Exploring the potential of explorative point clouds in floodplain maintenance

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List of Abbreviations

AHN Actueel Hoogtebestand Nederland

ALS Airborne Laser Scanning

ASPRS American Society for Photogrammetry and Remote Sensing

C2CD Cloud-to-Cloud Distance

EDL Eye-Dome Lighting

ESDA Exploratory Spatial Data Analysis

FME Feature Manipulation Engine

GIS Geographical Information System

HCI Human Computer Interaction

IMU Inertial Measurement Unit

LAS LASer

LiDAR Light Detection and Ranging

M3C2 Multi-scale Model to Model Cloud Comparison

NAP Normaal Amsterdams Peil

NDVI Normalized Difference Vegetation Index

NIR Near-Infrared

RSCD Remote Sensing Change Detection

RTK Real Time Kinematics

TLS Terrestrial Laser Scanning

TU Delft Delft University of Technology

UAV Unmanned Aerial Vehicle

VR Virtual Reality

WOCU Waardegedreven Onderhoudscontract Uiterwaarden

Contents

1 Introduction

Water management is an integral part of Dutch history, driven by the continuous need of reducing flood risk. Because a large area of the country is located below Normaal Amsterdams Peil (NAP), there is an ongoing challenge to safely discharge all the water through the rivers to the sea. Therefore, flood safety policy has become a crucial part of protecting the Netherlands from natural hazards. An essential part of this strategy involves managing the adjacent floodplains surrounding the rivers. Floodplains are areas to which excess water can flow during high water levels due to heavy rainfall and the annual melting of the Alps. It can also be seen as a natural storage area that offers ecological and social positive benefits in addition to its safety purpose. Ecologically, it provides climate regulation through carbon sequestration, connectivity to improve biodiversity, a new habitat for wildlife and fish, and enhancement of riparian forests and other ecosystem functions. In terms of social benefits, it provides not only flood risk reduction but also improved water and air quality, recreational opportunities and sustainable and intergenerational equity (Serra-Llobet et al., 2022).

1.1 Problem statement

It is important to maintain these floodplains regularly by for example preventing excessive vegetation growth to ensure that they retain their flood protection. Van Oord is since this year responsible for the maintenance of several floodplains of the Rijntakken in the Netherlands, as part of the project Waardegedreven Onderhoudscontract Uiterwaarden (WOCU). The need for the project has come about due to substantial changes in these areas compared to their initial designated state, or in other words, overdue maintenance. The main core task involved in this project is flood safety, which requires that all aspects of the floodplain are in good condition. Among the assets in the area are channels, bridges, culverts, roads, grids, and spillways, which require various maintenance tasks such as gully maintenance, pruning, mowing overgrowth, and maintenance of objects from baseline measurement, including for example bank erosion.

Maintenance is coupled with change detection with the ability to act where and when needed. It is actually about capturing changes in a particular position between different moments, which can also be seen as a spatiotemporal aspect. At this moment the main concern is the overgrown vegetation that counters the passage of water and hence, it is important to map the area in order to detect new changes. The current state of the floodplains is therefore compared with their initial state. Once all the vegetation and objects within the area have been restored to their original condition, it is planned to carry out periodic checks and perform maintenance work when necessary in the coming years. The inspection of changes currently takes place manually, which is time-consuming. In addition, the expanse of the area and certain areas being inaccessible pose a major challenge. This lack of efficiency and effectiveness calls for the use of other tools, in particular, the use of remote sensing techniques to facilitate change detection in the maintenance process. This is also known as Remote Sensing Change Detection (RSCD) (Salah et al., 2019). The use of remote sensing techniques could automate the process, eliminating the need for field inspections and showing more accurately where maintenance is needed, so making the process more efficient and effective. The idea is to move toward a data-driven maintenance process with the inclusion of such techniques so that these tasks will be based on a time-lag flow of acquired data.

One of the outputs of these existing remote sensing techniques are point clouds, which are a commonly used data source in a variety of fields nowadays to record heights and in this way extract data from terrains. Despite the fact that point clouds are used for a variety of applications, is the data often underused. This is because the huge memory of point clouds is processed fairly quickly to other forms. However, these processing steps can also lose important information at both spatial and semantic levels (Poux et al. (2016)). So, a raw point cloud can also function as an extensive data resource which probably has other potential use cases that are not explored yet. This comes together in the concept of an explorative point cloud which sees the explorative value of point clouds by adding tools, enriching it with semantics, or integrating information flows from different directions. The inclusion of human observation can for example be integrated into the semantics of the point cloud.

Another remote sensing technique is the multispectral sensor, which allows infrared data to be acquired. The advantage of this technique is that with the use of infrared data, an Normalized Difference Vegetation Index (NDVI) score can be calculated, which is an indicator of the type, density and health of vegetation, which the floodplain is mainly composed of. This can reflect, for example, stress or the state of vegetation after storms or drought. Thus, the point cloud could be enriched by adding more information to each point, namely the NDVI score of the point in question (Huang et al., 2020; Pettorelli et al., 2005).

This research will therefore explore the possibilities of explorative point clouds by integrating the expertise of present disciplines within Van Oord. Van Oord has engineers operating in a variety of fields, which means that a broad area of expertise is present within the company. Its interdisciplinary integration can be beneficial for identifying new insights into the current use of point clouds. The aim of this thesis is therefore to stimulate the usage of point clouds within the maintenance of floodplains.

1.2 Research questions

The related work, which can be found in Chapter 2, elaborated on the current applications concerning point clouds in floodplains and introduced the exploratory approach that can go along with innovative visualization techniques of point clouds. This integration could lead to a new insight into the use of point clouds for decision-making processes during floodplain maintenance. Based on this information, the objective of this research was determined and given the direction of exploring the potential of visualising raw point clouds in the maintenance of floodplains by integrating the knowledge of different disciplines with each other.

The main research question is as follows:

"To what extent are explorative point clouds, acquired via LiDAR UAV, useful in providing insights on change detection for floodplain maintenance by incorporating interdisciplinary perspectives?"

The aim of this study is to research the opportunities and effectiveness of such an integrated geo-visualisation of point clouds. In order to answer the presented main research question, sub-questions will be formed. To generate these sub-questions, the main research question was first divided into three sub-domains. These are as follows:

Domain A. The use of explorative point clouds acquired by LiDAR UAV
Domain B. Insights on change detection in the maintenance of floodplains
Domain C. Including interdisciplinary perspectives

For each domain, the following sub-questions shown in Table 1 were created to answer the main research question.

Table 1: Sub-questions

Domain	**Sub-questions**
A	1. How does LiDAR (UAV) influence the creation of point clouds? 2. What is the accuracy and reliability of point clouds acquired through LiDAR (UAV) technology? 3. What is an explorative point cloud? 4. What are the potential applications of explorative point clouds?
B	1. Which objects are measurable for changes in floodplains? 2. What is a suitable method to detect changes in point clouds of floodplains? 3. What are the requirements regarding maintenance to have a safe floodplain area? 4. Which maintenance operations must be carried out?
C	1. Which visualisation techniques are best suited for exploratory point clouds? 2. Which interdisciplinary expertise is involved in the maintenance of floodplains?

The subquestions of domain A will be answered mainly through a literature review. Domain B will focus on both a literature review and the collected data. For domain C, the expertise within the Van Oord organisation is particularly important besides a literature review.

1.3 Scope

1.3.1 Area

The spatial scope of this study is narrowed to a study area that includes the floodplain of Zaltbommel, which is part of the Rijntakken positioned in the Netherlands. The reason for this is that in this way it is possible to focus on the area in question to conduct a more in-depth analysis. Furthermore, it makes it easier to implement change detection of point clouds on a smaller scale, thanks to a smaller area to have to collect data for and thanks to a smaller file to perform comparisons on. Eventually, if it works on a small scale, it can be extended to larger areas.

1.3.2 Time

In order to compare the point clouds of two different moments in time, it is necessary to choose a time interval between these two moments. Determining the time interval will depend on several factors related to predicting the rate of change of all assets present in the floodplain, and the exact duration is yet to be decided. It is expected to be around one month due to the time limit of the duration of this study.

1.3.3 Content

In terms of content, this research will mainly focus on acquiring the point clouds, designing an interactive visualisation tool and integrating new insights.

Moscow In order to define the priorities of this research, there is made use of the MoSCoW method (Clegg and Barker, 1994). This method identifies four categories, each with a different priority within, in this case, this research. These include items that must be achieved (must), those that are feasible to achieve (should), those that can be realised if the resources are sufficient (could), and those that do not necessarily have to be foreseen (won't). Figure 1 gives an overview of the MoSCoW method applied to this study.

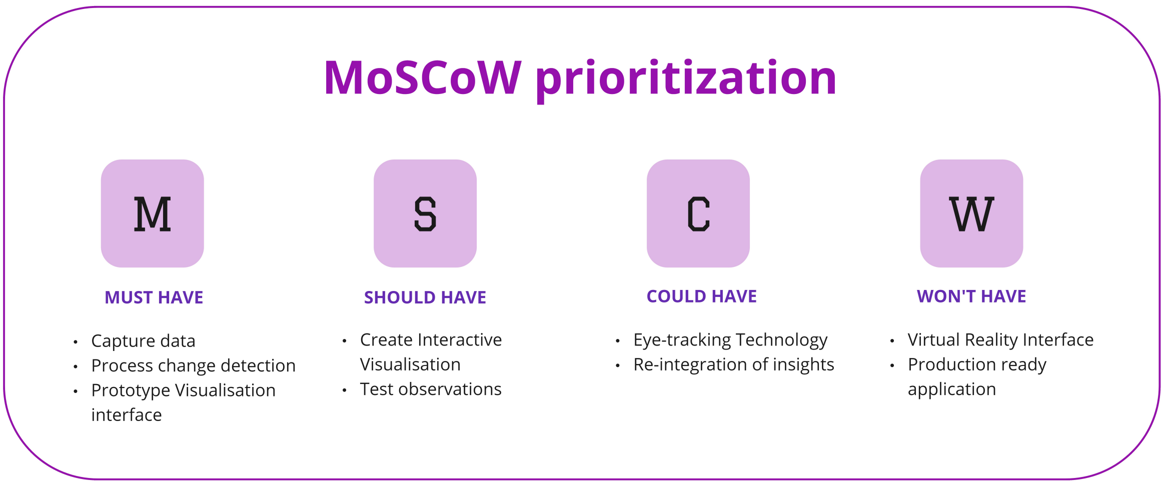

Figure 1: MoSCoW prioritization

Will not do To clarify what this research will not focus on, this section will appoint these items. The research is not concerned with the LiDAR technique. It is assumed that the survey department acquires the point clouds correctly, so no attention will be paid to this. In addition, this research will use an existing viewer for the interactive visualisation and no attention will be paid to developing a new one. Furthermore, existing interactive tools will be used and combined, and no attention will be paid to developing a new one. As mentioned earlier, this research will only focus on a pilot study area, and will not look further into implementing on a larger scale after this.

2 Related work

2.1 Introduction to point clouds

Firstly it is important to understand what point clouds are. Point clouds are three-dimensional models that consist of a collection of points with x, y, and z coordinates. However, additional possible properties can also be stored in the point cloud such as intensity, return number, point classification values, number of returns, return number, RGB (Red, Green, Blue) color values, and many more (ESRI, 2023). These point clouds can be used to represent certain objects, environments, or spatial phenomena from the real world in a discrete way (Discher et al., 2019). The following Figure 2 presents an example of a point cloud which is filtered on the basis of its height. The dataset used was obtained via GeoTiles, which provides the ability to download small tiles of the AHN4 dataset. The tile in question is 39CZ2_24, which contains part of the floodplain of Zaltbommel (GeoTiles, 2023).

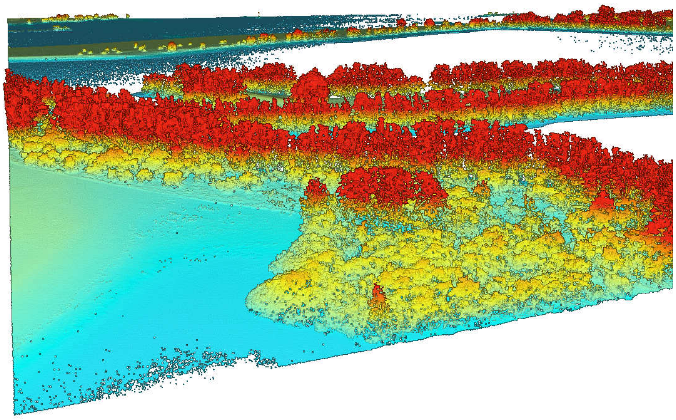

Figure 2: Point cloud - filtered on height

Developments in the field of 3D point clouds have led to the creation of the national open data source known as the Actueel Hoogtebestand Nederland (AHN). The AHN program was initiated in 1997 and has evolved from the AHN1 to the current AHN4 version (AHN, 2023). This data source can be used by many different people for a variety of purposes (Bregt et al., 2019). It is a challenging and expensive process to obtain and process the AHN dataset on a nationwide scale. Therefore are updated AHN dataset versions released on average every five years. Since this time frame is too long for detecting changes within floodplains, it is crucial to have a comprehensive understanding of the acquisition process involved in capturing point cloud data.

Several data collection techniques are available for acquiring 3D point clouds. Among them exist the active and passive forms.

The active techniques emit radiation toward the target by making use of their own energy source and it detects the reflected radiation back from the target. Two active methods are radar remote sensing, and Light Detection and Ranging (LiDAR). Due to the properties of laser radiation has LiDAR an advantage in areas of dense vegetation and floodplain mapping (Tolpekin and Stein, 2012). LiDAR involves measuring the distance from the scanner to the surface being scanned. From this can a 3D coordinate (x,y,z) be calculated. LiDAR devices make use of laser light pulses being sent to the object and measuring the time to return this signal after hitting the objects in its path. The exact distance between the sensor and the reflecting point can be measured by using the time-of-flight and the speed of light (see equation (1), *where d = distance to the object, c = speed of light, and t = time-of-flight between the light emitted and detected*). This technique can be seen as the most accurate one. One of its benefits is its ability to obtain measurements without being dependent on weather conditions (Dong and Chen, 2017).

$$d = \frac{c * t}{2} \tag{1}$$

The passive techniques measure reflected solar radiation in visible, near-infrared, and mid-infrared wavelengths, or absorbed and then re-emitted solar radiation in thermal infrared wavelengths. Two passive methods are multispectral remote sensing and hyperspectral remote sensing (Tolpekin and Stein, 2012). It is possible to generate a point cloud by combining images from different angles of an object. This is done by identifying overlapping features in both images and determining a 3D point from here. However, this step takes additional time and memory due to the extra processing.

The resulting data of these techniques are also referred to as "raw data" of the point clouds (Tolpekin and Stein, 2012). There are several advantages of laser scanning compared to image-matching photogrammetry techniques. Laser ranging does not depend on surface texture, is less weather dependent than passive optical sensors, has the ability to pass through the tree canopy (unless it is very dense), has a high accuracy, has multiple-return recording, and has no need for ground control.

So to further deepen in the LiDAR technique it is good to know that there are Airborne Laser Scanning (ALS) and Terrestrial Laser Scanning (TLS) techniques. The difference between them is that (TLS) is measured from the ground and (ALS) from the air. Ground-based land measurements (TLS) are more labor intensive compared to automated aerial methods (ALS). In addition, TLS has limited coverage, while technological developments in ALS have opened up new possibilities regarding conducting accurate and high-density measurements over large areas (Pucino et al., 2021; Dering et al., 2019). One of them is the use of LiDAR sensors in Unmanned Aerial Vehicle (UAV). UAV are common platforms that are autonomously operated and have the ability to carry several remote sensors including LiDAR devices and multispectral sensors (Ariff et al., 2020). A major advantage of integrating these sensors into UAV platforms is their wide range capability, which is needed when mapping and monitoring areas.

After obtaining the point clouds, there are several formats available to manage and exchange them. The LASer (LAS) file format is the most used data format for the dissemination of point cloud data (Ledoux et al., 2022). The American Society for Photogrammetry and Remote Sensing (ASPRS) maintains this binary-encoded standard format that contains information specific to the LiDAR nature of the data and currently operates at version 1.4 (ASPRS, 2023).

2.2 Explorative point clouds

Point clouds can also be seen as a bunch of points in a dimension that means nothing separately, but if several points are presented next to each other, you, as a human being, can easily recognize an object in this set of meaningless points. However, to a computer without processing this is still a meaningless set of unrelated points. Using this line of thinking, there are currently used a lot of processing techniques, which are time-consuming for large data sets, to convert the points to other models. In this way, the huge amount of raw data is quickly reduced and important information might get lost (Poux et al., 2016). Moreover, the acquisition of point clouds costs not only time but also quite a lot of money. So it is a waste not to look further into the possibilities of the unprocessed raw point cloud as a model on its own. Point clouds have more value than the derived models since they keep the details. Moreover, it is up to date and each detail is known. However, this added value is to be revealed by the user.

This leads to the introduction of exploratory point clouds which contain tools to integrate visualization techniques. The only question then is to what extent a tool makes a point cloud exploratory. In the case of floodplain maintenance, it involves making decisions about where and when specific operations should take place. Making these decisions is related to decision-making problems. Several factors can influence a decision-making process within flood defences, which include regulatory, financial, technical, and actor perspectives (van Laak, 2016). An important aspect of decision-making processes is that it includes human interpretation.

Understanding human creativity is complicated. Ideas can be unpredictable, or even seen as impossible. Creativity is the generation of new ideas that are seen as valuable. Actually, this creativity happens daily in the virtual aspect of our lives, which is naturally learned. Think for instance of perception, memory, or conceptual thinking. A distinction can be made between three types of creativity, one of which involves the exploration of conceptual spaces in people's minds. This is exactly the type of creativity that is attempted to be achieved with the use of visualisations of raw point cloud data. Exploratory creativity is valuable given that it can lead to someone seeing new possibilities that they did not see before, which opens up the question of the potential of the potency of this approach (Boden, 2007).

But how can this human interpretation be linked to a data-driven tool for making certain decisions in floodplain maintenance? That depends on what choices need to be made based on detecting changes in the landscape and confirmed objects. So that detection in turn is linked to the human interpretation, which can be seen as an input factor for the decision-making process. It helps if analysts can explore and play with the point clouds. This comes together in the idea of a spatial decision support tool.

A spatial decision support tool is an interactive system designed to help make decisions when solving a spatial problem (Rezvani et al., 2023; Jankowski et al., 2014). For this, it is important to describe the following two aspects to give a guideline for the requirements of such a type of tool in the case of a maintenance process (Santen, 2014). First, for what, i.e. what exactly the tool should be able to do. In addition, for whom, i.e. which disciplines are involved in the maintenance process. For the first aspect, such a tool should be able to explore where changes are detected. The second aspect concerns the visualisation of the floodplain to the various domains involved within Van Oord. This results in the question of determining the most suited approach, which involves the various existing visualisation techniques.

2.3 Normalized Difference Vegetation Index (NDVI)

Another way to make a point cloud exploratory is to enrich it with additional information. As introduced in the introduction (1), NDVI is one of the possible applications when using a multispectral remote sensing technique. Multispectral tools include image acquisition and processing techniques. Existing light waves are divided into different bands, depending on their wavelength. If such a light source bounces against a material, a certain absorption and reflection take place depending on the type of material. The intensity of this reflection per frequency light band makes it possible to determine certain properties of a material. These bands can be assembled into a particular band composition to be used for analysis. With these transformations, certain patterns can be visualised, for example, the representation of vegetation. One of these band transformations is the use of Near-Infrared (NIR) and red (visible) wavelengths to determine the NDVI. (Kriegler et al., 1969; Huang et al., 2020). The NDVI is calculated by using the following formula (2).

$$NDVI = \frac{NIR - Red}{NIR + Red} \tag{2}$$

This indicator is widely used for its ability to help make decisions regarding the goals of vegetation maintenance (Calero et al., 2018). The NDVI is attractive due to its ability to detect vegetation and various traits, including vegetative stress (Pettorelli et al., 2005). The NDVI values vary between -1.0 to 1.0, where negative values indicate water, positive values around zero indicate bare soil, positive values between 0.1 and 0.5 indicate sparse vegetation and higher positive values indicate dense green vegetation. The following applies: the higher the index, the healthier the plant is (Akbar et al., 2019). One option to extend an existing point cloud with additional information is to integrate it with this NDVI. Calero et al. (2018) describe a method to integrate the NDVI into a point cloud. The NDVI point clouds can be seen as an innovative method to more easily determine and visualise the health of vegetation (Jurado et al., 2020).

2.4 Change detection between point clouds

As mentioned in the introduction 1, maintenance and change detection are closely related. Since change detection is about the change of a certain area over time, it can be seen as a spatio-temporal approach. The detection of change determines which elements appeared and disappeared by examining the differences between 3D spaces. Where change itself can be seen as the triple change definition, including positive (objects added), negative (objects removed), or no change (Stilla and Xu, 2023). According to Ott et al. (2001) is the main purpose of a temporal aspect in Geographical Information System (GIS) to reproduce temporal processes or events of the real world in a model in such a way that they are accessible for spatial query, analysis and visualization. For instance, there may be visible changes or specific patterns in the landscape that could influence the dynamics of the floodplains. In the case of point clouds, this spatio-temporal aspect involves acquiring point clouds at different time intervals and comparing the obtained points. To determine the exact changes in the acquired area over time, several techniques are available that concern the computation of the distance between the unique neighbour pairs within both point clouds. One method to achieve this is by using a nearest neighbour distance algorithm, which computes the Euclidean distance between both points. CloudCompare has a tool which is able to do this, which is called Cloud-to-Cloud Distance (C2CD), which computes the distances between two clouds (CloudCompare, 2023a). Lague et al. (2013) developed the so-called Multi-scale Model to Model Cloud Comparison (M3C2) method which is useful for land cover changes, erosion, flooding, deforestation and changes in the tree canopy. Stilla et al. (2023) describe several change detection techniques for 3D geometries, including point clouds. Several challenges are mentioned, including inconsistent sampling, limited visibility, and missing semantics. In the change detection workflow, three stages are essential, including reference frame registration, geometric difference estimation, and spectral and attribute analysis. Another challenge that is important to consider is the uncertainty of the measurements, given that the measurements are taken at two points in time. This can influence the position of the points, so change detection techniques have to take this into account. An example could be to take into account a certain threshold so that changes are only detected if they are higher than this number. Besides detecting positional differences of points, it is also possible to compare the NDVI values in both obtained point clouds of the floodplain. In this way, it could be determined whether the vegetation has been changed and how might affect the maintenance of the area.

The result of these comparisons can be added as attribue to the point cloud. It could be visualised by using a color-scaled point cloud which shows the variations in distances and NDVI values. This can be utilized for providing a visual representation of the alterations in elevations and NDVI values that have occurred over the time interval of the acquisition of both point clouds. This initiates the exploration of the visualization of the clouds, focusing on identifying an approach that considers a comprehensive representation of the dataset.

2.5 Visualisation possibilities of point clouds

Visualization techniques have long been used to provide insight into complex data by visualizing it. Applications exist in various fields, including, for example, urban planning, logistics, healthcare, and market research. The domain of information visualisation focuses on graphical representation in an interface with the ability to perform interactive manipulations. The visualisation aspect is also considered a tool for visual thinking or decision-making (Dykes et al., 2005). One of the information visualisation domains is in the field of GIS, called geovisualisation. This refers to the use of certain tools and techniques to support geospatial data analysis by integrating interactive visualization. It is widely used for analysis concerning spatio-temporal data and the exploration of landscapes, such as the detection of changes in floodplain areas(Smith et al., 2013; Chen, 2013).

The emerging field of geovisualisation draws upon approaches from the discipline of Exploratory Spatial Data Analysis (ESDA), which is a manner to get insights from your data, by making use of tools for the visual exploration, analysis, synthesis, and presentation of data that contains geographic information (Dykes et al., 2005). The use of such tools makes it possible to examine data in order to obtain a deeper understanding of the phenomena to be investigated. It contains the relationship within the data and its potential correlation (ArcMap, 2023).

In the case of multi-dimensional data representation, which includes point cloud data because of its z dimension, several visualisation options are possible. For now, there is no universally appropriate approach for handling and visualising point cloud datasets, especially when exploratory research is involved(Bakker et al., 2018). As mentioned earlier, point clouds are often processed, into, for example, an elevation grid, before being visualised. However, there are drawbacks regarding the limited level of detail of reality. By processing the point clouds, some data disappears, whereas a point cloud itself can be interpreted as a virtual copy of the real world (Zhang et al., 2017, 2021). Due to this reason, Verbree and Oosterom (2015) recommend direct analysis on point cloud data to avoid such problems. Moreover, Poux (2020) states that direct visualisation of point clouds guarantees a simple application procedure given the elimination of data transformations that are time-consuming. Therefore, existing visualisation capabilities of unprocessed point clouds will be examined.

Human Computer Interaction (HCI) is the scientific field of identifying the human interaction with computers via for example an interface (Franzluebbers et al., 2022; Bochove et al., 2018). To translate multi-dimensional data into an interactive tool, the following factors need to be considered. First, human interaction, its usability, data display, interface, and interactive options to play with the data. The challenge is to create an application which enables several functionalities in a simple and useful interface. It is crucial to consider the lack of knowledge among users of the interface regarding point clouds, which causes the need for an interface that is easy to use and understand, in other words user-friendly. This makes it important to provide assistance where necessary so that users are able to use the application correctly (Andrienko et al., 2002; Dykes et al., 2005).

According to Shneiderman (2003) is the starting point of developing an advanced graphical user interface as follows: overview first, zoom and filter, then details on demand. The most common way is described as follows. By first showing an overview of the data, it is clear what overall view the user is looking at. After this, it is possible to zoom in on objects of interest. The user can then filter out items and obtain certain details of an item. An important aspect is the history task that allows users to recall actions they have performed. In the end, a selection of important findings can be extracted from the data (Shneiderman, 2003).

In addition to the use of visualisation, the exploration of point clouds requires the use of an interactive method for the user. Dykes (2005) argues several examples of interactive visualisation techniques. One of them is dynamic projection, which is an "automated navigation operation in which the projections are dynamically changed in order to explore a multi-dimensional data set". Another method is interactive filtering, which is a combination of select and view enhancement. In this way, a dataset can be divided into sections, allowing a certain focus on objects of interest. The well-known modification technique, zooming, is also mentioned. By using this option, non-important information can be omitted by focusing only on the compressed form of the relevant information. Distortion is a technique that displays some data with a high level of detail while others have a lower level of detail. Two popular techniques are brushing and linking, which are also often combined. Brushing is an interactive selection process and linking allows data to be translated into other views. Another technique used to visualise point clouds is Eye-Dome Lighting (EDL). It is a method, depending on the viewpoint, to enhance depth perception by using shading techniques. Thus, projected depth information is applied to point cloud visualisation (Boucheny, 2009). Another possibility is rendering, which is a technique for computing with the attributes of points, such as colour or intensity (Richter et al., 2014). Combining different visualisation methods avoids any shortcomings. For example, brushed points can be highlighted in the visualisation, where certain correlations can then be detected. Another advantage is that applying linking and brushing in conjunction with other techniques provides new information.

There are several existing interactive visualisation tools. One of them is the Visualisation Toolkit VTK, which is an open-source software system with a library for various processing and visualisation techniques. Both Python and C++ support the use of this toolkit. Modelling techniques such as contouring or customising the representation of points are possible (VTK, 2023). CloudCompare is another open-source processing software that can be used for visualising point clouds. Various toolkits are included, such as distance computation, statistics, and more. The software supports read files and provides tools that are allowed during further development of plugins in C++ (CloudCompare, 2023b). An additional open-source visualisation option is Potree, which is a WebGL-based renderer for large point clouds. The presence of a variety of measurement tools provides the ability to validate and analyse raw point clouds without additional processing steps and time (Schütz, 2016).

In the case of maintenance processes, such a visualisation tool should be able to show where changes have been observed over measured time. This is so that the user can immediately see which objects have shifted, for example, or grown in the case of vegetation. This could be done through an integrated colour scale that would allow users to more easily recognise certain patterns.

An alternative on HCI is the use of Virtual Reality (VR) instead of computers (Franzluebbers et al., 2022). Franzluebbers et al. (2022) present a hybrid immersive headset-and desktop-based VR visualisation and annotation system for point clouds. A comparison is made between different interfaces for annotation and counting tasks oriented towards application on laser scans of vegetation (Franzluebbers et al., 2022). Some time ago, the use of VR was introduced and promoted as "it offers new and exciting opportunities to visualise 3D GIS data" and that "VR is becoming a popular tool to visualize 3D GIS data" (Verbree, 2000). One of the positive contributions of using VR techniques is that there is potential to improve every phase of a project regarding design, planning, and preparation (Thabet et al., 2002). Germs et al. (1999) introduced the idea of a multi-view, which included a plan, model, and world view. The data is presented using different angles of information to create an overview that is as complete and realistic as possible. De Haan (2009) and Bochove (2018) also confirm that using VR creates a perception of being in a world comparable to the realistic world, allowing the 3D model to be approached from any perspective. In doing so, the use of VR enables the user to display detailed elements in space, which would not be possible without 3D rendering. If the space provides a realistic representation of the study area, the user of the VR system can genuinely feel like they are in a different environment (Verbree, 2000). Although it is important that the users should be able to control their position and orientation. All in all, the use of 3D in visualisation offers opportunities for the exploration of point clouds by interacting with geographical data.

3 Methodology

3.1 Approach

This chapter includes the proposed methodology for the research in order to answer the main- and sub-research questions defined in the introduction (1). This includes a workflow of three phases, which each consist of different steps, presented in Figure 3. The first phase involves the acquisition of the data. The second phase involves the visualization of the point clouds followed by the third phase where the integration of knowledge will draw certain conclusions and lead to new insights.

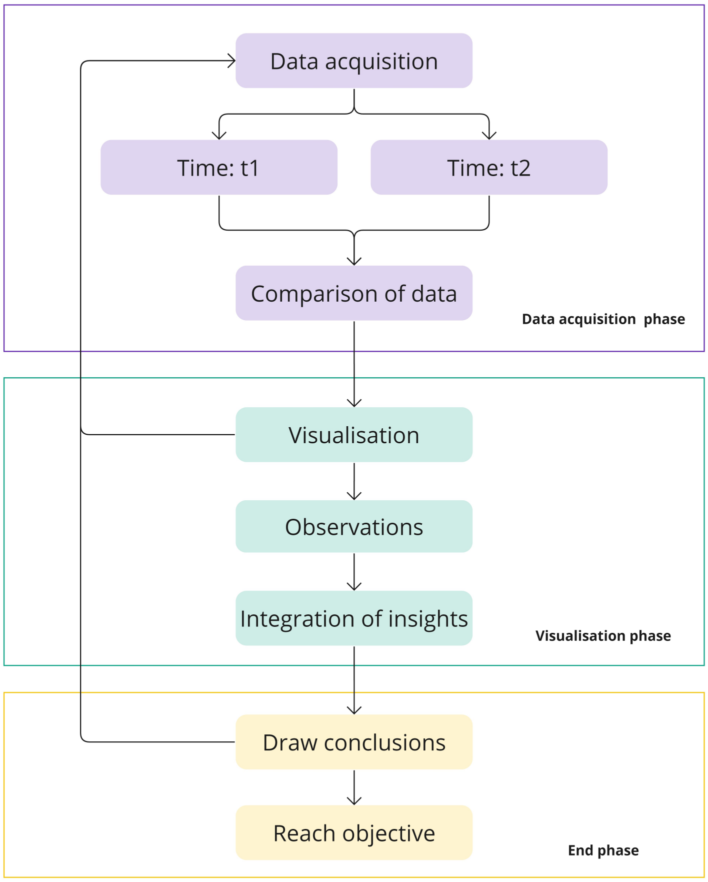

Figure 3: Workflow methodology

3.1.1 Phase I - Acquisition of data

Firstly, the preparation of the acquisition of the data takes place. This means that the study area within the floodplain of Zaltbommel will be determined above which the drone will be scanning. Moreover, this area to be surveyed must be incorporated into the drone's flight path. The flight parameters of the drone, including altitude, and flight path have to be determined. Thereby, the spatio-temporal approach of this research is an important aspect, which is established by the measurement of differences. This means a to-be-determined amount of days must be present between the first and second measurement moment. Another detail is that weather conditions at both measuring times will be taken into account so it will not negatively affect the data. After this, it is possible to collect the data with the later clarified Zenmuse L1 LiDAR drone, which is done in cooperation with Van Oord's survey department. The drone will automatically generate the data and this will result in a point cloud of the study area. After obtaining the point clouds collected at both times, it is time for the next step, in which the point clouds can be compared.

The second step concerns change detection, through the use of comparison techniques between the acquired point clouds data. For this, it is important to find the most suitable method and tool to achieve the most accurate and reliable results. Detecting the differences in the position of the points between both point clouds can be done based on the distance between each pair of points. The most suitable method to determine the differences in NDVI value should also be considered. These detections allow the change in height and NDVI observed for each point to be displayed, leading to an integration of knowledge for the next step, which concerns the development of a visualisation tool.

3.1.2 Phase II - Visualisation of data

For the visualization interface, it is important to determine both the design and the interactive features. Since the idea is to use an existing viewer, such as Potree, it is important to investigate the possibilities of integrating tools. Moreover, attention should be paid to the representation of the data, such as colours to indicate differences more clearly, overlay capabilities to view the point clouds at t1 and t2, and any annotations with further descriptions. Thereby, attention should also be paid to the interaction of the interface, such as intuitiveness and user-friendliness in use, and how to navigate in the point clouds, including zooming, rotating, filtering, and switching between screens. This should include considering the possibilities of being able to filter the visualisation of the point clouds, for example, only on the NDVI value or on altitude. Moreover, the way in which linked views will be applied to present data from different perspectives needs to be investigated. Furthermore, the possibilities of changing certain parameters to play with the data, such as a threshold for the distance between the point clouds, will be examined. Thereafter, the visualisation interface can be integrated with the relevant tools found and the data. This will probably take a lot of time, so that is why this will be done first with a small part of the data after which, if it works well, it can be implemented for the full dataset. After this, the prototype visualisation interface is hopefully developed far enough to move on to the next step, testing.

The next step concerns determining which expertise is present within Van Oord that is involved in the floodplain maintenance project. Based on these areas of expertise, it can be determined who will be involved in testing the visualisation tool. After this, a plan will be made in which way these people will be presented with the visualisation. Think for instance about the type of screen, how long, how many people and from which knowledge domains, and the assistance by means of, for instance, a GIS employee who can help with content-related questions. This preparation is crucial to obtain suitable insights after the test phase. It is also important to consider how the insights will be processed. So it will be necessary to find out which way is most suitable, such as an interview with questions or export possibilities of findings in the visualisation interface. After conducting these observations, it is time for the next step - integrating the observations.

In order to integrate the observations into new insights, it is necessary to determine how these can be brought together. For example, should findings be distinguished in the point cloud data by domain or by a combination of insights? It needs to be figured out how to take into account the interaction that took place per observation, what tools were used, were there ambiguities. In other words, how can all observations best be processed. From here, the research continues into the final phase, the reintegration of the results.

3.1.3 Phase III - Reintegration of results

The final phase involves the analysis of the human interaction with the visualisation interface. Firstly, a comprehensive analysis will be conducted to examine the insights from all the different disciplines regarding change detection in the floodplain area. Subsequently, an important step involves the reintegration of these results. This contains the process of bringing back new insights to either the acquisition phase or the visuals phase. For instance, the incorporation of a new acquisition technique or the usage of other settings might be seen as interesting based on human interaction. In this way, a continuous feedback loop is generated, which ensures an ongoing evaluation over time to strive for an optimized process. Lastly, the results found can be used to answer all the research questions generated and any inadequacies and improvements can be used as discussion points and further recommendations.

3.2 Risk analysis

The risks from this research have been identified and analysed to mitigate any impact. The biggest risk factor is getting the right data. In case it is not possible to acquire point clouds with the Zenmuse L1 LiDAR, an alternative will have to be used. Given that AHN data is available from floodplains in the Netherlands, the comparison of AHN3 and AHN4 data will then be considered. Another risk is obtaining the correct NDVI data by using a multispectral camera. If it is not possible within the time limit to obtain the correct data or to link the NDVI values to the points in the point clouds, then only the point clouds themselves will be used.

3.3 Datasets and tools

3.3.1 Datasets

As mentioned before, this research will focus on the floodplain of Zaltbommel, which means that the point clouds will be acquired above this area. In order to create the point clouds of the floodplains, there will be made use of the Zenmuse L1 LiDAR on a UAV drone. This will be carried out by the survey department of Van Oord. The advantage of having this acquisition method in-house is that the frequency of acquiring the data can be easily determined and altered when necessary. Van Oord has a subscription to the Trimble VRS Now service, which gives instant access to Real Time Kinematics (RTK) corrections on the measured x,y, and z values of the points generated for the point cloud (Geometius, 2023).

Zenmuse L1 LiDAR sensor The features of the Zenmuse L1 LiDAR sensor are as follows. The LiDAR module integrates with an RGB camera and a high-accuracy Inertial Measurement Unit (IMU). Furthermore, it has high efficiency by covering 2 square kilometres in a single flight. Its vertical accuracy is 5 cm and its horizontal is 10 cm. The point rate is about 240,000 points per second. The sensor supports 3 returns. The detection range is 450 meters (DJI, 2023).

3.3.2 Tools

To support the implementation of this study, a diverse set of tools will be used, which are presented in Table 2. For point cloud viewing, *CloudCompare*, *ArcGIS Pro*, and *Potree* will be used. For transforming and manipulating required data, *Feature Manipulation Engine (FME)* will be used. Combining data and integrating tools into the visualization interface will be written in *Python* and where appropriate *FME*. *Latex* will be used to complete the thesis report, using the template provided by geomatics found at: `https://github.com/tudelft3d/msc_geomatics_thesis_template`.

Table 2: Overview of tools

Tools	**Description**
ArcGIS Pro	Desktop GIS software system that will be used for visualisation of point clouds
CloudCompare	3D point cloud processing software for processing and visualisation of point clouds
FME	Geospatial integration platform that will be used to transform and manipulate data
LaTex	Software system that will be used for document preparation of the final thesis
PotreeDesktop	WebGL-based point cloud renderer for the visualisation of point clouds
Python	Programming language that will be used for developing the visualisation tool

4 Schedule

This graduation project will be carried out in the academic years 2022-2023 and 2023-2024.

4.1 Deadlines

The most important deadlines during the process of this thesis are presented in Table 3. The exact dates are to be determined.

Table 3: Deadlines

Date	Event
P2 presentation	19-06-2023
P3 presentation	01-09-2023 - 15-09-2023
P4 presentation	25-09-2023 - 06-10-2023
P5 presentation	30-10-2023 - 10-11-2023

4.2 Time planning

The schedule for conducting the research is shown in the form of a Gantt chart table presented in Table 4. This chart table is focused on the progression of the P3, P4, and P5 deadlines of the thesis.

Table 4: Gantt chart schedule

Phase	Time Planning		
	Start	**End**	**Duration**
P2 Presentation	19-06-2023		
Additional literature study	19-06-2023	07-07-2023	
LiDAR data acquisition	26-06-2023	26-07-2023	
Developing visualization tool	07-07-2023	08-09-2023	
Change detection of point clouds	31-07-2023	11-08-2023	
P3 Presentation	-to be determined-		
Testing human interaction	11-09-2023	15-09-2023	
Processing interpretation	18-09-2023	29-09-2023	
Writing thesis report	19-06-2023	29-09-2023	
Preparing P4 Presentation	02-10-2023	06-10-2023	
P4 Presentation	-to be determined-		
Thesis finalizing	09-10-2023	03-11-2023	
Preparing P5 Presentation	06-11-2023	10-11-2023	
P5 Presentation	-to be determined-		

5 General Information

- Delft University of Technology
  - First supervisor: Edward Verbree
  - Second supervisor: Martijn Meijers
- Van Oord
  - External supervisor: Irene Pleizier

Workplace Since the thesis is in collaboration with Delft University of Technology (TU Delft) and Van Oord, the workplace for conducting the research will be both at the faculty of TU Delft and Van Oord's office in Rotterdam.

Meetings Every two weeks a meeting is scheduled with the supervisors from TU Delft. Moreover, there is a weekly progress meeting with the external supervisor. Furthermore, there is a meeting together with the TU Delft supervisors and the external supervisor about once a month.

Progress In addition, the progress of the study, including schedule, status, and meetings can be found on the following MIRO board.

For questions, you can contact the student in charge of this study:
Name: Pam Sterkman

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