees for the approximation of geo-features refining a quad cell recursively (Mahdavi-Amiri et al., 2016);(Sahr, 2008). Each approach yields different results, with relevant distortions and differences that are appearing per different resolution and will be tested for data quality, geometric measurement, topology validity as well as their potential and limitations in geospatial analysis for the military.

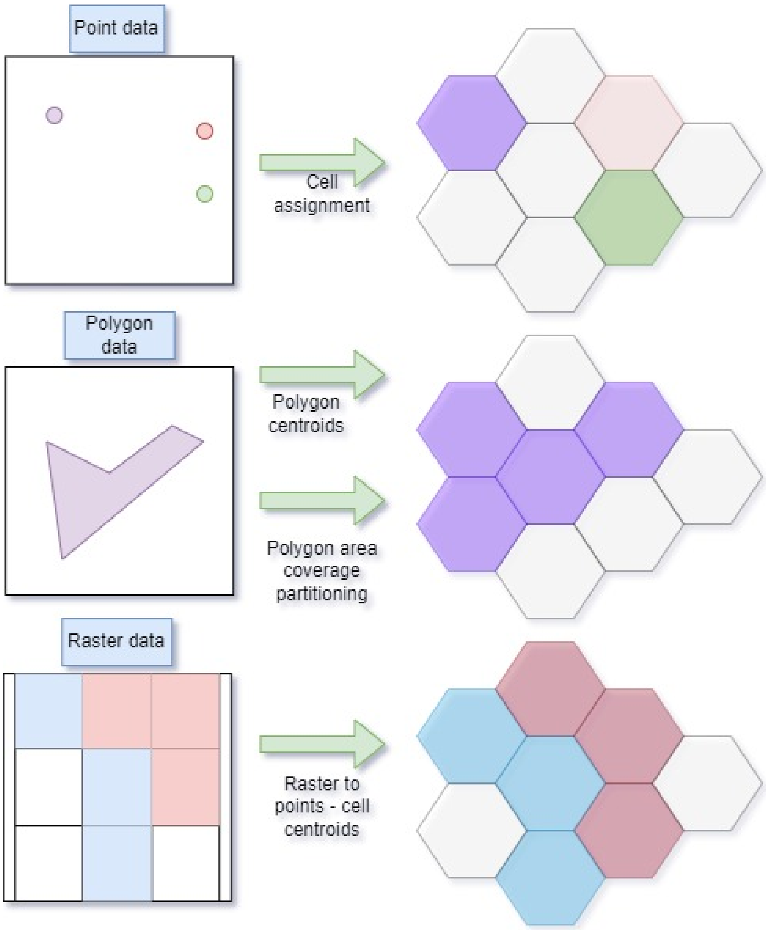


Figure 6: Approaches to assign different geospatial data to corresponding DGGS cells

Regarding the raster datasets, the process is relative to resampling the original raster to the corresponding DGGS cells (Li and Stefanakis, 2020). Specifically, the cell centroids of a raster stand for a reference which is directly assigned to a corresponding DGGS cell based on its locations. Based on the different approaches and resolutions, each DGG cell can contain either the direct original raster value or an aggregated value from different original raster cells (Rawson et al., 2021), accompanied with the corresponding limitations or potential distortions. Referring to the selection the basic quantization resolution, according to Robertson et al. (2020), the nearest to the original cell size can be applied for the raster datasets, while for the vector datasets it should be selected according to the accuracy of the original data.

After the pre-processing of the raw data and the quantization operation, the conversion to the DGGS has a certain impact. Based on the original data models there are various ways of assessing the data quality after this conversion. For instance, the raster conversion data quality can be investigated through comparison of the a-priori DGGS conversion values with the a-posteriori ones, of a set of sample points(i.e via Root Mean Square error method) (Li and Stefanakis, 2020). Regarding the vector spatial data, when converted to the designated DGGS model, the data quality can be assessed through the points' position displacement and the polygon features' geometry coherence (Li and Stefanakis, 2020). In order to test the different approaches and resolutions results, and evaluate the potential limitations, pros and cons the integrated data will be stored in a database. The research will aim to identify the differences between the approaches and their importance/effect on collaboration and efficiency.

### 4.2.2 Military Spatial Data storage

In the context of storing the integrated data of military purpose under a common framework, a database will be utilised. This venture is aiming to demonstrate the procedure of storing and updating spatial data coming from multiple civil sources and in various formats, in a military purpose database. Collecting geospatial data sources of various types from published services and fusing them in a coherent format containing metadata and spatial/non-spatial information, to transform them in a fashion ready for spatial analysis, is needed to designate the accessibility and interoperability of databases (Peterson and Shatz, 2019).

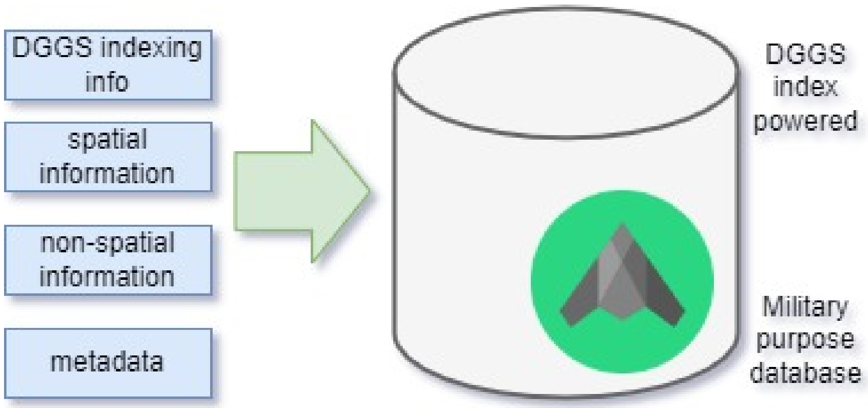


Figure 7: Different formats data accompanied with the DGGS index passed in the military purpose database

The DGGS application offers to solve various problems of fusing data across distributed data sources and exchanging geodata of various data formats (Li and Stefanakis, 2020). After the integration of the raw spatial datasets in the DGGS framework, the indexing, geometry and observations/values, along with the additional attributes(spatial/non-spatial) that accompany them, will be stored in the database. Preserving the datasets' attributes while using the DGGS indexing, aims to minimize the data loss and preserve the metadata and quality as much as possible. In parallel, the DGGS cell indexing mechanism, offers robust spatial positioning as well as hierarchical/neighboring cell navigation (Li and Stefanakis, 2020). Furthermore, according to Hojati and Robertson (2020), in-database spatial analysis using a DGGS framework has yielded a flexible architecture to be applied on massive data analysis, which would be purposeful for military scene concepts.

The use of a database aims to identify the potential of a military DGGS powered database, in terms of efficiency, dynamic storage of integrated different data sources and interoperability between civil-military parties. In parallel, the database will be used to gauge the results as a product to gain insight and perform geospatial analysis for military purposes, utilising the integrated spatial datasets. Storing multiple resolutions using the database, the effect of quantization per dataset in different resolutions can be investigated. The visualisation possibilities of the integrated datasets will also be explored.

# 5 Time planning

## 5.1 Important milestones

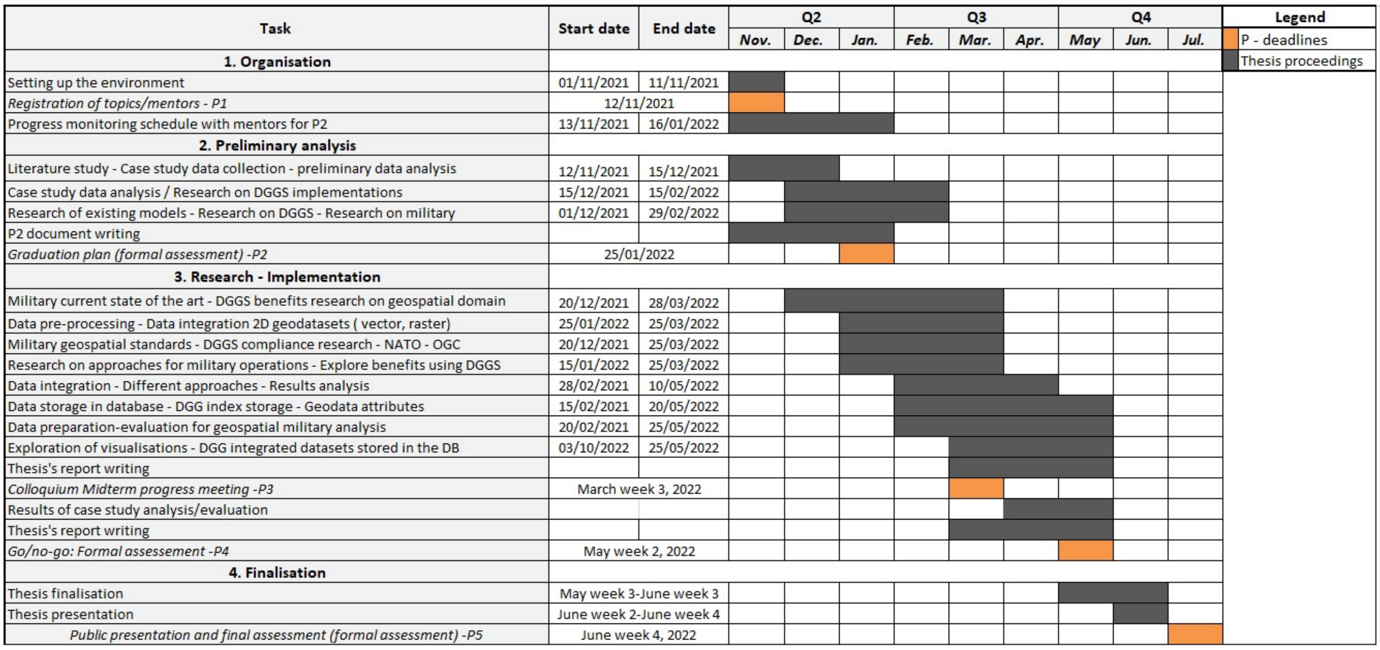
| Event | Description | Date |
|---|---|---|
| P1 | Progress review Graduation Plan | 12 November |
| P2 | Formal assessment Graduation Plan | 25 January |
| P3 | Colloquium Midterm | March Week 3 |
| P4 | Formal process assessment | May Week 2 |
| P5 | Public presentation and final assessment | June Week 4 |

## 5.2 Meetings

Meetings are conducted every two weeks, focusing on the project's progress monitoring. Feedback and guidance is provided by both the supervisors: Robert Voûte and Martijn Meijers. The co-reader still needs to be decided.

## 5.3 Gantt chart - planning

Beneath, a Gantt chart refering to the graduation calendar is demonstrated. During the year, some dates may explicitly change.



| **Task** | **Start date** | **End date** | **Q2** | | | **Q3** | | | **Q4** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | ***Nov.*** | ***Dec.*** | ***Jan.*** | ***Feb.*** | ***Mar.*** | ***Apr.*** | ***May*** | ***Jun.*** | ***Jul.*** |
| **1. Organisation** | | | | | | | | | | | |
| Setting up the environment | 01/11/2021 | 11/11/2021 | ■ | | | | | | | | |
| *Registration of topics/mentors - P1* | 12/11/2021 | | 🟧 | | | | | | | | |
| Progress monitoring schedule with mentors for P2 | 13/11/2021 | 16/01/2022 | ■ | ■ | ■ | | | | | | |
| **2. Preliminary analysis** | | | | | | | | | | | |
| Literature study - Case study data collection - preliminary data analysis | 12/11/2021 | 15/12/2021 | ■ | ■ | | | | | | | |
| Case study data analysis / Research on DGGS implementations | 15/12/2021 | 15/02/2022 | | ■ | ■ | ■ | | | | | |
| Research of existing models - Research on DGGS - Research on military | 01/12/2021 | 29/02/2022 | | ■ | ■ | ■ | | | | | |
| P2 document writing | | | ■ | ■ | ■ | | | | | | |
| *Graduation plan (formal assessment) -P2* | 25/01/2022 | | | | 🟧 | | | | | | |
| **3. Research - Implementation** | | | | | | | | | | | |
| Military current state of the art - DGGS benefits research on geospatial domain | 20/12/2021 | 28/03/2022 | | ■ | ■ | ■ | ■ | | | | |
| Data pre-processing - Data integration 2D geodatasets ( vector, raster) | 25/01/2022 | 25/03/2022 | | | ■ | ■ | ■ | | | | |
| Military geospatial standards - DGGS compliance research - NATO - OGC | 20/12/2021 | 25/03/2022 | | | ■ | ■ | ■ | | | | |
| Research on approaches for military operations - Explore benefits using DGGS | 15/01/2022 | 25/03/2022 | | | ■ | ■ | ■ | | | | |
| Data integration - Different approaches - Results analysis | 28/02/2021 | 10/05/2022 | | | | ■ | ■ | ■ | | | |
| Data storage in database - DGG index storage - Geodata attributes | 15/02/2021 | 20/05/2022 | | | | ■ | ■ | ■ | ■ | | |
| Data preparation-evaluation for geospatial military analysis | 20/02/2021 | 25/05/2022 | | | | ■ | ■ | ■ | ■ | | |
| Exploration of visualisations - DGG integrated datasets stored in the DB | 03/10/2022 | 25/05/2022 | | | | | ■ | ■ | ■ | | |
| Thesis's report writing | | | | | | | ■ | ■ | ■ | | |
| *Colloquium Midterm progress meeting -P3* | March week 3, 2022 | | | | | | 🟧 | | | | |
| Results of case study analysis/evaluation | | | | | | | | ■ | ■ | | |
| Thesis's report writing | | | | | | | ■ | ■ | ■ | | |
| *Go/no-go: Formal assessement -P4* | May week 2, 2022 | | | | | | | | 🟧 | | |
| **4. Finalisation** | | | | | | | | | | | |
| Thesis finalisation | May week 3-June week 3 | | | | | | | | ■ | ■ | |
| Thesis presentation | June week 2-June week 4 | | | | | | | | | ■ | |
| *Public presentation and final assessment (formal assessment) -P5* | June week 4, 2022 | | | | | | | | | | 🟧 |

| **Legend** | |
|---|---|
| 🟧 | P - deadlines |
| ■ | Thesis proceedings |

Figure 8: Calendar of graduation

# 6 Tools and datasets used

## 6.1 Datasets

For the case study aiming to integrate different datasets on a DGGS framework, several datasets will be used. Military naval data (vector) and Vessel traffic (raster), in the European region were selected.

- **Vector Point datasets: EMODdnet_HA_MilitaryAreas_20210201.shp.** A dataset containing offshore military areas(points) in the European region, provided by the European Marine Observation and Data Network (EMODnet), (`https://www.emodnet-humanactivities.eu/search-results.php`).
- **Vector polygon datasets: EMODdnet_HA_MilitaryAreas_20210201.** A dataset containing offshore military areas(polygons) in the European region, provided by the European Marine Observation and Data Network (EMODnet), (`https://www.emodnet-humanactivities.eu/search-results.php`).
- **Raster datasets: EMODnet Human Activities, Vessel Density Map.** A dataset containing maps based on AIS data purchased yearly from Collecte Localisation Satellites (CLS) and ORBCOMM. The maps are provided in GeoTIFF format by the European Marine Observation and Data Network (EMODnet), (`https://www.emodnet-humanactivities.eu/search-results.php`).

## 6.2 Tools

In order to test the case study several tools are needed and will be used. Concerning the datasets visualisation and pre-processing, QGIS and FME will be used among others. Concerning the data processing, DGG creation and manipulation-visualisation most of the intermediate procedures will be conducted using Python3. Using Python several libraries are going to be utilised. Most importantly, h3-py package(`https://h3geo.org/`) will be used to exploit the implemented hexagonal hierarchical geospatial indexing system, and integrate the aforementioned datasets. In order to use a database to store the integrated DGGS indexed datasets, PgAdmin will be used. During the research several libraries to visualise the integrated data will also be explored.

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