Information Visualization in Three-Dimensional Photorealistic Environment: A Case Study of Forestry and Visual Impact Assessments

by

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ABSTRACT

Visual impact assessments are an integral part of forest operations often conducted by foresters to prevent excessive visual damage to the scenery. In this thesis, we take a deep dive into how visual impact assessments are currently conducted and explore how information visualization can complement this process. We start by deriving important tasks and design requirements from i) a review of relevant documents and ii) findings from interviews with domain experts. Then, we describe Evergreen, an information visualization system in a three-dimensional photorealistic environment informed by these tasks and requirements. Finally, we report on a qualitative evaluation of Evergreen where domain experts completed the derived tasks. We found that the system can effectively assist foresters in conducting visual impact assessments and that participants would include Evergreen in their current workflow. The results highlight directions for future research including how navigation, interactions, and visual encodings can make communicating information within a 3D environment more precise and effective.

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Chapter 1

Introduction

This thesis explores how information visualization can assist foresters in conducting visual impact assessments. As a first step, we reviewed existing government regulations and guidelines and interviewed domain experts to discover how information visualization may help with the current practice of conducting visual impact assessments. Next, we derived a list of tasks and design requirements from the knowledge gained and designed and implemented a visualization system for foresters. Finally, we evaluated the system with domain experts to gain insights into how well it can assist them in performing their tasks.

1.1 Context & Motivation

Environmental impact assessment is the analysis of the environmental impact that proposed operations may produce. It is usually conducted early in development projects so that issues can be addressed before the project is carried out. Visual impact assessment (VIA) is a part of the environmental impact assessment process. It is the analysis of the potential visual effect proposed operations may have on the scenic landscape (Figure 1.1). It is often used in the design or planning phase of de-

Figure 1.1: Part of the visual impact assessment process in which foresters analyze the percentage of already-modified land within a target area to understand how much additional modification the area can undergo [63].

velopment projects to understand the visual impact they may cause and to ensure the projects do not cause excessive damage to the scenery of an area and its local communities. If a project proves to be problematic and causes too much disturbance in the target area, VIAs may also serve as guidance for designing or planning modifications.

Although the exact procedures and requirements differ, VIAs are used in many disciplines, such as civil engineering, environmental science, and forestry. In addition, although regulations differ across countries, the use of impact assessments, including VIAs, is a well-established procedure, and governments around the world typically require developers to conduct assessments during the design or planning phase to avoid preventable damages [65]. This may include building a new high-rise, determining where to place wind turbines, or deciding which parts of the forest to harvest.

In this thesis, we focus on visual impact assessments conducted within the scope of forestry regulated by the province of British Columbia (BC), Canada.

In BC, forest resources are managed by the Ministry of Forests, in accordance with regulations from the Forest Practices Code of British Columbia Act. To maintain the alluring landscapes of BC, the Act requires that VIAs be completed in known scenic areas before modification operations are carried out.

To assist foresters in conducting VIAs, the BC government has established and maintains a database of visual quality objectives for scenic areas in the province. The visual quality objectives dictate the maximum percentage of timber that can be harvested from a given area of the forest. To maintain the scenic landscape, the visual impact of modification operations must not exceed the established visual quality objective.

For this thesis, we studied the intersection of information visualization and forestry, or more specifically, we looked at how information visualization techniques may assist foresters in conducting VIAs. Due to the characteristics of VIAs, which simulate the visual effects of modification operations in perspective view, we focus on three-dimensional information visualizations in a photo-realistic environment. Although 3D visualizations have existed for a long time, it is more commonly used in the field of scientific visualization, which focuses on visualizing complex physical data with inherent spatial references [13, 56, 38]. In the information visualization community, 2D versus 3D information visualizations have long been debated. Some argue that using 3D visualizations requires more cognitive load from the user and provides little to no benefits compared to using a 2D visualization [41]. However, for this thesis, since visual impact assessments are tightly coupled with spatial references and the inherent benefit of using perspective views provides a sufficient rationale to design for a 3D information visualization.

There exists several tools and systems designed for the purpose of conducting visual impact assessments in forestry. These tools focus on the analytical aspect of assessments. However, the visualization aspect is rarely the emphasis of these tools. For example, conducting slope analysis in QGIS results in a heat map overlaid onto a 2D map [66]. Although this approach may be suitable for simple operations, it becomes overwhelming for the user when completing complex operations such as visual impact assessments.

This is not to say that 3D visualizations do not exist in this space. There are numerous tools and extensive research on 3D visualizations for viewshed analysis, or visibility analysis. Viewshed analysis focuses on delineating the visibility of certain areas from a given location. However, these tools are often designed for civil engineering, specifically city planning [24, 64, 67]. The emphasis of these tools is often placed upon the obstruction of visibility. For example, if a new high-rise is placed at a given location, how does it affect the view within the city? This differs from viewshed analysis conducted within forestry, where the focus is placed on delineating the visibility of certain areas from high-traffic locations.

In this thesis, we look into understanding the process of current practices foresters employ to conduct visual impact assessments and derived tasks and design requirements in accordance with the task-centered system design technique [43]. We aim to design a 3D visualization that is exploratory and analytical [84]. The system should support discovery and decision-making, including situations where the users do not know what they want or the users know what they want but is confirming if what they want is available in the data.

This chapter discusses the motivation and the context for this research. It also includes the research questions we aim to answer, the approach we took to answer them, and the contributions of this research. Finally, we discuss the scope of this thesis and conclude with an overview of the structure of this thesis.

1.2 Research Questions

This thesis aims to answer the overarching research question: **How can information visualization assist foresters in conducting visual impact assessments**?

Specifically, the definition for “assist” in this scenario includes efficiency and quality, meaning the results of this thesis should increase the efficiency of foresters or the quality of the completed visual impact assessments.

This high-level research question can be further broken down into six sub-questions:

- Question 1: How are visual impact assessments currently being conducted? Which aspects of the process are essential, and which have limitations or barriers?
- Question 2: What are the tasks and design requirements characterized by the current visual impact assessment process?
- Question 3: Which aspects of the visual impact assessment process can be enhanced by information visualization?
- Question 4: How can information visualization techniques be integrated with the visual impact assessment process?
- Question 5: How can information visualization techniques be effectively applied to a 3D photorealistic environment?
- Question 6: Can domain experts leverage the designed system for their decision-making process?

1.3 Research Approach

This thesis centers around answering the research question **How can information visualization assist foresters in conducting visual impact assessments** and its six sub-questions.

Due to the interdisciplinarity of the research, we began by gaining familiarity with forestry and visual impact assessments. The approach we took at this stage of the research was exploratory, with a focus on qualitative data collection and analysis. This is to ensure the results of this phase be as rich as possible without limiting the scope of the research prematurely and missing opportunities.

We reviewed government documents relating to visual impact assessments that served as a baseline for uncovering how assessments are currently done. To complement the government documents, we also conducted three interviews with domain experts to ensure the validity of the analysis of government documents and to look at visual impact assessments from a real-world perspective. This phase answers questions 1, 2, and 3.

Question 1: How are visual impact assessments currently being conducted? Which aspects of the process are essential, and which have limitations or barriers?

The review of government documents provided a detailed explanation of this question, with an entire document dedicated to helping foresters prepare visual impact assessments.

However, although the government documents are extremely detailed in providing the recommended procedures for conducting visual impact assessments, we were also curious as to how things were done in real-world settings. To understand this, the interview participants were asked to provide a clear description of the last time they conducted a visual impact assessment from start to end. This question focused on areas of the process that differ from the government's guidelines. Tools that they use to complete the assessments were also examined to uncover gaps between the process and the tools.

We also broke the term "aspects" into two lower-level concepts: the process and the data. We relied mainly on data collected through the interviews. Although the government documents provided insights as well, it is limited due to the subjectivity of the question. The participants were asked to answer these questions by referring to their experiences and providing concrete examples.

This research question is answered in chapter 3.

Question 2: What are the tasks and design requirements characterized by the current visual impact assessment process?

Using the analysis results of the government documents and interviews, we extracted tasks and design requirements derived from the tasks. The tasks focused mainly on current practices practitioners employ to conduct visual impact assessments, complementing the results with aspects of the process that the foresters considered can be further improved.

This research question is answered in chapter 3 and chapter 4.

Question 3: Which aspects of the visual impact assessment process can be enhanced by information visualization?

To answer this question, we analyzed the previously gathered data using grounded theory. To ensure we maximize the results from the analysis, no criteria are selected and everything is coded. Using the results, we determined which aspects of the assessment process can be improved with information visualization techniques.

This research question is answered in chapter 3 and chapter 4.

Question 4: How can information visualization techniques be integrated with the visual impact assessment process?

Using the aforementioned tasks and design requirements, we designed a system to assist with the visual impact assessment process. Several prototypes were created, and internal meetings were held with research collaborators to select the best aspects of the prototypes. After implementation, an evaluation was held with domain experts to ensure the usefulness of the implemented system.

This research question is answered in chapter 4 and chapter 5.

Question 5: How can information visualization techniques be effectively applied to a 3D photorealistic environment?

To ensure effective information visualization techniques are selected, we reviewed existing research on 3D visualizations, focusing on visualizations within a 3D photorealistic environment. Insights and inspirations from these research are then considered, and, using my understanding of the VIA process and the needs of foresters, the system is designed. An evaluation was held with domain experts to understand the effectiveness of the implemented techniques and how they may be further improved.

This research question is answered in chapter 4 and chapter 5.

Question 6: Can domain experts leverage the designed system for their decision-making process?

To answer this question, an evaluation was held with domain experts towards the end of the research to ensure the usefulness of the implemented system and to understand which aspects of the VIA process the system helps the foresters or may help better. The evaluation focuses on the foresters' user experience while interacting with the designed system and takes into consideration their individual workflow and significant tasks.

This research question is answered in chapter 5.

1.4 Research Contributions

This thesis includes three main research contributions:

- A collection of tasks foresters carry out when conducting visual impact assessments, including the planning phase and the assessment phase. These tasks are derived from analyzing official government guidelines and interviewing domain experts.
- The implementation of Evergreen, a system designed to assist foresters in conducting visual impact assessments. Evergreen is designed using the guidance of design requirements derived from the aforementioned tasks.
- The evaluation of Evergreen with domain experts. This confirms the usefulness of Evergreen in terms of conducting visual impact assessments. The findings also suggest the direction for future work and the improvement of Evergreen.

1.5 Thesis Scope

This thesis falls within three fields:

- Information Visualization, and more specifically, visualizations of abstract data situated in a three-dimensional environment.
- Forestry and environmental studies, through visual impact assessments.
- Human-Computer Interaction, through applying the task-centered system design technique.

This thesis focuses merely on aspects of forestry and environmental studies that apply to information visualization. For example, this includes topics such as how to present data to the users and how to improve cognition of the presented data. Topics that do not overlap the field of information visualization are not considered. For example, we do not address how the current process of conducting visual impact assessments can be modified to be improved.

This is so that the main component of this thesis remains in the field of Computer Science, and the resulting design complements current practices used in Forestry instead of reinventing the wheel. After all, the BC government defines the higher-level process of conducting visual impact assessments, which is unlikely to be modified.

1.6 Thesis Overview

This thesis contains six additional chapters:

- Chapter two reviews previous research into information visualization, specifically information visualization situated in a three-dimensional environment, and previous research that overlaps the field of information visualization and forestry.
- Chapter three describes, in detail, the formative study, where we analyzed official government documents and interviewed domain experts to retrieve the design requirements for the system.
- Chapter four describes, in detail, the implementation of Evergreen.
- Chapter five describes, in detail, the evaluation of Evergreen.
- Chapter six concludes this thesis by discussing the findings and summarizing the research.
- Chapter seven concludes this thesis and summarizes the research and directions for future work.

Chapter 2

Background

This thesis touches on the design of a visualization system rendered in a photorealistic 3D environment intended for domain experts in a specific field. Therefore, this chapter contains the following sections:

- Visualization Design and Evaluation
- Information Visualization in 3D
- Information Visualization in Photorealistic 3D Environments

In the visualization design and evaluation section, we looked at the literature on frameworks and techniques of system design, both from the perspective of human-computer interaction and information visualization. We also examined how the resulting system can be validated and evaluated and how further improvements to the application can be extracted from research.

In the second section, we looked at several 3D software visualizations, primarily visualization for hierarchical data, as that fits the theme of this thesis. Focus is placed on the problem they intend to solve and the techniques they use. We also examined the advantages and disadvantages of 3D information visualizations and how they compare to 2D visualizations.

Finally, in the third section, we looked at several 3D software visualizations in photorealistic environments with similar use cases to the system designed for this thesis. We categorized the techniques they use into four main categories and described their advantages, disadvantages, and design rationale.

2.1 Design and Evaluation

In this section, we reviewed frameworks and techniques of system design and evaluation. This knowledge will guide the research process as this thesis revolves around the creation of a system that aims to solve a domain-specific problem.

First, we looked at this topic from the perspective of human-computer interaction. We went over the concepts of human-centered design, which provided guidance for the design and evaluation of generic systems and the high-level processes this thesis followed. Then, we looked at related research in information visualization, which provided low-level details that filled in the gaps. The knowledge gained from human-computer interaction and information visualization is considered separately, as visualization systems differ from generic systems and are constrained mainly by data.

2.1.1 Design and Evaluation in Human-Computer Interaction

The design and evaluation of systems is one of the most researched topics in the field of human-computer interaction [35]. This includes all systems related to computing, such as interfaces, interactions, and materials [48]. Extensive research has been conducted to propose frameworks for the purpose of guiding researchers and designers when creating new systems, including user-centered design and task-centered design, which this thesis takes inspiration from.

In 1977, R. Kling coined the term “user-centered design” and proposed a framework that analyzes the circumstances under which a software design organization is likely to produce software designed for users [39]. Norman and Draper expanded the term and defined user-centered system design to be the design of computer systems tailored towards the needs of users, focusing on gaining an understanding of who will be using the developed system [59]. In their publication, they looked at several disciplines, such as psychology and architecture, and proposed several processes and techniques for design. Using the user-centered design framework, important points of consideration include the understanding of users and designing accordingly to their wants and needs, which results in increased usefulness and usability of the system [90].

Since then, user-centered design has become one of the commonly applied methods for design [96]. Multiple research has focused on optimizing the base approach proposed by Norman and Draper [89], and practitioners adapted several variations of the approach to suit their specific needs [90]. However, the core principle of user-centered design can be described as the following three steps [72].

- Analysis: understanding users and their needs
- Design: brainstorming and conceptualizing
- Evaluation: testing for usability

A variation to user-centered design is “task-centered design”, proposed by Lewis and Rieman [43]. It is a framework that focuses on designing based solely on users’ real-world tasks, as opposed to user-centered design, which takes into consideration users as a whole, including the users' needs, the users' wants, the context of use, the environment, and so on. Based on user-centered design, task-centered design follows a similar core principle described as the following four steps.

- Identification: figuring out who is going to use the system and to do what
- Requirements: prioritizing and choosing representative tasks to design
- Design: brainstorming and conceptualizing
- Evaluation: testing for usability

Both design frameworks are iterative, going back and forth between the phases and incorporating any new insights and knowledge into the final design.

2.1.2 Design and Evaluation in Information Visualization

In the field of information visualization, "design studies" are a variation of user-centered design and sibling to task-centered design. Design studies use a problem-driven approach to understand the users, focusing on the tasks users want and need to do. However, different from frameworks from human-computer interaction, design studies are primarily constrained by data, and careful considerations must be placed on the abstraction and encoding of data.

T. Munzner proposed a nested model for visualization design and validation [57]. Different sets of threats to validity are identified for each level within the model, and validation approaches are discussed in accordance with the threats identified. The nest characteristic indicates the iterative nature of the process: each level affects not only the next level but also the previous one; past levels may be revisited for refinements using newer knowledge gained; and the validation of a level may not be possible as it relies on the results of a nested level. The model consists of the following four stages.

- Domain problem characterization
- Data / operation abstraction design
- Encoding / interaction technique design
- Algorithm design

In a separate study, Sedlmair et al. proposed a nine-stage framework that expands upon the nested model [75]. The framework is organized into three categories: precondition, core, and analysis, describing what must be done before, during, and at the end of a design study. Multiple pitfalls and opportunities were identified in each stage to guide researchers and designers through the process and to prevent inaccuracy of the results from traveling upstream and downstream through the iterative process.

Research also exists that does not propose frameworks or processes to conduct design studies but offers recommendations on making studies as concrete as possible. Meyer and Dykes explored the nature of design studies, listed several characteristics of the nature of design studies, and proposed six criteria of rigor to consider when planning, executing, and reporting design studies to ensure the value of the research [52].

2.2 Information Visualization in 3D

In this section, we reviewed some existing 3D visualizations for hierarchical data, as this resembles the dataset this thesis aims to visualize the most.

First, we provided three examples of systems that fit the criteria and are well-known in the information visualization community and often discussed by members of the community. We described both the visualization and interaction aspects of the systems and discussed the design rationale and the strengths and weaknesses of these implementations. Then, we provided some context into research that compares and evaluates 3D visualization with 2D counterparts and described, at a higher level, when it may be suitable to use 3D and vice versa.

2.2.1 Past Works

Using 3D to visualize data has been a topic of interest for researchers in the information visualization community for decades [50, 86, 95, 87].

Robertson et al. presented a visualization technique, the cone tree, for visualizing hierarchical data [71]. Each node within the data set is represented using a rectangular-shaped label attached to its parent using a line, with the sole exception of the root node, which is placed near the ceiling of the display. Each sub-tree is organized into a cone-like structure, with the vertex connected to the base of its parent and the base connected to the vertex of its children. Efforts are made so that each layer has the same cone height, and the entirety of the visualization fits within the display. Cones and labels are rendered with transparency to reduce occlusion. Interactions include rotating the cones and selecting the labels to bring nodes of interest to the front, highlighting other labels on its path. The authors describe the technique as having efficient use of available screen space and allows the whole hierarchical structure to be visualized by using depth, manipulated using size, lighting, and links, to visualize more information, while a 2D representation of the same data would likely not fit on the display. However, they mentioned that the cone tree becomes less effective with a high number of nodes and that the technique is more effective when used to visualize unbalanced trees, as the visualization becomes challenging to track when interacting due to the uniform appearance of balanced trees.

Rekimoto and Green presented another visualization technique, the information cube, that uses nested cubes to represent hierarchical data [69]. Nodes are represented using semi-transparent cubes with labels rendered on the surface and children of the nodes nested within the cube. Efforts are made to ensure the nested cubes are scaled and positioned correctly so that cubes can be contained within their parent and each level appears uniform. Transparency controls the complexity and amount of data displayed to users through intentional occlusion. Interactions include moving and rotating the cube and selecting cubes of interest, which moves users to the focused cube. The authors describe the technique as intuitive to recognize and inspect, since hierarchical structures are nested in nature. It also answers some issues with the cone tree, such as increasing the number of nodes that can be effectively visualized and the ability to produce asymmetrical structures for balanced trees that allows better memory retention of the structure of the hierarchy in such scenarios.

Moreover, Andrews presented the harmony information landscape that uses building-like structures placed on a textured plane to represent hierarchical data [2]. Nodes are represented using flat blocks on the plane with lines attaching each node to its children. Unlike cone tree and information cube, terminal nodes use an independent metaphor. They are represented by rectangular prisms placed on top of the nodes, where size and color may serve as visual encodings to visualize additional information. Interactions include manipulating the camera, such as moving and rotating, to simulate flying over the landscape.

2.2.2 Advantages and Disadvantages of Using 3D

Brath stated that 3D visualization might be more effective for multi-dimensional datasets that can be translated into a 3D mental model [7]. They also listed several intrinsic attributes of 3D that can be used as visual representations, such as height, meshes, surfaces, lighting models, spatial separation, and perspective.

However, some studies show that 3D has zero to negative effects. Wagner Filho et al. evaluated a 2D and 3D scatterplot and found that task completion time is three times slower in 3D due to additional navigation and interaction costs [91]. Kyritsis et al. evaluated a 2D and 3D file manager. They found that 3D does not provide any benefits while creating too much clustering and visual obstructions and increasing interaction complexity, which escalates the cognitive load on the user and may lead to lower performance and frustration [41].

In the study conducted by Teets et al., they found that 3D works best for more complex tasks while, for more straightforward tasks, 2D will suffice [83]. They suggest that the level of task integration and the dimensionality of the visual representation should have a positive correlation and conclude that the amount of time used for task completion depends on both visual representation and task complexity. In another study, Brath noted that considerations must be made with 3D to ensure that the resulting visualization and the extra dimension provide a benefit, whether through visual encodings or interactions [7]. To guide researchers and designers, past works exist that offer guidelines and metrics for effective 3D visualization that can be used to aid the creation and evaluation of such visual representations [6, 5, 28].

2.3 Data Visualization in 3D with photorealistic rendering

Despite the disadvantages found to be associated with 3D information visualizations, for the purpose of this thesis, the 3D aspect is necessary as the data is environmental, meaning it is tightly coupled with a spatial component and can be translated intuitively into a 3D mental model within a photorealistic environment.

In this section, we reviewed some existing 3D visualizations in photorealistic environments and took note of the techniques they applied. We identified four main categories of techniques and describes each one in the following subsections, also detailing their advantages and disadvantages.

2.3.1 Textures

Adding or modifying texture is one of the most common techniques for visualizing both qualitative and quantitative data with spatial properties within a 3D environment. This includes directly applying texture to the terrain or to a newly created 3D object, such as a plane on top of the terrain.

The classic approach to visualizing single attribute data is the use of color overlays, which fills the surface of the terrain with a single layer of color and encodes information using a color scale. Dubel et al. presented several techniques to visualize data on a three-dimensional terrain [22]. This includes using a discrete color scale to encode the elevation of the terrain and using a continuous color scale to encode humidity. However, the authors mentioned that the blending of the color used to encode data and the shading of the terrain surface must be carefully considered as they may affect each other.

To visualize data with two attributes using color overlays, one option is to utilize the alpha channel, or transparency [33]. Dubel et al. investigated techniques to visualize geospatial data and its associated uncertainty on a 3D terrain [21]. They proposed an approach in which the RGB channel encodes geospatial data and the alpha channel encodes uncertainty, resulting in data with high confidence being more visible on the terrain compared to data with low confidence. In addition to manipulating the alpha channel, they proposed mapping geospatial data and uncertainty using a table and assigning discrete colors to each cell using a bivariate color scale. However, this method only provides a general overview and a coarse representation of the data.

Grid overlays can also be directly applied to the terrain and can be implemented as triangular or rectangular fishnets placed on the surface of the terrain. The resolution of the meshes can be used to encode information as such high values are represented with more finely subdivided meshes [21]. Other approaches include placing horizontal or vertical lines of equal distance onto the terrain, which communicate the depth and distance of locations within the terrain [22], or contour and boundary lines, which communicate the structural features of the terrain [22].

On the contrary to directly applying texture to the terrain, some systems apply texture and color to newly created 3D objects placed on top of the terrain. Brooks et al. proposed a hybrid system that integrates both 2D and 3D views of the same data [8]. While it also supports the classic approach of using texture on the surface of the terrain, the system also allows users to raise the texture and separate it from the terrain, resulting in a standalone two-dimensional layer on top of the 3D environment. Users can execute this technique to multiple attributes and create multiple 2D layers. Interactions include rearranging and organizing the vertical ordering of the layers and overlapping layers at the same height to support easier comparison. Data layers that are insignificant to users can be temporarily hidden by increasing their transparency. Using this approach, it is possible to extend the amount of information visualized by utilizing multiple layers of texture, as the data is no longer constrained to the surface of the terrain.

By placing texture on top of the terrain, layers are also capable of representing information through the use of visual encodings other than color. Williams et al. presented a visualization of ocean current flow and mesoscale eddies [97], which are a kind of three-dimensional high-vortical feature sized 20 - 300 kilometers horizontally that transports heat, salt, and nutrients across the ocean [29, 47]. To represent the thermocline, the transition layer of cold and warm water at a specific depth that is significant to researchers, they used a green semitransparent color layer placed at a constant height. However, the color layer is not completely above the terrain, as some sections of the layer are occluded from users depending on the elevation of the location. In this scenario, the height of the color layer within the 3D environment represents the depth of the thermocline and uses position as visual encoding.

Using textures, whether placed on the surface or on top of the terrain, can emphasize 3D structure and improve surface perception, providing users a better understanding of the terrain's depth and curvature [22]. The techniques described above can be combined in order to increase the amount of information visualized. It is also suitable to combine the techniques with extrinsic encodings, such as incorporating additional visualization artifacts, which will be elaborated in the next subsections [21].

2.3.2 Adding 3D components

Another common technique for visualizing data within a 3D environment is adding new 3D components whose purpose is to communicate data visually. These components are usually in the form of constructive solid geometry primitives, such as cubes, cylinders, cones, spheres, tetrahedrons, and triangular prisms [70].

In their work of visualizing Antarctica water masses and ice shelves, Abram et al. utilized spheres to represent water masses [1]. They first sampled the volumetric water data to a set of points and used color hue to encode the four categories of ocean water masses. The authors pointed out that although volumetric data fits well with the use of color overlays, it is not suitable for their specific scenario as overlaps exist within water masses, which may cause ambiguity and occlusion. In addition, by reducing volumetric data to points, they gain finer control over the visualization by modifying the sample density and sphere radius.

Williams et al. utilized cylinders within their work of visualizing ocean current flow and mesoscale eddies to represent the eddies [97]. They used the upper and lower bound of the cylinders to match the upper and lower bound of the eddies, encoding their height and depth, and color hue to encode the vorticity of the eddies. The authors opted to render the cylinders with a fixed radius to avoid cluttering the display with information; however, radius is also a viable visual encoding that may be used. Eddies that do not penetrate the thermocline and are of less interest to researchers are represented as gray diamonds.

There are other works that utilize geometric primitives as visual representations. Tominski et al. proposed a visualization of the global surface air temperature network using a node-link approach [85]. They utilized spheres to represent vertices, or weather stations, within the network and used size and color hue to encode betweenness and degree respectively. Brooks et al. used spheres to represent point layers within geographic information system data and proposed using size to encode one aspatial attribute, such as the location of towns and its population, respectively [8]. The authors also used rectangular prisms to represent landmark layers and cityscapes.

Complex shapes can also be used. Liu et al. presented a visualization of ocean mesoscale eddies [45]. In addition to visualizing the physical properties, the focus is placed on the migration path and internal structure of eddies. Three-dimensional isosurfaces are volume rendered to represent eddies and color value and color hue are used to encode physical properties such as temperature, salinity, and vorticity. Spatial properties of the eddies such as position and size are encoded into the three-dimensional environment using the rendered isosurfaces. The migration paths of eddies are conveyed by utilizing multiple models of the same eddy, sampled per timestep, and placing them at their corresponding position in series. Eddies in older timesteps have increased transparency.

There are also systems that represent data using established visualization techniques. In their same work, Brooks et al. illustrated visualizing chart layers within geographic information system data using three-dimensional pie charts, using color hue to encode data category and height and angle to encode value [8]. In their work of visualizing data produced by IoT infrastructure within smart cities, Bouloukakis et al. used three-dimensional bar charts to represent sensory data such as temperature [4].

2.3.3 Modifying existing 3D components

Modifying existing 3D components, such as the terrain and lighting, can also be used to convey information. In their work of visualizing crime scene data, Wolff and Asche mapped the minimum distance to the closest crime site to the cityscape's skyline, or building height, resulting in buildings within the visualization being taller the further it is to crime scenes [98]. In their work of visualizing city-scale shadow accumulation over time, Miranda et al. combined the use of shadows and color so that areas more impacted by shadows are shaded in a deeper color [54].

It is also possible to make modifications to existing 3D components through more intrinsic attributes. Dubel et al. adjusted the level of detail of the terrain to prioritize what the users will perceive, the terrain or the data [22]. They showed examples by modifying contour lines, shading, and lighting, as well as adding noise or fog to the surface of the terrain to limit the users' vision. In another work, Dubel et al. described and provided more elaborate details of these methods [21].

2.3.4 Adding 2D components

Similar to 2D visualizations, 2D components can be used in the form of labels, legends, and parameters placed within the 3D environment as user interface components [22].

It can also be used to support metaphors created by 3D components within the visualization. For example, within Liu et al.'s work of visualizing mesoscale ocean eddies, two-dimensional arrows are rendered above the migration path in conjunction with adjusting the transparency of the eddies to concrete the directional and temporal sequence [45].

Another interesting approach is using both 2D and 3D components in conjunction and allowing users to select which to prioritize. Within the hybrid system proposed by Brooks et al., users are able to raise the texture from the terrain, creating a standalone two-dimensional layer on top of the 3D environment [8]. By doing so, 3D components within the area, such as spheres, rectangular prisms, and pie charts, are flattened into disks, rectangles, and pie charts, respectively, and placed onto the 2D layer. The authors stated this approach allows more flexibility and is able to make use of the extra dimensionality provided by 3D while being less affected by issues such as self-occlusion and terrain occlusion.

Chapter 3

Formative Study

In this chapter, we describe the process of how we gained enough understanding of the domain of forestry and the process of conducting visual impact assessments in BC in order to design Evergreen. We reviewed government documents including regulations and guidelines, published by the B.C. Ministry of Forests and existing forest data from the database from the Government of British Columbia. To explore insights and new opportunities and to validate the results from official sources, we conducted semi-structured interviews with three domain experts, all of whom are researchers or foresters that are experienced in visual impact assessments. Finally, we compared and aggregated the results from the two data sources and established a generalized process of conducting visual impact assessments that is sound both theoretically and practically to guide the design of Evergreen.

3.1 Government Documents

This thesis focuses on the intersection of the field of computer science and forestry, or more specifically, visual impact assessment in the context of visual resource management. Being more familiar with computer science research, it is crucial to gain knowledge of forestry and visual impact assessments before the research can be continued. Since forest activities, including scenery management, are regulated by the BC government, to kick start the research, we first referred to documents published by both the provincial and federal governments to solidify my understanding of visual impact assessments. In this section, we introduce the documents used as reference and describe the knowledge derived from these documents.

3.1.1 Data Sources

There exists several government-published documents that aim at providing guidance to foresters for conducting visual impact assessments. These include not only legislation and regulations, such as the Forest Practices Code of British Columbia Act enacted in 1995 and the Forest and Range Practices Act enacted in 2004, but also various other documents, such as guidebooks, manuals, posters, etc. There are also resources from external sources, such as review documents and completed visual impact assessments from forestry partners in the province. In this research, we focused on two documents, which are the Visual Impact Assessment Guidebook [62] and the Visual Landscape Inventory Procedures & Standards Manual [61], both published by the Ministry of Forests, BC. We focused on these two documents because together, they cover different aspects of visual impact assessments in an explicit manner and give a good overview of the entire process.

The *Visual Impact Assessment Guidebook* helps foresters implement responsible forest practices that comply with the legislation in regard to visual resource management. It focuses on visual impact assessment itself and includes detailed descriptions of the topic, in the context of both visual resource management and legality. It also provides a detailed explanation of the visual impact assessment process and breaks it down into five comprehensive steps that will be elaborated on in the next subsections.

Although the document describes the procedures and practices of conducting visual impact assessments, the content it bears is not part of the legislation or mandatory requirements. Instead, it describes recommendations that are in line with the legislation, allowing flexibility and a range of options and outcomes for foresters carrying out the process.

The *Visual Landscape Inventory Procedures & Standards Manual* also aims at helping foresters understand the visual impact assessment process. However, instead of providing insights into the workflow, it lays out a clear structure of the parameters used to provide information about a forest's visual conditions. This includes what the parameters mean, how they are derived, and what their place is in the entire process.

Note that in May 2022, a Visual Impact Assessment Handbook [63] was published by the Ministry of Forests, BC. It serves to replace the Visual Impact Assessment Guidebook. This document is not included in the initial analysis that took place prior to its publication. However, we still referred to it to validate the results of the analysis and to ensure the legislation, regulations and recommended procedures and standards have not changed over the past twenty years.

In the following subsections, we describe the knowledge and insights gained from the government documents and explain forestry-specific words to make this thesis more accessible to non-forestry experts. Due to the flexibility of the visual impact assessment process, we provide a generalization of the process whenever practical.

3.1.2 Visual Impact Assessments

According to the data sources described above, visual impact assessments are the analysis of the potential visual effect proposed forest activities, such as harvesting and road developments, may have on the scenic landscape. It is often used in the design or planning phase of development projects to ensure the projects do not cause excessive damage to the scenery of an area and its local communities. If a project proves to be problematic and causes too much disturbance in the target area, visual impact assessments may also serve as guidance for design or planning modifications.

As the name implies, visual impact assessments focus on the visual aspect of human perception. This means that in order to successfully conduct a visual impact assessment, the forester must first define an observee and at least one observer. In the context of forestry, the observer is viewpoints and the observee is visual sensitivity units.

The *observer*, also called *viewpoint*, is a place or location that is accessible to the general public from which the proposed operation is visible. Viewpoints are locations that have high traffic, such as highways or public roads, or have high viewing duration, such as parks or campgrounds.

The *observee*, or *visual sensitivity unit*, is a more complex concept that requires first understanding how an area of land can be dissected and how landforms are delineated. At the topmost level are landscapes, which are the entire view of a location at one time from one place. Next are landforms, which are sub-units delineated from landscapes and are parts of the landscape that can be seen from only one specific viewpoint. Landforms are usually defined by natural geographic features such as ridges and valleys.

To derive the visual sensitivity units of an area, the landforms of that area and its surrounding viewpoints are required. Similar to landforms, visual sensitivity units are sub-units of the landscape as well. However, visual sensitivity units can be viewed from one or multiple viewpoints in succession, whereas landforms are delineated based on a single selected viewpoint. Visual sensitivity units are defined by the homogeneity and the biophysical features of the landscape. Given their characteristics, visual sensitivity units are typically larger and contain multiple homogeneous landforms, depending on the precision of the delineation.

To give a simplified example, imagine you are on the highway and driving past a mountain range. Thinking the scenery is beautiful, you took a picture. The landscape in this example would be the entire scenic area inside the photo, as it is the entire view of the location at one time, the moment you took the photo, from one place, the position the photo was taken in. Looking at the photo, you may see several mountains separated by ridges or valleys. These individual mountains are the landforms. Finally, as long as the landforms are homogeneous and have similar biophysical features, multiple landforms can be merged to become a visual sensitivity unit.

To complete a visual impact assessment, the forester must conduct several lower-level tasks on the target visual sensitivity unit and its relevant viewpoints such as viewshed analysis, landform analysis, and digital terrain modeling. However, despite its complexity, the entire process can be simplified into two tasks: i) to create visual simulations of the proposed operations in perspective view to estimate the level of visual impact, and ii) through the simulations to confirm whether it will comply with the established visual quality objective of the visual sensitivity unit. Visual quality objectives are objectives assigned to visual sensitivity units established by the BC government. It is used to dictate the expected visual conditions of visual sensitivity units, which in turn sets the maximum percentage of timber that can be harvested from a given area. To determine whether the visual quality objective is achieved, the forester must compare the objective with the visual sensitivity unit's existing alterations and proposed operations.

Although visual impact assessments play an important role in ensuring the scenery is sufficiently protected, it is not mandatory according to the legislation. Instead, it is considered due diligence the foresters must consider when planning forest activities. However, ensuring visual sensitivity units stay within the established visual quality objectives is part of the regulations and, once the visual impact assessment has been approved, it becomes legally enforceable and foresters must abide by the submitted plan.

In conclusion, visual impact assessments are used to understand how proposed alterations may affect the view of scenic landscapes. It can be broken down into the following tasks.

- Where you are placing the alteration?
- How you are modeling the alteration?
- From where is the alteration visible?
- What the visual state of the area is currently?
- What the visual impact of the alteration is to the area?

3.2 Interviews

Although the government documents describe in detail the knowledge required to complete visual impact assessments, as mentioned in the previous section, the information the government documents provide is merely recommendations, or generalized best practices, that comply with the legislation and regulations around visual impact assessments. These documents do not describe how the process is completed in a real-world setting and how foresters adjust the process to suit different scenarios. In addition, the government documents center solely around the literal completion of visual impact assessments with no mention of the decision-making process behind them.

To resolve this problem, we conducted a qualitative study by interviewing forestry domain experts. The study aims to not only verify the analysis of the government documents, but also to gain knowledge of how visual impact assessments are conducted in reality, how they differ from official recommendations, and which pain points exist in the process. We seek to answer the above questions from both the perspective of completing the actual visual impact assessment and the decision-making process that surrounds it.

3.2.1 Participants

To achieve the goals of the study outlined above, we recruited adult domain experts with both a forestry-related background and experience with visual impact assessments. We required that participants had conducted visual impact assessments at least once, whether in an academic or industrial setting. Participants were offered an optional compensation with a monetary value of $20 CAD, should they choose to accept it.

To recruit participants, we used the snowball sampling technique, starting with a research collaborator. Since snowball sampling provides participant filtering through the recommendation/snowball process, we did not include filtering questions but verbally confirmed their eligibility with the participants at the beginning of the interview.

Three experts participated in the study (two males, one female). Table 3.1 describes the demographics of the participants. Participants A and C are students of graduate level in the field of forest sciences and participant B is a researcher who holds a management-level role at a research forest located in BC. Participant A has only experience conducting visual impact assessments through coursework and research while participant B and C have conducted visual impact assessments in an industrial setting as well. Participant B is familiar with the decision-making process in addition to conducting visual impact assessments.

Table 3.1: Participant demographics for interviews

ID	Occupation	Forestry background	Industry experience
A	Graduate student	Y	N
B	Researcher	Y	Y
C	Graduate student	Y	Y

3.2.2 Study Design and Rationale

As the goals of the study are both confirmatory and exploratory, a qualitative study is more suitable than a quantitative one because it can reveal deep insights.

Due to the open-ended nature of the study's goals, we chose to conduct semi-structured interviews, which allow flexibility in terms of data collection and allow the participants to provide non-apparent insights through sharing their experiences and perspective.

The interview had three phases and fifteen questions. Phase 1 focuses on the current process and practices of conducting visual impact assessments and contains five questions. Phase 2 focuses on the sub-tasks of conducting visual impact assessments and contains seven questions. Phase 3 focuses on the ideal tools for conducting visual impact assessments and contains three questions.

Both phase 1 and phase 3 overlap with the information the government documents provide; therefore we had an approximate idea of what to expect from the participants. These phases are therefore more confirmatory and the focus was placed on discovering parts of the process that differ from the government documents when conducted in a real-world setting. Phase 2 seeks to uncover aspects of the process that are less documented in the government documents, making it more exploratory in nature.

Due to the semi-structured format of the interviews, follow-up questions were used to fill in the gaps, generally in the format of who, what, when, where, why, and how questions wherever applicable. These questions serve to probe the participants and to gain more knowledge of their experience and perspective of the topic at hand.

Phase 1 focuses on understanding how visual impact assessments are conducted in actuality, but also on uncovering how it differs from government recommendations. It includes the following questions.

- Q1: Tell me a story about a time you conducted a visual impact assessment.
- Q2: Are there any specific examples of barriers or limitations this process has where it is frustrating or not very efficient?
- Q3: What do you like about the way that visual impact assessments are conducted, and why?
- Q4: What do you dislike about the way that visual impact assessments are conducted, and why?
- Q5: In this process, what happens when the visual impact assessment is completed? How do you know if it is good and / or effective?

Q1 uses the storytelling technique [42] to ensure the collected data includes insights into visual impact assessments in a practical setting instead of how it is theoretically conducted. In addition, by asking the participants to think about their personal experience, they are less likely to overlook details and accidentally skip information that they may feel are obvious as domain experts but not to us, the researchers.

Q2, Q3, and Q4 focus on the advantages and disadvantages of the process they adopted. Q2 uses the critical incident technique [42, 26], with which the participants are more likely to recall rare events. Q3 and Q4 then bring the topic to a more general level, asking what the participants like and dislike about the process without being limited to their own personal experiences. Q5 focuses on how the participants evaluate completed visual impact assessments.

Phase 2 focuses on the sub-tasks of conducting visual impact assessments, in terms of both parameters and the workflow. As mentioned in the previous section, visual impact assessments can be described as one major task: comparing visual quality objectives with the existing visual conditions and the proposed modification. Although the government documents broke this task into a general five-step workflow, it is unclear how it can be derived into sub-tasks that can be used to guide the design of a technological solution. In addition, this phase seeks to rank the importance and priority of the resulting sub-tasks, in order to maximize the value of Evergreen. Therefore, we made assumptions regarding potentially important sub-tasks using the existing data and my understanding of visual impact assessments. We then used these assumptions as a baseline for probing the participants. Phase 2 centers around verifying the assumed sub-tasks and uncovering unanticipated sub-tasks. It includes the following questions.

- Q6: Ask about sub-tasks derived from the participants' responses in phase 1.
- Q7: Which viewpoint-related parameters (i.e., viewpoint importance, viewing distance, viewing duration, etc.) are important and how important to see, and why?
- Q8: Which low-level visual sensitivity unit-related parameters (i.e., visual absorption capability, viewing condition, biophysical rating, viewer rating, etc.) are important and how important to see, and why?
- Q9: Which high-level visual sensitivity unit-related parameters (i.e., visual quality class, visual sensitivity class, existing visual conditions, etc.) are important and how important to see, and why?
- Q10: Is it important and how important is it for you to see the relationship between visual sensitivity units and viewpoints, and why?

- Q11: Is it important and how important is it for you to see the relationship between visual sensitivity units, and why?
- Q12: Is it important and how important is it for you to see the relationship between viewpoints, and why?

Q6 asks the participants to elaborate on any unexpected sub-tasks that can be derived from their responses in phase 1. This question is flexible and focuses on sections of the participants' responses that differ from the government documents and assumed important sub-tasks. Q7 – Q12 then aim to verify my assumptions on what sub-tasks are important and should be supported in Evergreen. Q7, Q8, and Q9 are sub-tasks that focus on revealing which of the parameters described in the government documents are important. Q10, Q11, and Q12 focus on revealing the relationships between major components used in visual impact assessments, viewpoints, and visual sensitivity units. The participants were asked to answer the questions from not only the standpoint of completing visual impact assessments but also in terms of the decision-making process, which is more subjective.

Phase 3 focuses on the ideal tools for conducting visual impact assessments. Although the government documents include mentions of useful tools and software when introducing each step in the visual impact assessment process, this phase is centered around uncovering gaps between user needs and existing tools. Participants were asked to think of an ideal tool for the process and to think of barriers such a tool may bring. Phase 3 includes the following questions.

- Q13: What would you like to be able to do in a system that assists in conducting visual impact assessments, and why?
- Q14: What would be a single, or two, feature you would propose that would make conducting visual impact assessments much easier and / or better, and

why?

- Q15: Do you envision some barriers to the adoption of a digital tool for conducting visual impact assessments?

3.2.3 Procedure

The participants attended the sessions separately, with only the participant and members of the research team present. One researcher acted as the interviewer while other researchers acted as observers whose roles were to take notes and occasionally ask follow-up questions. Each session lasted approximately one hour. Due to COVID restrictions, the interviews took place remotely on Zoom.

Prior to the sessions, the participants were provided with the consent form and were asked to review it. Key points from the consent form were emphasized, including anonymity, confidentiality, and the participant's right to withdraw. The participants were asked if they had any questions or concerns regarding the consent form in a follow-up email.

At the start of the sessions, the participants were asked to provide consent verbally. They were asked the following screening questions, all of which must be responded to positively for the consent process to complete.

- What is your name?
- Have you read and understood the consent form?
- Do you have any questions about the information in the consent form?
- Are you willing to participate under the conditions described in the consent form?

As part of the consent process, the participants were also asked if they were willing to allow their anonymized data to be used in future research. This optional question did not block the consent process if they responded negatively.

Finally, the participants were asked if they were willing for the interview session to be recorded. We provided detailed descriptions of why the recording is important and how the recording will be used. An alternative was also provided to the participant, explaining what happens if they do not consent to the recording. If the participants agreed to the recording, we reminded them of their right to withdraw and explained that the recording could be stopped during the session at any time.

After the consent process, an icebreaker took place to familiarize the participants and the researchers and to encourage the participants to speak. The researchers quickly introduced themselves, after which the participants were asked the following questions.

- What is your education and / or job?
- How much experience do you have in the field of forestry?
- How much experience do you have with visual impact assessments?

These questions served not only as a chance for participants to get used to speaking in a research and interview environment but also served to retrieve demographic data from the participants. Additional follow-up questions were asked to ensure the consistency and quality of the demographic data collected.

The participants were then asked the fifteen questions (Q1–Q15) we described with additional follow-up questions wherever required.

3.2.4 Data Analysis

We transcribed the recordings from each interview session. Due to the open-ended nature of the sessions, we opted to produce a full transcription [74, 51]. Participants' non-verbal cues were not included in the analysis. Additional care was taken to ensure the quality of the transcription [23].

Three researchers participated in the data analysis. Of the three researchers, two researchers attended the interview sessions and were familiar with the data being analyzed. The other researcher was not present during the interviews and was originally unfamiliar with the field. This researcher was explained the data to ensure the quality of the analysis. Grounded theory was used to discover hidden constructs using NVivo [46].

An initial meeting took place between the three researchers to discuss the criteria and the expectations for the analysis in order to maintain the consistency of the results.

The analysis was then completed as an iterative process with three coding iterations.

Each iteration consisted of two phases. In the first phase, the researchers each examined the transcriptions separately and conducted open coding and axial coding to generate preliminary codes and themes [9]. In the second phase, the researchers convened and discussed while comparing the codes and themes line by line. During the discussion, codes were kept if mutual agreement was reached. In cases where researchers generated different codes or created diverging interpretations of the transcription, discussions were held until a consensus was reached, keeping only the agreed-upon codes.

Each iteration took as short as possible, typically around three days each, in order for the researchers to retain memory of previous discussions. In the first coding iteration, the researchers went through the transcriptions line by line and created codes for everything, regardless of their relevance to forestry and visual impact assessments. The iterative process ended when no new codes were generated and opinions converged, which happened in the third iteration.

3.3 Findings

To gain an understanding of visual impact assessments, from both the theoretical and practical perspectives, we conducted a review of government documents and carried out a round of qualitative interviews with domain experts.

In this section, we describe the aggregated results of the two data sources. First, we clarify the definition of important parameters used in visual impact assessments. Next, we detail a generic workflow for conducting visual impact assessments by complementing the recommended workflow documented in the government documents with the workflow narrated by the participants during the interviews. Finally, we report additional knowledge that does not fit within the scope of parameters and workflow.

As described in table 3.2, the first and second subsections rely on both government documents and the interviews. The parameters are well defined by the regulations and the information retrieved from the interviews closely corresponds with the government documents. The workflow is less defined by the regulations, with only recommendations provided for the workflow, and uses the interviews as supporting material to fill in the gaps. Finally, the last subsection relies solely on the interviews as it focuses on knowledge that exists outside the government documents.

As we will detail in subsection 3.3.3, the visual impact assessment process is highly subjective. Therefore, some contradictions may occur between interviews or, more

Table 3.2: Data source used in formative study findings.

Subsection	Government documents	Interviews
Parameters	Primary	Secondary
Workflow	Primary	Secondary
Additional knowledge	/	Primary

rarely, between government documents and interviews. If such situations arise, focus is placed on the government documents while still briefly describing the contradictions.

Lastly, to distinguish between the data sources, knowledge gained from the government documents is labeled with [D] and knowledge gained from the interviews with [I]. In the case that both data sources provided similar information, the description is labeled with [DI]. Unless specified otherwise, the content in the rest of the section derived from the government documents comes from the three aforementioned documents in section 3.1.

3.3.1 Parameters

There are two major components required to complete visual impact assessments, *viewpoints* and *visual sensitivity units*, each with their associated parameters [DI]. However, not all parameters are of equal importance– some are involved in the decision-making process behind visual impact assessments and some are used only for record-keeping purposes. Figure 3.1 shows a generalized depiction of the parameters and their structure.

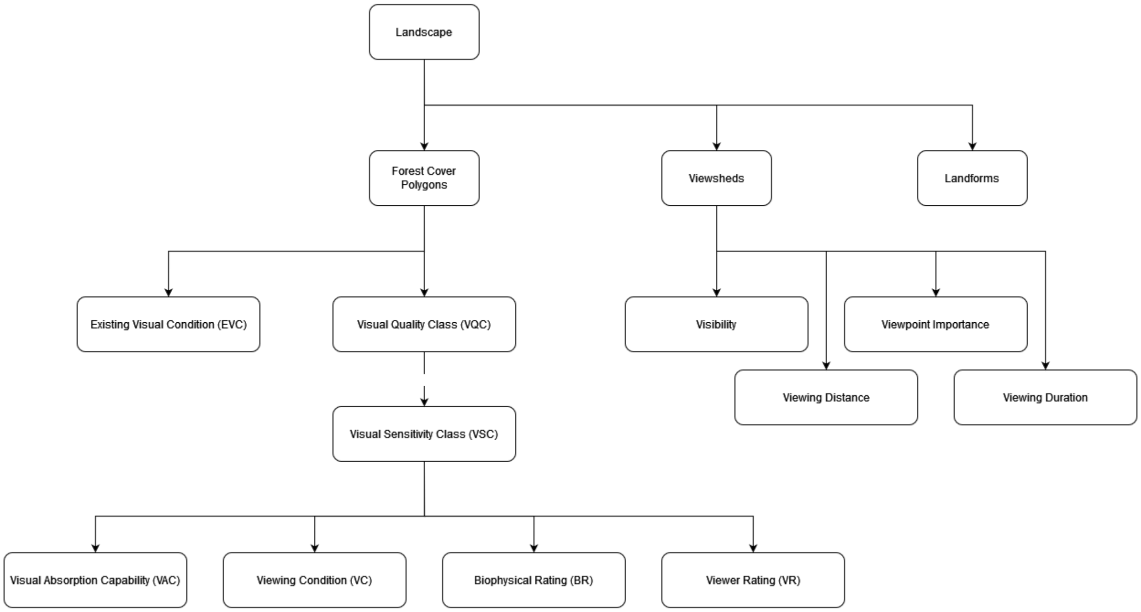


Figure 3.1: A generalized depiction of the parameters and their structure

Viewpoints have a position (latitude and longitude) and an elevation (in meters). They also have the following parameters:

- viewpoint importance,
- viewing duration,
- viewing distance, and
- viewing direction.

Viewpoint importance is the measure of a viewpoint's potential importance to its viewers, which provides a generalized understanding of the viewpoint and takes into consideration information such as the number of viewers, frequency of visits, duration of viewing, etc. [DI]. Viewpoint importance is ordinal data with three levels: major, minor, and potential [D]. For example, a viewpoint at a popular campground may constitute being a high-importance viewpoint as it has both high foot traffic and high viewing duration with stationary views.

Viewpoint duration measures the duration of which the general public can view the target area. It is a useful indicator for understanding how viewers perceive and react to a visual landscape [DI]. Viewpoint duration is ordinal data with three levels: high, moderate, and low [D]. For example, a viewpoint on a highway may have a low viewpoint duration, as viewers are typically moving at high speeds and will not get a quality view of the scenic landscape. However, a viewpoint at a campground will have a high viewpoint duration as viewers will typically gain stationary views of the target area.

Viewing distance and *viewing direction* measure the physical distance and viewing angle of the viewpoint to the scenic landscape. Although viewing distance and viewing direction are quantitative measures, while true for viewing direction, viewing distance is more often recorded as ordinal data with three levels: foreground, middleground, and background [D].

Of the four viewpoint-related parameters, viewpoint importance and viewing duration are independent of the target visual sensitivity unit [DI]. This means that, no matter which visual sensitivity unit is being assessed, the values of the two parameters will remain constant. However, viewing distance and viewing angle are visual sensitivity unit-specific and values are variables based on the visual sensitivity unit being assessed.

Visual sensitivity units, in addition to their position and shape, have parameters that can be broken down into two levels: high-level parameters and low-level parameters [DI]. The high-level parameters are what is used mainly in the process of visual impact assessments, both to guide the decision-making process as well as to complete the visual impact assessment package [DI]. On the contrary, although references to the low-level parameters are not required during the visual impact assessment process, they provide a deeper understanding to a visual sensitivity unit whenever using solely the high-level parameters for decision-making is not enough [DI].

The visual sensitivity units' high-level parameters include the following:

- visual quality objective (VQO),
- existing visual condition (EVC),
- visual quality class (VQC), and
- visual sensitivity class (VSC).

Visual quality objective and *visual quality class* are similar: they describe the level of alteration that would be appropriate for a visual sensitivity unit based on its physical attributes and social concerns and they dictate the maximum amount of alteration a target area can allow [DI]. While visual quality objectives are legally binding objectives and are well defined by regulation and established by the government [14], visual quality classes are recommendations and not legally binding. The two parameters are ordinal data with five levels: preservation, retention, partial retention, modification, and maximum modification [D].

Visual quality objective and *visual quality class* can be determined using two independent methods: quantitative descriptions and qualitative measures [DI]. For example, the regulations define preservation as *"consisting of an altered forest landscape in which the alteration, when assessed from a significant public viewpoint, is very small in scale, and not easily distinguishable from the pre-harvest landscape"* [17]. However, using qualitative descriptions requires professional judgment, introducing subjectivity. As such, the qualitative measures of the two parameters can be used to calculate the rudimentary maximum amount of alteration a visual sensitivity unit allows in the percentage of the total view, following Table 3.3 [18].

Table 3.3: Visual quality objective, visual quality class, and maximum amount of alteration conversion [18].

Visual quality objective & Visual quality class	Maximum amount of alteration
Preservation	0%
Retention	0 - 1.5%
Partial retention	1.5 - 7%
Modification	7 - 18%
Maximum modification	18 - 30%

Existing visual condition measures the current amount of alteration caused by human activities on a visual sensitivity unit [DI]. By calculating the difference between existing visual condition and visual quality objective, foresters are able to derive the maximum size of the alteration they can propose. The parameter is ordinal data with six levels: preserved, retained, partially retained, modified, maximally modified, and excessively modified [D].

Like visual quality objective and visual quality class, existing visual condition can be determined using both qualitative descriptions and quantitative measures [DI]. However, instead of working together, the initial value of existing visual condition is first determined using the percentage within the visual sensitivity unit that is not visually effectively greened-up, following Table 3.4.

Table 3.4: Existing visual condition and existing amount of alteration conversion.

Existing visual condition	Existing amount of alteration
Preserved	0%
Retained	0 - 1.5%
Partial Retained	1.5 - 7%
Modified	7 - 18%
Maximally modified	18 - 30%
Excessively modified	> 30%

The initial value of existing visual condition is then considered with the qualitative descriptions, which act as modifying factors in the override methodology used to determine the final value of existing visual condition [D].

Finally, *visual sensitivity class* measures the sensitivity of a visual sensitivity unit to visual alterations based on both biophysical and viewing characteristics [DI]. The parameter is ordinal data with five levels, usually recorded using numerals from one to five [D]. The lower the value is, the more sensitive a visual sensitivity unit is to human-made visual alterations.

By using visual sensitivity class, a visual sensitivity unit's visual quality class can be calculated, following Table 3.5 [19].

Table 3.5: Visual sensitivity class and Visual quality class conversion [19].

Visual sensitivity class	Visual quality class
1	Preservation - Retention
2	Retention - Partial retention
3	Partial retention - Modification
4	Partial retention - Maximum modification
5	Modification - Maximum modification

However, the conversion between visual sensitivity class and visual quality class is not absolute and the table only generates a default visual quality class. Similar to the above parameters described, professional judgment is required to determine the final visual quality class of a visual sensitivity unit [D].

The visual sensitivity units' low-level parameters are all ordinal data with three levels, usually represented using low, moderate, and high, or using numerals from one to three, respectively [D]. The low-level parameters are as follows:

- visual absorption capability (VAC),
- biophysical rating (BR),
- viewing condition (VC), and
- viewer rating (VR).

Visual absorption capability measures a visual sensitivity unit's ability to absorb alterations caused by human activities based on the area's biophysical characteristics [D].

Biophysical rating, similarly to visual absorption capability, is also derived from a visual sensitivity unit's biophysical characteristics. However, instead of calculating the area's sensitivity to change, it focuses on the visual interest it creates and its attractiveness to viewers [D].

Viewing condition measures how a visual sensitivity unit is most commonly perceived in regards to the "where". The parameter focuses on the viewpoints and takes into consideration the viewpoints from which the visual sensitivity unit is visible and their associated parameters as described above [D].

Viewer rating measures how a visual sensitivity unit is most commonly perceived in regards to the "who". The parameter focuses on the viewers and takes into potential expectations or concerns the viewers may have for how a visual sensitivity unit should look [D].

The four low-level parameters are determined using multiple factors unique in the calculation for each parameter, which is in turn determined using qualitative measures. The initial values of each parameter can also be overridden in the calculation for the final value, similar to the process of generating existing visual condition [D].

The four low-level parameters are used to calculate the visual sensitivity unit's visual sensitivity class (VSC) using the following equation [DI]:

$$(BR + VC + VR) - VAC = Initial\ Value\ of\ VSC$$

As the four low-level parameters have a minimum value of one and a maximum value of three, the results from this equation will have a range of zero to eight. This result is different from the description above for visual sensitivity classes. As such, a simple conversion is required following table 3.6 [D].

Table 3.6: Visual sensitivity class initial value and final value conversion.

Initial value of visual sensitivity class	Final value of visual sensitivity class
8	1
6, 7	2
3, 4, 5	3
1, 2	4
0	5

3.3.2 Workflow

Visual impact assessments can be broken down into the following five-step workflow.

- S1: Gathering information
- S2: Conducting fieldwork
- S3: Developing alteration designs
- S4: Assessing alteration designs
- S5: Completing the visual impact assessment package

The prerequisite of using this five-step workflow is already having an idea of the general location of where the alteration will be proposed. In real-world settings, this is usually the case, as this location is determined beforehand by considering multiple factors, such as economics and social considerations, and is not a decision the foresters conducting the visual impact assessment make [DI].

Participant B summarizes the visual impact assessment workflow as follows: *"The Ministry of Forests puts out some parameters that give you the visual quality objectives for different areas in the province and the new disturbance has to comply with whatever the visual quality objectives are. So the process usually involves getting out in the field,* *to these key observer points [viewpoints] and taking pictures and making notes of the landscape, then modeling, in some way, the cutblock and calculating what the impact of that cutblock is, and whether it could comply with the visual quality objectives that have already set in stone by the government. Once you've done that field part, you also have to look at the existing alterations in the field, so these are existing cutblocks or rocks or things that are altering the landscape, and then add the new cutblock to that alteration and see if you can fit inside the visual quality objective that's being given to you."* Next, we detail each step **(S1–S5)** of the workflow.

First, the foresters gather information **(S1)** about the target visual sensitivity unit and its surrounding area, which will provide knowledge of the target area and guide the following steps within the workflow. This comprises both spatial and visual information, such as maps and associated parameters including the established visual quality objective, existing visual condition, and visual sensitivity class [DI].

Using the spatial information gathered at this stage, the foresters identify locations from which the target area is most visible from, by conducting a view shed analysis using maps or digital elevation models. It is from these locations that significant public viewpoints will be selected and will be used in the remainder of the workflow. The proposed alteration will be assessed from each of the identified significant public viewpoints [DI].

Next, the foresters conduct fieldwork **(S2)** by traveling physically to each of the viewpoints identified during the previous stage to familiarize themselves with the target area. The foresters record the physical attributes of each viewpoint such as position, elevation, and viewing direction and angle to the target visual sensitivity. They also estimate parameters such as viewpoint importance and viewing duration. They take photographs at each viewpoint to document the process and to ensure the accuracy of the assessment [DI].

Then, the foresters develop one or more designs for the alteration **(S3)**. Although design guidelines exist for the design of roads and cutblocks, this stage of the workflow relies strongly on professional judgment. Using each developed design, the foresters then create visual simulations, simulating how the design and scenic view will look from the selected viewpoints [DI]. This can be done using digital tools or with pen, paper, and photographs taken previously. At this stage, foresters delineate the landform they are working on and will be assessed in the visual impact assessment [DI].

After, the foresters assess the developed designs **(S4)** using the created visual simulations to ensure the designs comply with the established visual quality objective or recommended visual quality class. As mentioned above, the two parameters can be determined using both qualitative descriptions and quantitative measures. To use the qualitative descriptions, the foresters evaluate the simulations ocularly and determine the description that fits best with their observations. To use the quantitative measures, the foresters must compute the area of the developed design and existing alterations that are not visually effectively greened-up. To comply with the regulations, the percentage of the sum of the computed area within the scenic landscape must not exceed the maximum percent alteration allowed by the visual quality objective or visual quality class. This calculation must be carried out for each of the identified viewpoints and developed designs [DI]. This stage of the workflow is iterative. If the developed designs are not in compliance with the regulations, the foresters must return to the previous step and develop new design options. As the two methods are independent, it is desirable that the calculations from the two methods are identical and both comply with the regulations. However, in the scenario where the two results are different, the qualitative descriptions should serve as the primary criteria while the qualitative measures provide supporting information [DI].

Finally, to complete the workflow, the foresters complete the visual impact assessment package **(S5)** by filling out the assessment form and attaching supporting images and documents generated during the above steps [D].

3.3.3 Additional Knowledge

In this subsection, we describe the additional knowledge and insights that exist outside the government guidelines and regulations that we have retrieved solely by conducting interviews with domain experts. As there exist multiple parameters associated with viewpoints and visual sensitivity units, it is important to note their individual importance and relationship with one another.

For viewpoints, the parameters include viewpoint importance, viewing duration, viewing distance, and viewing direction. The participants described the four parameters as equally important, as they are all recorded in the completed package. However, participant C pointed out that viewpoint importance may be the primary parameter in regards to gaining insights on a viewpoint and its surrounding area, as viewpoint importance takes into consideration of multiple other information, including viewing duration. This does not include viewing distance and viewing direction, which are specific to the visual sensitivity unit being assessed.

For visual sensitivity units, there are two sets of associated parameters. High-level parameters include visual quality objective, existing visual condition, visual quality class, and visual sensitivity class. Low-level parameters include visual absorption capability, biophysical rating, viewing condition, and viewer rating. The participants described the four high-level parameters as equally important, as they provide the baseline for foresters to understand how much alteration can be placed and how to place the alteration. In addition, visual sensitivity class, visual quality class, and visual quality objective are essentially the same thing and can be converted using one another, with the main difference being visual quality objectives are established by the government. Table 3.7 lists some quotes from the participants regarding the high-level parameters.

Table 3.7: Participant's opinion on the individual importance of high-level visual sensitivity unit parameters

Participant ID	
A	N/A
B	They [the high-level parameters] are all part of the final calculations of the [visual impact assessment], you need to follow them in order to make your decision. It is not one more important than the other.
C	Visual sensitivity class and visual quality class are really the same things. They're related to each other... It's crucial [to know the parameters]. If based on the sensitivity class, you're only allowed to harvest 7%, then you need to know how much, currently, the landform does not have visual green-up (existing visual condition).

Although the low-level parameters are important, as they are used to generate the visual sensitivity class, participants rated their importance to be lower than the high-level parameters. Indeed, while the low-level parameters are useful for fine-tuning the alteration, the final calculations for the visual impact assessment rely on the high-level parameters. In addition, the four low-level parameters are of unequal perceived importance, and this subjective importance varies from forester to forester. For example, if there exist multiple visual sensitivity units with the same high-level parameters that may be potential locations for alterations, the foresters may refer to the low-level parameter of their preference; however, decision-makers are not required to reference the low-level parameters. Table 3.8 lists some quotes from the participants regarding the low-level parameters and table 3.9 lists some quotes from the participants regarding the comparison between the low-level and high-level parameters.

The following relationships between viewpoints and visual sensitivity units were identified and discussed with the domain experts:

- between viewpoints and visual sensitivity units,

Table 3.8: Participant's opinion on the individual importance of low-level visual sensitivity unit parameters

Participant ID	
A	N/A
B	They [the low-level parameters] are all equally important. They have different effects on the final score [of the visual sensitivity class].
C	They're [the low-level parameters] all important. I don't know how to rank them, there are other ecological characteristics of the forest for that matter. They're all pretty equally important... The forester might have a personal preference as to which ones are more important, if, at the high level, all things being equal. Of course, at that point, you might make a decision not so much to do with visibility, I might make a decision based on value and the cost of logs. They'd be taking non-visual parameters into consideration.

- between two or more viewpoints, and
- between two or more visual sensitivity units.

The relationship between viewpoints and visual sensitivity units focuses on visibility. This includes whether a visual sensitivity unit would be visible from a specific viewpoint and visual sensitivity unit-dependent viewpoint parameters such as viewing distance and viewing duration. As visual impact assessments revolve around analyzing the visual impact of alterations on visual sensitivity units from viewpoints, the participants affirmed this is the most important of the three identified relationships. In addition to the conduction of visual impact assessments, visibility is also an essential part of the preprocess, as the delineation of visual sensitivity units from landscapes relies strongly on the viewshed analysis from surrounding viewpoints. Table 3.10 lists some quotes from the participants describing the relationship between a viewpoint and a visual sensitivity unit.

Next is the relationship between two or more viewpoints. This focuses on visibility as well and examines the visibility of each viewpoint and attempts to identify overlapping areas. It focuses on knowing which viewpoints can see, or not see, selected

Table 3.9: Participant's opinion on the comparison of the importance of high-level and low-level visual sensitivity unit parameters

Participant ID	
A	N/A
B	The higher-level parameters are calculated based on the lower-level parameters, so I really need all of them in order to come up with my conclusion. But if I were a forest manager, I probably would not care too much about the lower-level parameters. If they [the forest managers] trust the process that was driving these calculations to arrive at these numbers then probably they would not need to see that.
C	The higher-level is what you want to work with because it integrates all the information, but the lower-level ones are the ones that create the higher-level parameters.

visual sensitivity units. The participants stated this relationship is important as well, though not as crucial as the first. It is important as, often, foresters are required to complete multiple visual impact assessments if multiple significant public viewpoints are identified. Participant A also stated it may be important to identify viewpoints within the same community. For example, viewers traveling on a highway are highly likely to view the scenic landscape from its destination as well. However, this information is not presented in the viewpoint-associated parameters. Table 3.11 lists some quotes from the participants regarding the relationship between two or more viewpoints.

Finally is the relationship between two or more visual sensitivity units. This is also related to visibility and looks at understanding which visual sensitivity units are visible, or invisible, from a target viewpoint. However, it extends from visibility and attempts to identify visual sensitivity units, within the view from a viewpoint, that consists of similar high- or low-level parameters such as visual sensitivity class or visual absorption capability. One participant considers this relationship to be important stating existing alterations within a view should be placed into consideration as well when conducting visual impact assessments. Another participant considers it to

Table 3.10: Participant's opinion on the importance of the relationship between a viewpoint and a visual sensitivity unit

Participant ID	
A	It comes down to what I was talking earlier about, the fact that when you're in a cutblock, like trees around, depending on how tall they are, they can have an impact on what you can see from the viewpoint. But also, it has an impact on... so depending on which stage is your forest cover and your polygon, like if it's regeneration or like much older, like, it has an impact on the visual quality or impact assessment.
B	Most of the visual impact assessments that we're doing are actually viewshed analysis, or visibility analysis. You need these [parameters related to visual sensitivity units and viewpoints] in the first place to calculate the visual quality polygons.
C	That's the whole thing. If it's not visible, then there's no point in doing visual quality analysis. In terms of the visual quality analysis, if there's no viewpoint then there's no visual quality analysis to do.

be unimportant while emphasizing, again, the importance of viewpoint - visual sensitivity unit relationship. Table 3.12 lists some quotes from the participants regarding the relationship between two or more visual sensitivity units.

Participant C stated that the importance of the relationship depends on the scenario. If the two visual sensitivity units share similar parameters while existing on the same landform, they should be combined. If the visual sensitivity units exist on separate landforms and are not visible from the same viewpoint, then the relationship is not important. On the other hand, if the visual sensitivity units exist on separate landforms but are visible from the same viewpoint, then the relationship may potentially be important, though the foresters should still calculate the visual quality of the visual sensitivity units separately.

In conclusion, visual impact assessments are an inherently subjective process. It is not data-driven and often relies on professional judgment and the forester's interpretation of the regulations and scenic view. In addition to the subjectiveness described in the parameters and the workflow such as how the parameters are determined and how

Table 3.11: Participant's opinion on the importance of the relationship between two or more viewpoints

Participant ID	
A	The relationship is important to see if it's part of the same community or if it's the same people who go to those places. Basically, it's the same thing as a cutblock, right? You don't want them to be too close to each other. If they're too close I guess it makes them more important, you need to be more careful around that and what they can see.
B	When we conduct these assessments, we might conduct them from multiple viewpoints. Usually, it is from one that we deem as the most important, but sometimes there is a couple. So, that is kind of important to know that I have two viewpoints that I am going to possibly have to conduct two assessments from these two viewpoints.
C	N/A

the landforms are delineated, participants also provided some scenarios as examples.

For visual sensitivity units that are visible from multiple viewpoints, the process of selecting significant public viewpoints is not well-defined. Participant A stated *"Well, we're not looking to see if there could be a viewpoint, or an interesting viewpoint. We just consider what is already existent. So that kind of reduces the opportunity in the future but, also, we can't account for everything."* Participant B stated *"Viewpoints are given to them [foresters] and so they'll have to choose the key observer points [significant public viewpoints] that fit best with the location of the cutblock."* Participant C stated *"The thing is, what's a viewpoint... I was given these crucial viewpoints that have already been decided. Part of me wondered, what makes an important viewpoint. Some of them were pretty obvious, some of them [were not]... If you're walking through [location], there are a few viewpoints, there's a lot of areas in between the viewpoints through the forest is visible from, but they weren't given a viewpoint... There's definitely subjectivity in choosing what the viewpoints are."*

Another challenge occurs when multiple assessments of the same visual sensitivity unit have been conducted from different viewpoints and the results from these

Table 3.12: Participant's opinion on the importance of the relationship between two or more visual sensitivity units

Participant ID	
A	That's a really important one because... so if you have one viewpoint that has multiple polygons that are being planned to be cut, well, you want to be careful with that because if they're overlapping during a time, and if it's, like, more than fifty percent of your visual, it's not okay... So you want to make sure you're not overloading the landscape or the visual with too many clear cuts. So, it's really important to see the relationship between the polygons that you're planning because you don't want to... again, it's related to the spatial distribution of your cutblocks in the landscape. You don't want them to be too closed, I guess.
B	That really does not matter. What matters from that viewpoint is where your cutblock is. So your cutblock is in polygon B or polygon A, and your viewpoint is at Loon Lake, I really do not care about the polygon, I care about my landform, the visual quality objectives of my landform where my cutblock is going to go.
C	N/A

assessments are different. For example, if one assessment from viewpoint A passes and another assessment from viewpoint B fails then the established visual quality objective is not defined and the decision rests heavily on the forest manager using professional judgment. Participant B stated *"That is up to the forest manager to decide. For example, I have a park that has 200 thousand people coming a year and another viewpoint that is just a dock, where maybe a boat or two a day will come. So there is a big difference between the importance of these two viewpoints. I might decide I am going to conduct an analysis from the dock as well but it is not going to be as important as the big park that has 200 thousand people. I might decide it is important, but it is really up to the forest manager to make these decisions."*

Apart from the subjectivity within the workflow that causes differences across foresters, there are also differences caused by outside factors, such as the location of the land and the type of land being assessed. The regulations around visual impact assessments are different across the country and determined by the provincial government. Participant A stated multiple times descriptions such as *"I don't know for sure in BC, but in Quebec..."* or *"I'm not sure if they're doing this in BC..."* The regulations surrounding public land and private land within BC are also different and only apply to public land. Foresters conducting visual impact assessments on public land are generally under closer scrutiny while foresters conducting visual impact assessments on private land are able to add and remove steps to the process, develop new methods, and their own specific processes. Visual sensitivity units within private land also do not have government-established visual quality objectives, with only a few exceptions. Participant B stated *"We're doing a bit differently here [in private land]." Participant C stated "The vast majority of the research forest is privately owned by [institution] and does not have provincial classes [objectives]."*

Finally, decisions may be made based on considerations such as value and cost instead of visual impact. Visual impact assessments are not necessarily the main criteria used in choosing where to place an alteration, although it is useful for fine-tuning. Table 3.13 lists some quotes from the participants regarding other considerations that may be important.

Table 3.13: Participant's opinion on other considerations when designing alterations

Participant ID	
A	I guess the visual impact assessment is also a part of trying to spatially organize the cutblocks, right? So it's depending on the treatment or the way your forests are organized in your province.
B	The visual impact assessment is not necessarily the main criterion that is used in choosing where to put the cutblock. It may be a criterion that we use to change the shape of the cutblock, perhaps move it slightly back and forth, but usually, there are other criteria that we use in choosing a cutblock, that pertain more to forest management and to type of treatment that we want to do in there and silvicultural things, but the visual quality will allow us to fine-tune this.
C	Visual quality is only one criterion, right? There's also wildlife habitat and all sorts of other things. At that point, you might make a decision not so much to do with visibility, I might make a decision based on value and the cost of logs. I'd be taking non-visual parameters into consideration to decide.

Chapter 4

Design and Implementation

Evergreen is a visualization system made with Unity [82] that presents data in a 3D environment which aims at assisting foresters in conducting and completing visual impact assessments. In this chapter, we describe the process of how Evergreen was designed and implemented.

First, we established a list of design requirements based on the results described in section 3.3. Then, we describe the data that was available for the design of Evergreen, the format it was in, and how it was processed. Next, we describe the prototyping process we went through and present some prototypes that influenced the final design. Finally, we describe the implementation of Evergreen.

The rest of the thesis will focus on the human-computer interaction and visualization aspect of the research. To account for the focus shift, we will refer to visual sensitivity units as polygons from now on, as this better fits the visual metaphor within Evergreen.

4.1 Design and Task Requirements

Following the task-centered system design methodology, it is crucial to identify tasks that the system will be used to accomplish. The tasks should be from real-world scenarios and from people who will be using the system in order to ensure the usability of the system [43].

Due to the complexity of the visual impact assessment process, it is unrealistic to design Evergreen to support the entirety of the process. Using the five-step workflow described in section 3.3, we determined which portions of the process to support with Evergreen with both feasibility and effectiveness from a visualization perspective as criteria. The following is a reminder of the five-step workflow:

- S1: Gathering information
- S2: Conducting fieldwork
- S3: Developing alteration designs
- S4: Assessing alteration designs
- S5: Completing the visual impact assessment package

Of the five steps, S1 has the most potential of being supported in a visualization system, and S4 and S5 could be supported. Information visualization looks at representing data visually so that it can be better understood by the users. S1 focuses on obtaining the various parameters of visual sensitivity units and viewpoints which is a suitable task to be supported. S4 focuses on comparing two of the parameters, which is a suitable task to be supported as well. However, S4 relies on the forester's design of the alteration, which lowers the task's priority for support. Finally, S5 focuses on completing the visual impact assessment package, which involves retrieving data and filling in the form, making it a suitable task as well.

On the contrary, S2 and S3 are less focused on viewing or understanding data. S2 focuses on the fieldwork in which foresters are required to physically be in the selected visual sensitivity unit or viewpoint. S3 involves designing the modification, which relies strongly on professional knowledge and is subjective, as the design guidelines do not result in set results. S4, as mentioned above, although involves comparing two parameters, is a less suitable task due to it being reliant on the alteration design.

Due to the above reasons, we decided to focus on only some specific steps of the workflow to limit the scope of this research. These are also steps that seem very well-suited and can benefit from integration with visualization, so we started with this most promising direction. Evergreen fully supports S1, partially supports S4 and S5, and does not support S2 and S3. In addition, to take advantage of the benefits information visualization provides for decision-making, Evergreen supports the pre-visual impact assessment phase as well, where the focus is placed on discovery and exploring potential polygons and viewpoints suitable for additional alterations.

Table 4.1: Level of support provided by Evergreen in reference to the five-step workflow

	Pre-Phase	S1	S2	S3	S4	S5
Level of support	Full	Full	None	None	Partial	Partial

The following are the task that were derived from the aggregated findings described in section 3.3. If contradictions occur between the two data sources used in the analysis, priority is given to the interviews in the case the resulting task remain compliant with the legislation and regulations and to the government documents if otherwise.

- R1: The user should be able to see which parts of the terrain can have additional modifications within the province's guidelines in terms of visual quality.

- R2: The user should be able to see polygons and attributes associated with them.
- R3: The user should be able to see viewpoints and attributes associated with it.
- R4: The user should be able to see the relationship between polygons and viewpoints.
- R5: The user should be able to see the relationship between polygons.
- R6: The user should be able to see the relationship between viewpoints.
- R7: The user should be able to view the target polygon and its surrounding area in a first-person view.

Of the seven tasks, R1 has the topmost priority because it ensures users can gain an understanding of the general status of the land. This task is useful for both the pre-visual impact assessment phase and S4. Foresters can swiftly examine which parts of the land can have additional modifications and which parts to avoid. By supporting this task, Evergreen allows the foresters to focus solely on areas that are important.

This task also partially supports S4, which is to ensure the proposed modification complies with the established visual quality objective. R1 provides the comparison of the established visual quality objective and the existing visual condition with no regard for the proposed design. By doing so, although it does not provide a strict compliance check, it provides information on how much more alteration an area is able to receive in percentage and is sufficient to provide some guidance to the foresters in terms of compliance with the regulations.

R2 and R3 are very similar tasks, with the difference being the focus on the two major components of visual impact assessments, polygons and viewpoints. For R2, parameters include the position and shape of polygons as well as the related parameters, both high-level and low-level. The focus of R2 is placed on visualizing the high-level parameters, as the high-level parameters are what is needed to complete the visual impact assessment. However, R2 requires visualizing each individual parameter for both the high-level and low-level parameters, as the importance of the parameters is subjective and different for each forester conducting the visual impact assessment.

For R3, parameters include the position of the viewpoints and viewpoint importance. R3 is simpler in terms of complexity compared to R2 due to the viewpoint-related parameters having only one layer as opposed to two, the high-level parameters and the low-level parameters. In addition, although there are multiple parameters associated with viewpoints, such as viewing duration and viewpoint distance, only two are specific to each viewpoint, viewpoint importance and viewing duration. Of the two parameters, viewpoint importance is considered to be of higher priority to visualize, as it already encodes information such as viewing duration and viewing frequency. As such, R3 requires visualizing only viewpoint importance to avoid cluttering the display with redundant information.

R2 and R3 are derived from the pre-visual impact assessment phase, S1, and S5. Having these data is important in the decision-making phase. For polygons, it is crucial to have the high-level parameters as it informs the foresters where to place the modification and how much modification is allowed. Less important, are the low-level parameters, which are important when a deeper understanding of the area is required, in the case, for example, that multiple modification-suitable areas exist. For viewpoints, it provides guidance to the foresters when selecting the key observer point from which the visual impact assessment will be conducted.

R4 focuses on the relationship between polygons and viewpoints, or more specifically, on the visibility of polygons from viewpoints. Similar to R3, this is so that the foresters can effectively select the key observer point and is derived from the pre-visual impact assessment phase, S1, and S5.

R5 and R6 focus on the relationship between polygons and viewpoints, respectively. Although, from the results of the formative study in section 3.3.3, the priority of R5 and R6 is lower than the other tasks. Moreover, R5 and R6 will focus primarily on visualizing the two relationships in regard to visibility, such as which polygons are visible from a specific viewpoint. Knowledge and requirements in relation to forestry will not be supported, such as combining polygons due to their similarity in associated parameters as participant C described. This decision is made because the focus of Evergreen should be placed on visualization instead of forestry and is out of the scope of a visualization system. In addition, tools that complete these tasks already exist and rely on professional forestry knowledge, as it is a subjective process. R5 and R6 are derived from the pre-visual impact assessment phase and S1.

Finally, the user should be able to view the target polygon and its surrounding area from selected viewpoints from a first-person perspective as if the user is physically there. This is so that the foresters can verify their decision from the pre-visual impact assessment phase before actually conducting fieldwork, which conserves resources that may have been potentially wasted during the fieldwork phase. As mentioned in subsection 3.3.3, this task does not look to replace the actual fieldwork, as it is still crucial for foresters to gain a detailed understanding of the proposed area.

Although not explicitly listed in the above requirements, general usability guidelines were considered as well in the design process. The system should be easy to learn, easy to use, and should provide a clear and concise overview while providing details on demand.

Table 4.2: Origin of the tasks in reference to the five-step workflow.

	Pre Phase	S1	S2	S3	S4	S5
R1		▨	▨	▨		▨
R2			▨	▨	▨	
R3			▨	▨	▨	
R4			▨	▨	▨	
R5			▨	▨	▨	▨
R6			▨	▨	▨	▨
R7			▨	▨	▨	▨

4.2 Data

In order to fully support the design and task requirements listed in section 4.1, the following data is required.

- Terrain data
- polygon data
- Viewpoint data

4.2.1 Data Sources

We obtained the terrain data from LlamaZOO Interactive Inc., a tech company located in British Columbia that specializes in visualizing geospatial, engineering, and IIOT data.

For the forestry-related data of polygons and viewpoints, there are two potential data sources: the British Columbia government or Malcolm Knapp Research Forest, situated in BC. The data from the two sources are all publicly available data and are suitable for the purpose of this thesis.

The British Columbia government publishes and provides open access to a wide range of data resources through the BC Data Catalogue [15], including various forestry data. The available forestry data covers almost all of the province, however, the quality of the data is low, with over-generalized polygons and missing data attributes in random locations. In addition, the data does not include some of the needed low-level parameters such as biophysical ratings and viewing conditions.

In comparison, the data provided by the research collaborator originates from a research forest in British Columbia, Malcolm Knapp Research Forest. Although limited in terms of coverage, covering only the research forest itself and slightly extending outside the boundaries of the forest, it is detailed in terms of the quality of the derived polygons, viewpoints, and their associated parameters. In addition, the data can be verified with the research collaborator whereas this is not possible with the government-provided data.

For the purpose of this thesis, we opted to use the research collaborator-provided data. The limited coverage of the data is an insignificant factor for consideration that fits the scope of this thesis as, at this stage, we are only looking at how information visualization techniques may assist foresters instead of a complete product. However, the main drawback of using the research collaborator-provided data lies in the scalability of the design and how Evergreen can be expanded to support the entirety of British Columbia in future works.

4.2.2 Data Attributes

The terrain used in Evergreen is a proprietary three-dimensional model of a 6x6 km target area that was packaged inside a Unity project. It includes the base model that contains information such as height, slope, and textures – which add coloration and finer details to the terrain. It does not include information such as soil-, water-, and vegetation-related.

Both viewpoint and polygon data are obtained in the format of a shapefile. Shapefiles are a commonly used format to store geometric information and the associated attributes of geographic features. In shapefiles, geometric information is saved as vector data and represented using three basic spatial elements: points, lines, and polygons. This enables shapefiles to describe features with up to two dimensions.

The *polygon data* used in Evergreen contains all polygons inside the target area and includes data such as the id, position, and shape of the units along with their high and low-level parameters. The geometric information held in the data is represented using vector polygons.

Polygons have the three following ordinal high-level parameters:

- Visual sensitivity class: Integer number $[1, 2, 3, 4, 5, 6, 7, 8]$.
- Visual quality class: String object [’preserved’, ’retained’, ’partially retained’, ’modified’, ’maximally modified’, ’excessively modified′].
- Existing visual condition: String object [’preserved’, ’retained’, ’partially retained’, ’modified’, ’maximally modified’, ’excessively modified′].

Polygons also have the four following ordinal low-level parameters:

- visual absorption capability: Integer number $[1, 2, 3]$.
- biophysical rating: Integer number $[1, 2, 3]$.
- viewing condition: Integer number $[1, 2, 3]$.
- viewer rating: Integer number $[1, 2, 3]$.

The viewpoint data does not include all viewpoints in the research forest’s database. It contains only viewpoints used in a previous visual impact assessment conducted in-house for research. The geometric information held in the data is represented using vector points. The data includes the id and position of the viewpoints and their importance. In the data, viewpoint importance is ordinal with three possible values $[1, 2, 3]$.

4.2.3 Data Processing

As Evergreen is implemented using Unity, some conversion and processing are required so that the data can be understood and loaded into the game engine.

For the terrain data, the processing procedures are simple. As the terrain data is already packaged in a Unity project, we utilized the asset exporter that comes with Unity. This generates a package that includes the terrain model and all of its associated settings which we can then import into Unity projects of my choosing, or, in this case, into Evergreen.

However, processing the polygon and viewpoint data is a much more complex process. The data can be broken down into two parts, one that holds the geometric information, such as the position, size, and shape of the objects, and one that holds the forestry-related parameters. In order for Unity to understand the geometric aspect of the data, it must first be converted into meshes, or triangles and vertices, that can be used to display graphics.

To achieve this, we used a proprietary in-house Unity asset from a research collaborator. This tool accepts geojson files, which is another commonly used spatial data format similar to shapefiles, and is able to convert spatial data into game objects in Unity and place them into the correct position in the 3D environment using their real-world coordinates. The tool is able to convert polygon vectors into game objects with meshes of their shape and point vectors into game objects with cube meshes. In the case of point vectors, the cube meshes are used as placeholders and can be modified or removed. However, the tool is unable to convert line vectors, as line vectors have no thickness and cannot be represented using meshes.

As the tool does not support shapefiles, we must first complete the shapefile to geojson conversion for the data at hand. In addition, for the polygons, two meshes are required for each unit, one for the actual polygon and one for its boundaries. As the tool is unable to generate meshes for line vectors, the boundary mesh will need to be represented as polygon vectors as opposed to line vectors. The boundary meshes will be used as outlines in the visualization later on.

To complete these geospatial data manipulations, we used QGIS [3], a geographic information system application that focuses on viewing and editing geospatial data such as these. Using QGIS, it is a simple process to convert shapefiles to geojson files without any additional manipulation and can be done by loading the data into QGIS and save as geojson. This is sufficient to create the files needed to generate the data for the polygons' polygons and the viewpoints. However, in order to create the files for the polygon' boundaries, additional steps are required. First, the units need to be duplicated and extended outwards. Then the difference between the duplicated units and the original units needs to be computed, with the results being polygon vectors of the boundaries of the units. QGIS comes with several processing tools, including the buffer and difference tool, which are used to complete the aforementioned process. As the boundaries created using this process are thin meshes with thickness in actuality, to ensure these boundaries resemble outlines in Evergreen, we set the thickness to one centimeter in real-world scale.

In addition to the files that will be used to generate the meshes, we also used QGIS to create a geojson file containing the point vectors of each polygon. This data will be used by Evergreen in order for it to manipulate the visualization based on the computed position of the polygons instead of relying on the bounds of the meshes, which is significantly more inaccurate. QGIS comes with several tools that convert polygon vectors to point vectors, of which the two most commonly used are the centroid tool and the point-on-surface tool. Although the two tools aim at solving the same problem, they are implemented using different algorithms. While the point-on-surface tool is more computationally expensive, it ensures the generated points are within the bounds of the polygon vectors. Due to this characteristic, we opted to use the point-on-surface tool, as the longer computation time does not affect the runtime of Evergreen and by ensuring the points are within the polygons, the visualization Evergreen generates will be more accurate in terms of position.

Finally, the associated attributes, or, in this case, the forestry-related parameters, included in the data are cleaned and then attached to the geojson files containing the point vectors for both the polygons and the viewpoints. We removed attributes that are not used in Evergreen and renamed several columns to match Unity's naming convention. As all the forestry-related parameters ordinal data, we also converted the non-integer parameters such as visual quality class and existing visual condition into integers using their respective orders, which allows for easier data manipulation and consistent data operation with other parameters in Unity. To load the data into Unity, we utilized the JsonUtility library that is built into Unity and saved the parameters as global variables that can be accessed at runtime.

4.3 Evergreen

To guide the design and implementation of Evergreen, we conducted a prototyping phase in which design ideas were generated based on the established design and task requirements and the knowledge of the available data [34]. Comprehensive details of the prototyping process and rationale for the methods we employed can be found in appendix A.1.

In this section, we describe Evergreen by breaking it down into the following subsystems:

- Visualization components
- Non-visualization components

- Base system

To introduce each subsystem, we elaborate on each component, including their visual encodings and integrated interactions, the design rationale, and real-world applications that use a similar arrangement.

In the field of information visualization, encoding is the act of transforming data into graphical representations and visual encodings are the visual marks and channels used to complete the encoding [10]. For example, visual encodings used within a pie chart, a commonly used visualization, includes angle and color hue, which encode value and category, respectively. Other common visual encodings include position, length, area, etc.

Interaction techniques used by the components will be broken down and introduced using the taxonomy of interaction techniques proposed by Yi et al. [99], which breaks down interaction techniques into the following seven general categories according to the user's intent when using the interactions and the system.

- Select (mark something as interesting)
- Explore (show me something else)
- Reconfigure (show me a different arrangement)
- Encode (show me a different representation)
- Abstract/Elaborate (show me more or less detail)
- Filter (show me something conditionally)
- Connect (show me related items)

At the end of the section, we provide an overview of Evergreen using the previously introduced knowledge and break down the system using the visual information-seeking mantra. We also provide suggestions for the workflow and how Evergreen may be used to complete the tasks identified in section 4.1.

4.3.1 Visualization Components

Visualization components within Evergreen are defined to be components that convey forestry and visual impact assessment-related data. These components include the following:

- the viewpoints
- the polygons
- the bars that visualize polygon-associated parameters
- the links that visualizes the relationship between viewpoints and polygons

Visual Encodings

There are two major components within visual impact assessments, the viewpoints and the polygons, with additional information branching out from the components such as the associated parameters. Evergreen includes visual metaphors following this structure.

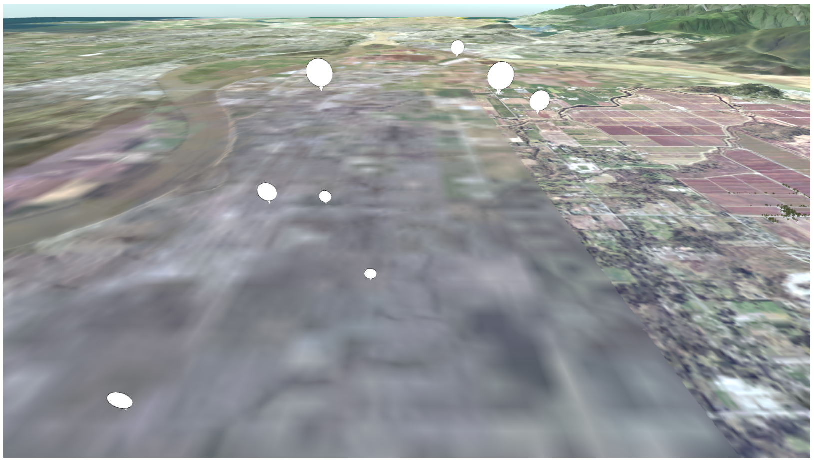


Figure 4.1: Viewpoints within Evergreen. Viewpoint size represents viewpoint importance.

Viewpoints (Figure 4.1) within Evergreen are represented by a white 3D model of pinpoints placed on the terrain at their respective real-world position. The practice of using pinpoints to represent the user's points of interest, whether in a 2D or 3D environment, is well established in existing tools. For example, Google Maps uses pinpoints to visualize locations that may be of the user's interest, such as restaurants, stores, and parks nearby.

To represent locations that are of the user's interest, such as locations the user actively searched for or clicked on, Google Maps uses a larger and more prominently colored pinpoint. Following a similar concept, Evergreen encodes viewpoint importance into the 3D models using 1D size, or length, of the model's radius across the x-axis and z-axis. The radius is multiplied by a set constant in accordance with the viewpoint's importance and, the higher the viewpoint importance, the larger the 3D model of the viewpoint will seem.

As the viewpoint is visualized using a 3D model and is placed in a 3D environment, one could consider using 2D size, area, or 3D size, volume, as the visual encoding for viewpoint importance. However, research suggests 1D size is both more expressive and effective at encoding ordinal data such as viewpoint importance [49], making it more accurate to decode for the users. 1D size is also easier for the user to create an estimation for, as human perception often underestimates areas and largely underestimates volumes while perfectly estimating length [27, 80].

Finally, Evergreen attempts to simulate the viewpoints, which are inherently 3D models, as 2D icons within the 3D environment. This is because pinpoints are often depicted as user interface elements for systems in both 2D and 3D environments. To achieve this effect, the viewpoints are programmed to be constant in size, disregarding their distance from the user, and will always face toward the user. To ensure readability, in Evergreen, the viewpoints are placed on top of the terrain with a height offset of fifty Unity units, which converts to fifty real-world meters.

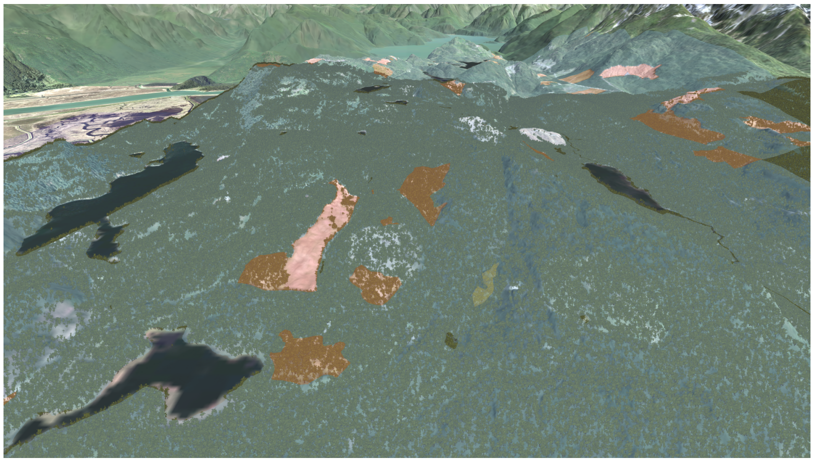


Figure 4.2: Polygons within Evergreen. Polygon color hue represents whether additional modifications can be placed on that polygon.

Next, polygons (Figure 4.2) are represented as color overlays in corresponding shapes placed on the terrain at their respective real-world position. This approach is commonly used in 2D and 3D environments, for example, ArcGIS allows the user to overlay colors onto a 2D map and provides controls to the user to modify the overlay's color hue and opacity.

In Evergreen, the overlays encode whether additional modifications can be placed on the targeted polygon in terms of visual quality. This is determined by comparing the polygon's existing visual condition and visual quality objective or visual quality class. As there are only three possible outcomes (additional modification can be added, can maybe be added, or can not be added), this is considered to be nominal data, which is suitable to be encoded using color hue.

ColorBrewer [20] was used to generate a color scheme consisting of three data classes for diverging data. A color scheme similar to traffic lights, consisting of green, yellow, and red, was selected, due to its semantic resonance and similarity in terms of concept with the data. For example, a polygon overlaid with red would mean additional modifications can not be placed there, similar to the red traffic light meaning "stop". To improve color blindness accessibility, color blindness simulations were conducted on the selected colors and slight modifications were done to ensure people affected by protanopia, deuteranopia, or tritanopia could still identify the colors differently.

As the terrain includes a variety of features, such as areas with dense trees and areas where the terrain is bare, the colored overlays are placed not just on the terrain but also on additional features on top of the topography. This includes both the texture of the terrain as well as trees within the polygons. This ensures the uniformity of the polygons and guarantees the overall look is consistent regardless of the area's biophysical characteristics. For example, without a color overlay on the topmost layer, the terrain would look drastically different depending on the amount of plantation and the overlay would look less apparent in areas with dense trees, as the trees would overwrite the overlays visually.

However, it is also crucial that the color overlays do not completely conceal the features on top of the terrain as it should still be readable to the users to convey the information it represents. Research suggests the acceptable opacity for color overlays within 3D photo-realistic environments to range from 20% to 70% for the users [33]. As such, the polygons use a fill pattern set at 30% opacity, which is approximately the lowest acceptable opacity that is preferred by the users. Although the addition of outlines outside the overlays may further decrease the acceptable opacity by 5% [33], the polygons do not include outlines by default, due to hardware restrictions, and are only enabled using interactions and will be further elaborated later in this section.

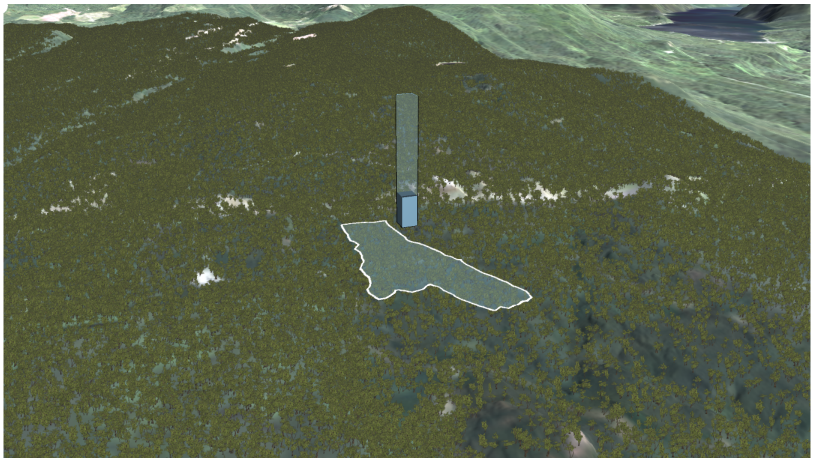


Figure 4.3: A high-level bar within Evergreen depicting visual quality objective.

To represent the 5 parameters of each polygon (visual quality objective, visual absorption capability, biophysical rating, viewer rating, and viewing condition), an additional visual metaphor relying on three-dimensional bars was created. Bar graphs have been used for hundreds of years, dating as far back as the 1800s after making an appearance in William Playfair's work, Commercial and Political Atlas [79]. Its place as a commonly used visualization and statistical tool has been well established and, in British Columbia, bar graphs are included in the math curriculum for students in grades K-9 [16].

The bars (Figure 4.3) implemented in Evergreen consist of two overlapping rectangular prisms, a smaller opaque one and a larger transparent one. The opaque rectangular prism shows the value of a parameter while the transparent rectangular prism visualizes the maximum value the parameter may have. Similar to the polygons, the transparent rectangular prisms are set to be 30% opacity, which was determined through discussions and tests with members of the research team.

As the polygon-associated parameters can be broken down into two levels, the bars follow a similar structure as well. At the high level, as only one parameter is visualized, only one bar is shown above the center of the polygon, with a height offset of a hundred Unity units. The single bar uses color hue similar to the polygons, encoding whether additional modifications can be added to the target area.

However, to visualize the four low-level parameters, a different approach is required. The created visual metaphor must also insinuate the relationship between the visual quality objective and the four low-level parameters, in which visual sensitivity class equals the sum of biophysical rating, viewer rating, and viewing condition subtracted by visual absorption capability. To achieve this, an approach taking inspiration from both stacked bar charts and layered bar charts is adapted. Stacked bar charts are used to visualize multiple attributes of data and present the sum of the data attributes while showing the contribution and distribution of each data attribute to the overall total [81]. To insinuate the ”add” concept of the attributes, bars are stacked on top of one another within stacked bar charts. This is useful as there are multiple low-level parameters and the sum of the low-level parameters calculates to the high-level parameter. However, as visual absorption capability is subtracted from the equation, a stacked bar chart can not be directly applied to Evergreen. Similar to stacked bar charts, layered bar charts also visualize multiple attributes. However, the emphasis of layered bar charts is placed on the distribution of values in each data attribute across all data cases and comparison within the same data attributes, which can not be easily done with stacked bar charts as there is no common baseline for each data attribute [81]. This is done by placing each bar side by side horizontally and providing the same starting height vertically.

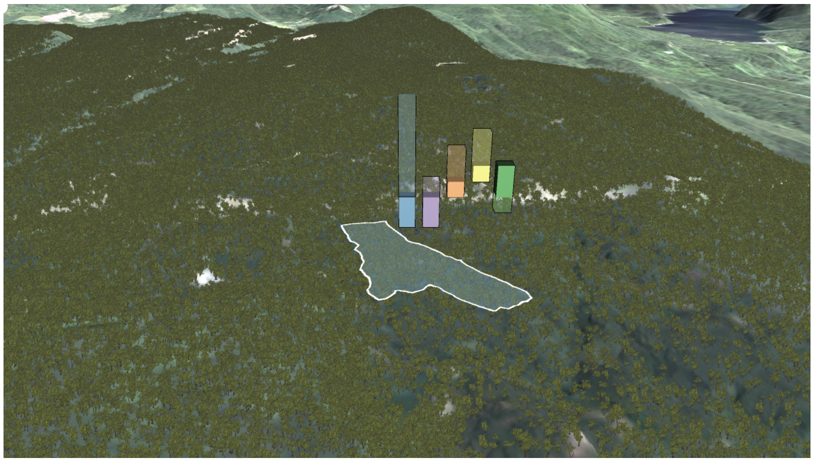


Figure 4.4: A low-level bar within Evergreen depicting visual quality objective and the remaining parameters.

In Evergreen, this is implemented using four bars (Figure 4.4), one for each of the four low-level parameters, placed side by side horizontally. The first bar is placed at the base height of the larger bar and each adjacent bar is placed at the height of the previous bar's opaque portion vertically. Apart from visual absorption capability, which is subtracted from the equation, the bars are set to be upright, to simulate an "added" sentiment. The bar representing visual absorption capability is inverted, with the opaque portion at the top. This approach retains the benefits of stacked bar charts and users are able to understand how the visual sensitivity class is formulated and the distribution of the low-level parameters. However, as the common baseline is removed, the bars do not retain the benefits of layered bar charts and users can not easily compare the value of the low-level parameters across polygons easily. By default, the four bars are hidden and can be shown via interaction. Color hue differentiates the four bars. Although reusing visual encodings (color hue is used both for polygons and for bars) may cause confusion for the user when reading the visualization, this drawback is acceptable as color hue is one of the most effective visual encodings for categorical data. In addition, as the initial state of the four bars is hidden, the user is less likely to be confused by the reused visual encoding.

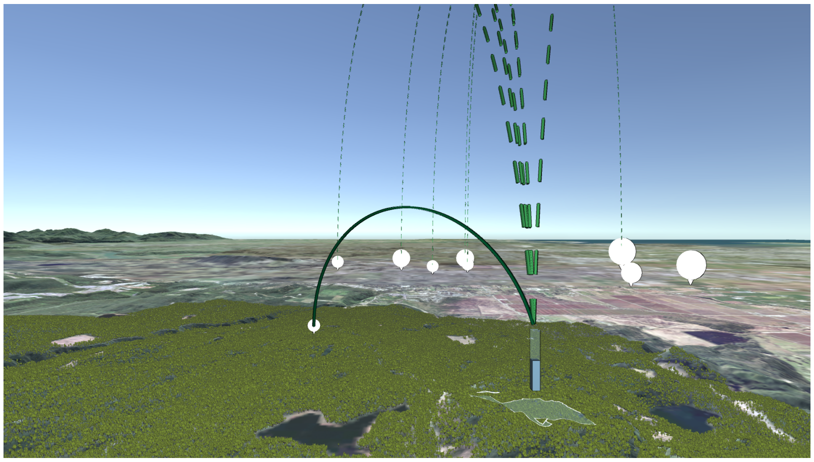


Figure 4.5: Links within Evergreen depicting the relationship of a polygon and viewpoints.

Finally, links (Figure 4.5) show the relationship between viewpoints and polygons in regard to visibility. This is a common approach for representing the relationship between two entities within a network, which may include relationships, interactions, communications, kinship, and so on [93]. For example, Zachery created a graphical representation of the social relationships of individuals in a karate club in which links are used to represent interactions between individuals [100].

In Evergreen, the links are placed on top of viewpoints and at the center of polygons with a height offset of fifty Unity units, or, if the bars are in the view, on top of the bars, which are also shown in the center of the polygons. If a link exists, it means that at least some part of the polygon is visible from the viewpoint. To differentiate between different degrees of visibility, Evergreen breaks down the relationship into three categories, low visibility, medium visibility, and high visibility, ranging linearly from 10% to 40% visible, 40% to 70% visible, and 70% to fully visible, respectively.

Visibility relationships below 10% are discarded, as from section 3.3, participants described errors that are generated by the processing software may result in low visibility ”strands” of land. In addition, viewpoints from which only a small portion of the target polygon can be seen are often not of interest to the forester for the purpose of conducting visual impact assessments. Although during the preliminary study, concepts of low, medium, and high visibility did appear in both the government documents and the interviews, these documents did not strictly define how the three categories are classified. The range used by Evergreen was not derived from the literature and was decided through a linear equation.

To encode the three categories of visibility, both color value and spatial frequency are used. For color value, the links are displayed in light green, green, and dark green if the visibility is low, medium, and high, respectively. Research in color psychology suggests that colors have the ability to evoke human emotions [40] and, by using green, it can be associated by the user that the deeper the green, the better a viewpoint or polygon is for the purpose of visual impact assessments, since green is often considered to be a positive color [58]. Transparency could have been used instead of color value, however, as the links are placed in a 3D environment and in front of a terrain with complex geometries and textures, using transparency in this instance would result in a low data-ink ratio and make the visualization more difficult to read [88]. Spatial frequency is also used as dashes within the links. The higher the spatial frequency, meaning the denser the dashes, the higher the visibility, and at high visibility, the link is represented as a solid line. This visual metaphor is intuitive to read as spatial frequency in this scenario is associated with visibility as well. For example, if a polygon is barely visible, the sparse dashes express that with the lack of links and the abundant empty space in between the viewpoint and the polygon. Although the use of multiple visual features for the same data attribute, also known as redundant encoding, is something that is generally considered should be omitted [88], research has shown that it may sometimes be beneficial and enhances perception and reading accuracy [60]. In the guideline proposed by Brath, they stated the use of redundant encoding may aid the interpretation of visual components in the case of occlusion, which occurs frequently within 3D environments [5].

Interactions

Of the four components, only the viewpoints and the polygons are considered major components. In their initial states, the bars and the links are hidden from the display and are activated through interactions with the system.

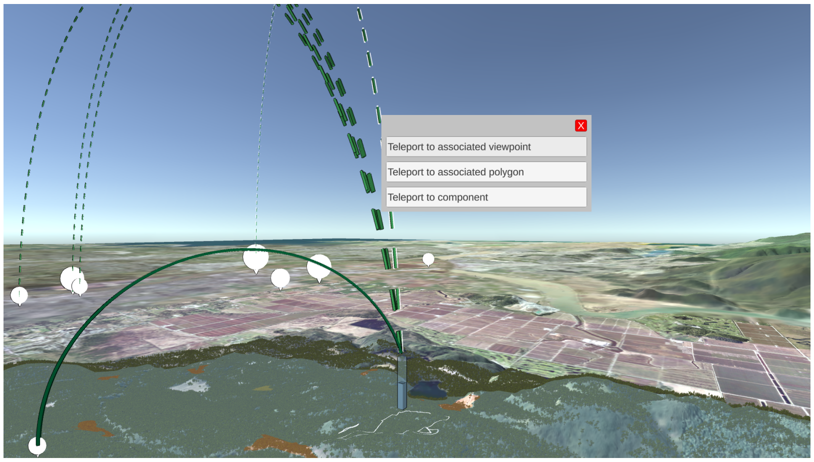


Figure 4.6: Before teleporting to the associated viewpoint of a link.

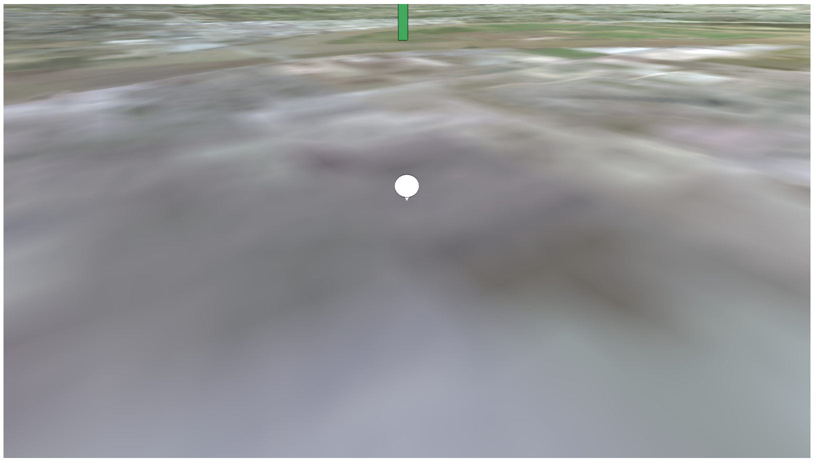


Figure 4.7: After teleporting to the associated viewpoint of a link.

First, Evergreen supports the *explore* interaction technique through the built-in camera. Of the three commonly used actions, panning, rotating, and zooming, Evergreen allows the users to pan and rotate the camera, through the use of the keyboard and the mouse respectively. In addition, the four components include a ”teleport to” functionality, which moves the camera to a distance and angle that emphasizes the selected component. The links also include a ”teleport to the associated viewpoint” and ”teleport to associated polygon” functionality. This uses both the *explore* and *elaborate* interaction techniques and aims to assist users who are not yet familiar with the WASD control scheme as an alternative method of controlling the camera. Figure 4.6 and figure 4.7 depict the before and after of using the ”teleport to” functionality of a link.

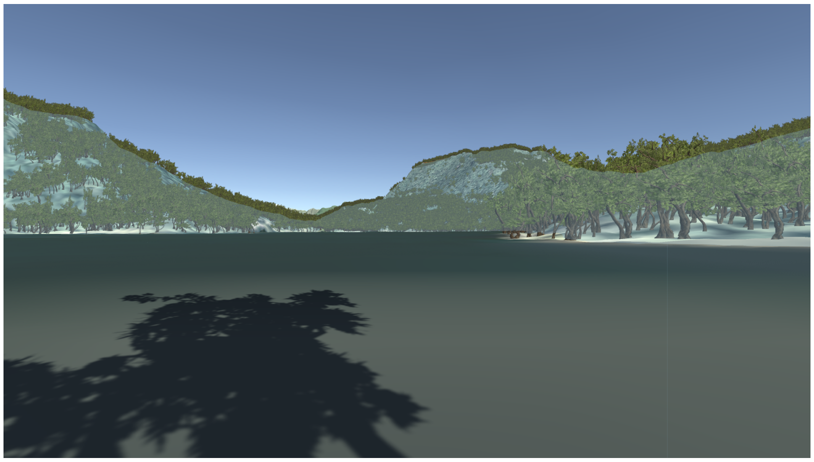


Figure 4.8: First person view from a viewpoint overlooking Loon Lake, BC.

Another interaction that uses the *explore* and *elaborate* interaction techniques within Evergreen allows the user to enter a first-person view from a selected viewpoint. This simulates field work and allows the user to view the surrounding landscape from the viewpoint as if they were physically at the location. Similar to the ”teleport to” functionality, the camera is also moved and angled, but always placed at the location of the viewpoint with a height offset of 1.7 Unity units above the terrain to simulate the height of an average Canadian, disregarding gender [76]. The camera is then locked to this height until the user escapes first-person view mode using the ESC key. Figure 4.8 depicts the first-person view from a viewpoint near Loon Lake within Malcolm Knapp Research Forest.

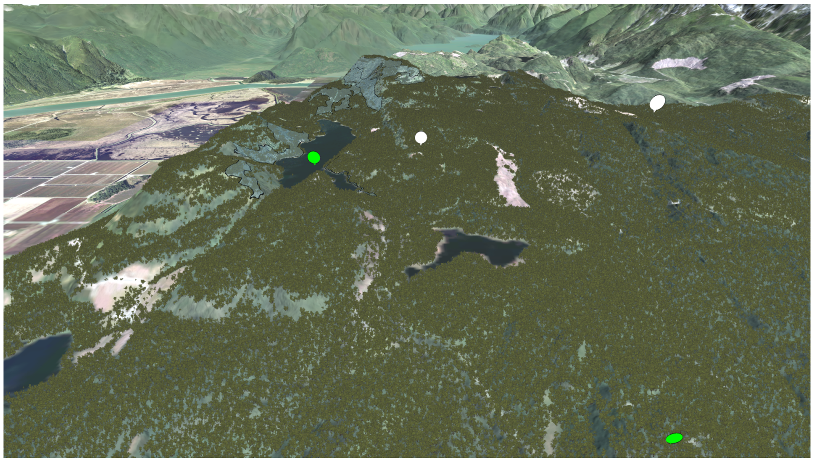


Figure 4.9: Enabling filters to only display polygons that are visible from both Loon Lake viewpoint and Blue Trail viewpoint, BC.

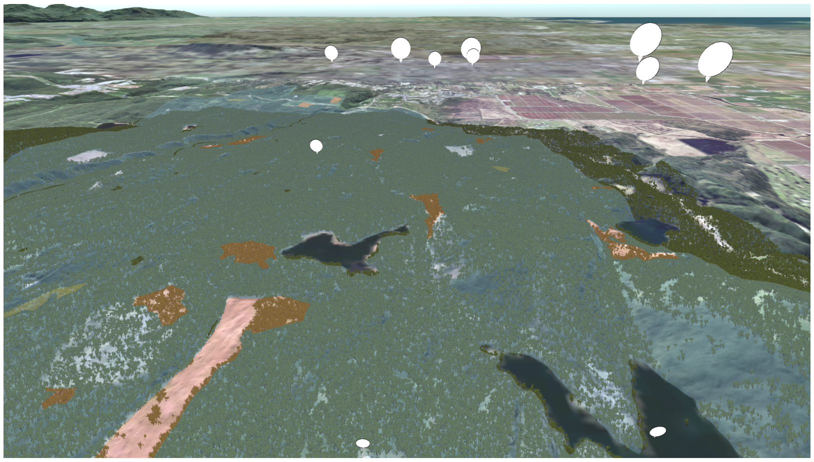


Figure 4.10: Before enabling filters to only display viewpoints that two polygons near Blaney Lake, BC are visible from.

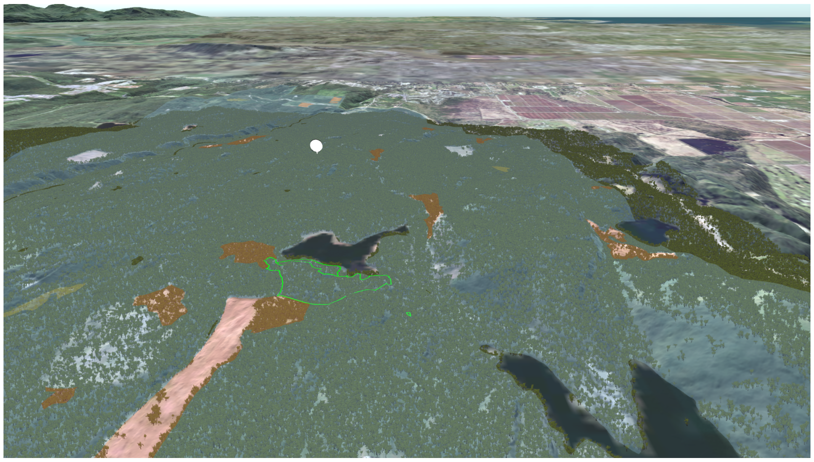


Figure 4.11: After enabling filters to only display viewpoints that two polygons near Blaney Lake, BC are visible from.

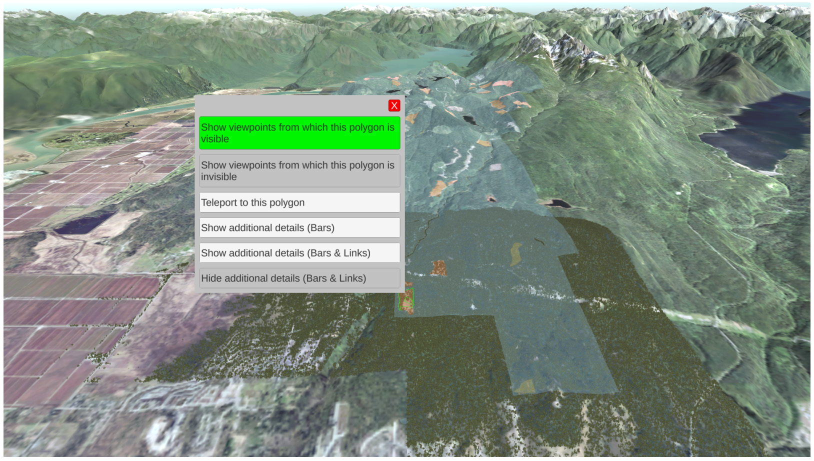


Figure 4.12: An example of the menu for a polygon after the visibility filter is enabled.

Next, Evergreen supports *filter*ing to display only viewpoints or polygons that are either visible or not visible from a selected polygon or viewpoint, respectively. If two or more components are toggled to filter based on visibility, the logical AND operation is applied. For example, the user can select a viewpoint of interest and filter the polygons to show only the ones that are visible from the selected viewpoint and, if two viewpoints are selected, only polygons that are visible from both viewpoints will be visible. The components selected as the filter condition are modified in color hue, displaying green for visible and red for not visible, using the same rationale as explained in subsection 4.3.1. In the case of viewpoints, the entire 3D model is modified and the color changes from white to either green or red, depending on the scenario. However, as the color hue for polygons also encodes whether additional modification can be placed at the location, only the outline is modified to retain this information. Figure 4.9 depicts the filtering using two viewpoints, near Loon Lake and Blue Trail, within Malcolm Knapp Research Forest, and displaying only polygons that are visible from the two positions. Figure 4.10 and figure 4.11 depict the filtering using two polygons near Blaney Lake, within Malcolm Knapp Research Forest, and displaying only viewpoints that the two polygons are visible from. Figure 4.12 depicts the menu for a polygon after the visibility filter has been enabled.

Although there exist two subsystems within Evergreen that attempt to assist the users in identifying the visibility relationship of viewpoints and polygons (the links that connect related viewpoints and polygons, and the filtering included with the two components) the two let the users complete the task differently with distinct benefits and drawbacks. The links approach provides a detailed view of the selected relationships and visualizes how visible the components are. However, it may be overwhelming for the users to read when too many links are visualized as the display becomes cluttered. On the other hand, although the filter approach does not clutter the display through additional components, it in turn also does not provide any additional information.

As mentioned previously, the bars and links are, by default, hidden from the display and only revealed by interacting with their respective viewpoints or polygons, which uses the *select* and *elaborate* interaction techniques. The user can select the polygon of interest and activate the bar that visualizes the high-level parameter. To display the bars that visualize the low-level parameter, the user can either hover over or click on the initial bar, displaying the four smaller bars, respectively, temporarily and permanently, until the user toggles the initial bar again. The relationship between the polygons and the bars is one-to-one mapping, which means that for every polygon within the data, there is for certain a set of bars that are associated with it.

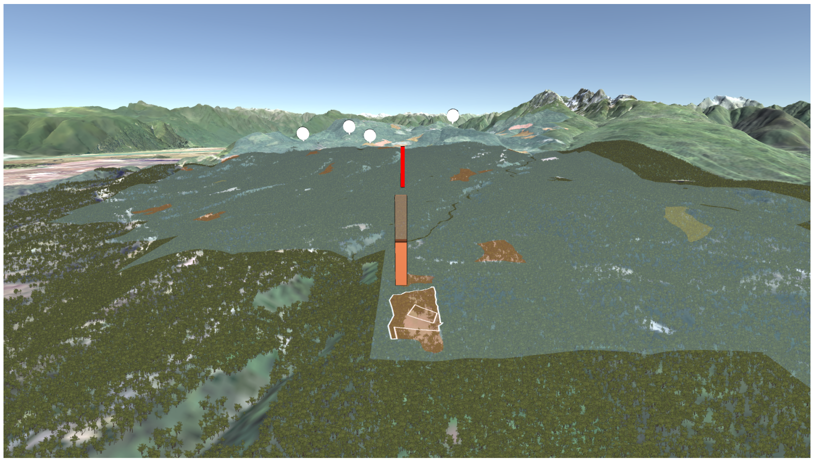


Figure 4.13: After enabling links for a polygon that is not visible from any viewpoints.

Unlike the bars, the links exist on either side of the equation when making sense of visibility and are associated with both viewpoints and polygons. The links visualize the relationship of the two components and the user can interact with either the viewpoint or polygon of interest to activate the links, as opposed to just the polygons for the bars. The relationship between the viewpoints or the polygons and the links is one-to-many mapping, which means that there may be multiple links associated with one viewpoint or one polygon, which is usually the case. There are also viewpoints and polygons that are not visible from other components, in which case a red smaller rectangular prism that stretches straight up appears in place of the links, simulating a dead connection. This offers informative feedback to the user as it provides the user with the knowledge that their action is registered within the system. This is considered to be one of the eight golden rules of interface design [77] and provides psychological closure and a sense of completion to the user [53]. Figure 4.13 depicts the result after enabling links for a polygon that is not visible from any viewpoint.

Finally, Evergreen supports the *select* interaction technique, which is implemented globally onto all four visualization components, using point selection through mouse hovers. It highlights the components of the user's interest by differentiation in light and size [44], by thickening the component's outline and replacing the color hue with a contrasting color to make the component more prominent. In this instance, highlighting is used as a visual aid and aims to direct the user's attention to the highlighted object while retaining the context of the visualization as a whole [25]. Research suggests that the bolding approach used in Evergreen, which emphasizes relevant data, is less performant than the de-emphasizing approach, which de-emphasizes irrelevant data [11], and the two approaches can be considered conceptually similar and apply the Gesalt principle of similarity to form perceptual groups [94] However, the de-emphasizing approach may remove context from the irrelevant data [11], making it unsuitable for Evergreen, in which background information within the terrain and other components are important points for consideration for the visual impact assessment as well.

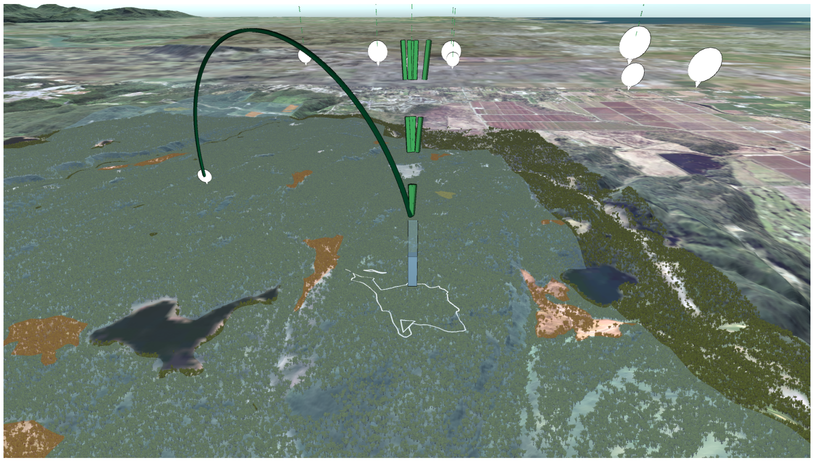


Figure 4.14: Before hovering over a polygon that has enabled its bars and links.

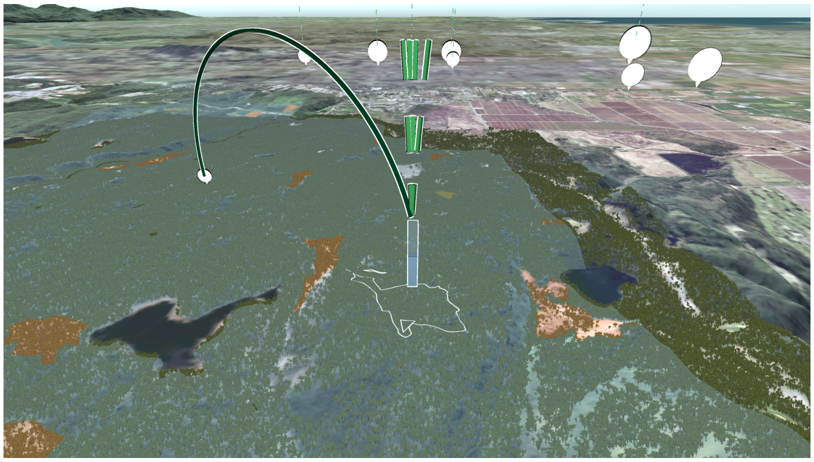


Figure 4.15: After hovering over a polygon that has enabled its bars and links.

In addition to highlighting the individual components of the user's interest, Evergreen also supports the *connect* interaction technique through the highlighting of associated components. For example, if the user hovers the mouse over a polygon, the selected polygon, all visible bars and links, and the connected viewpoints will all be highlighted. This helps the user create a sense of association for the related components, even more so for the links, as, oftentimes, the viewpoints and polygons the links are connected to usually span across a great distance and are difficult to view or find the ends of the links, depending on the user's current location. Navigation in large networks is a well-researched topic [32] with many proposed techniques that focus on improving the performance time and accuracy of reading such visualizations [55]. The approach implemented in Evergreen has been used in other systems [31]. Figure 4.14 and figure 4.15 depict the before and after the user hovers on a polygon which has enabled its bars and links.

Table 4.3 provides a summary of the interactions used by the visualization components within Evergreen sorted by user's intent [99].

Table 4.3: Interactions used by the visualization components within Evergreen sorted by user's intent [99].

User's Intent	Interaction
Select	Display / hide bars and links Highlight components
Explore	Camera panning and rotation The "teleport to" functionality First person simulation from viewpoints
Reconfigure	N/A
Encode	N/A
Abstract	First person simulation from viewpoints Display / hide bars and links
Filter	Visibility filter for both viewpoints and polygons
Connect	Highlight associated components

4.3.2 Non-Visualization Components

Non-visualization components within Evergreen are components that do not convey forestry- and visual impact assessment-related data. These are:

- the compass,
- the altimeter,
- distance filters, and
- additional user interface components.

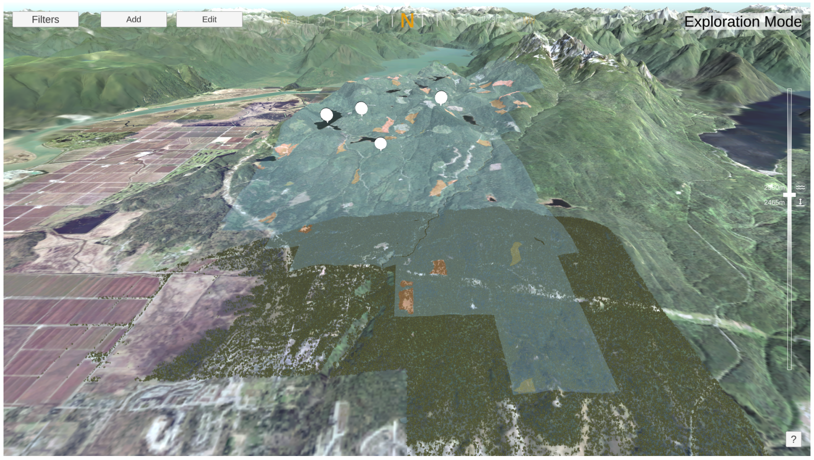


Figure 4.16: An overview of non-visualization components within Evergreen.

These components are elaborated in more detail in appendix A.2, as although they are relevant, these non-visualization components are not core to the research.

4.3.3 Base System

The base system is defined as segments of Evergreen that exist persistently regardless of the state the system is currently in. This includes the camera controls and the 3D terrain environment.

User control is an important aspect of software systems and can have a significant impact on the user's experience and it is crucial for the user to have a sense of control over their actions within the system to have a positive experience [37].

Given the inherent similarities between Evergreen and modern video games, including the first-person view, the explorable 3D environment, and is targeted for personal computers, control schemes for the camera can be directly applied from video games. The WASD + mouse control scheme is implemented due to its prevalence in video games across different genres and is used in well-known video games such as Minecraft, Counter-Strike: Global Offensive, Grand Theft Auto V, and so on. Experienced players often prefer the WASD control scheme over other control schemes [68] and, for inexperienced players, the WASD control scheme is considered intuitive and natural to learn and use [12]. Table 4.4 describes the complete control scheme for the camera used by Evergreen.

Table 4.4: The control scheme for the camera used by Evergreen

Action	Function
Right mouse	Turning / aiming / camera movement
A	Move left
D	Move right
S	Move backward
W	Move forward
E	Move up
Q	Move down
Shift key	Accelerate
Space key	Disable up / down movements

4.3.4 Level of Details

Evergreen follows the visual information-seeking mantra, which states overview first, zoom and filter, then details on demand [78]. Using the components described in this section, Evergreen can be broken down into the following four levels of detail:

- 1st level of detail: Overview
- 2nd level of detail: Filtering
- 3rd level of detail: Understanding the polygons
- 4th level of detail: Understanding the relationship between the viewpoints and polygons

As explained in previous sections, the main considerations during visual impact assessments are viewpoints and polygons. Evergreen follows this structure and, as the overview of the terrain, shows only the two main visualization components and hides the bars and the links, in its initial state. At this level of detail, the information shown includes the position of the viewpoints and the position and shape of the polygons as well as viewpoint importance and whether the polygons can have additional modifications in regard to visual impact. This is information that is often required early in the process of conducting visual impact assessments, sometimes even required before the visual impact assessment has begun. The information is represented in such a way that is easy for the user to understand at first glance, using data that is encoded into the 3D environment, such as position and shape, and preattentive visual features [30], such as size and color hue. This reduces the amount of data displayed, only visualizing data that is essential to the early parts of the assessment, making the visualization less overwhelming to use and allowing the user to quickly place focus on areas that may be of interest without excessive mental effort from them.

Next, filtering focuses on limiting the amount of data displayed and visualizing only important information, based on the scenario and criteria the user provides. Evergreen provides three forms of filtering based on visibility, physical distance, and associated parameters, each useful in different scenarios. Each method supports the input of multiple criteria and the system supports multiple filters functioning in parallel, calculating the final result using the logical AND operation. For example, using Evergreen, the user can easily view only polygons that are visible from viewpoint A and viewpoint B, within five kilometers of a local landmark and has existing visual condition as preserved. This allows the user to gain knowledge of potential candidates for the visual impact assessment using criteria suitable for the scenario and focus their attention only on the candidates continuing the assessment by removing unwanted information from the visualization.

Finally, visualizing the bars and the links, which is the 3rd and 4th level of detail, respectively. The bars visualize the associated parameters of polygons and the links visualize the relationship between viewpoints and polygons in terms of visibility. This allows the user to gain a deeper understanding of the component of interest, and combined with filtering, avoids cluttering the display with unwanted information.

Chapter 5

Evaluation of Evergreen

In this chapter, we describe the process of how Evergreen is evaluated to understand the value it holds to foresters while conducting VIAs. We conducted evaluations with four domain experts who were asked to complete tasks related to VIAs. We collected primarily qualitative data where the participants expressed their experience using the system and supporting quantitative data such as completion time and error rate. Our analysis of the data provides insights into the advantages and disadvantages of the system and how it can be improved to further support the completion of VIAs.

5.1 Participants

Similar to the interviews described in section 3.2, the snowball sampling technique was used to recruit participants. A research collaborator that also participated in the interviews was recruited as the first participant and was asked to recommend potential participants after completion. Preliminary selection questions were not used to filter the participants, instead, we trusted the recommendation process that the participants meet the recruitment criteria and then verbally confirmed with the participants to verify their eligibility.

We recruited four participants (two males, two females), to participate in the evaluation. Of the four participants, three were graduate students and one was an undergraduate student, all in the field of forest sciences. Three participants reported having at least some experience with visual impact assessments, information visualization, and 3D environments in the demographics questionnaire provided before the study. One participant reported having no experience in the three aforementioned fields, however, they stated during the study they do in fact have some experience in these topics.

5.2 Procedure

The evaluative study follows a similar structure to the interviews described in section 3.2. The participants attended the evaluations separately, with only members of the research team present. In the sessions, one researcher acted as the primary researcher and handled all interactions between the research team and the participants. Different from the interviews, the responsibility of the other researchers present was strictly note-taking. Each session lasted approximately one and a half hours. Due to COVID restrictions, the sessions took place remotely on Zoom.

As the participants are expected to operate Evergreen during the remote evaluation, participants could either download a standalone application of Evergreen or directly use Evergreen via a cloud computing service and a remote desktop streaming service (see Appendix A.3 for details).

Prior to each session, the participants were provided with a digital package containing the consent form, the demographic questionnaire, information on how to access Evergreen, and a cheat sheet that documents how to use Evergreen (see Appendix A.4 for more details). As the learnability of the system is an aspect that was evaluated during the study, the participants were asked to only download the provided files and to refrain from launching Evergreen before the start of the evaluation session.

The participants were asked to go over the consent form in detail before the session. Key points from the consent form were emphasized, including anonymity, confidentiality, and the participant's right to withdraw. They were asked if they have any questions or concerns regarding the consent form in a follow-up email.

To start the evaluations, the participants were asked to launch Evergreen on their computers and to enable screen sharing through Zoom. A semi-guided exploratory phase was then provided to the participants. First, we walked the participants through the various components within Evergreen and explained the visual variables used and their supported interactions, following the cheat sheet the participants were provided access to before the session. This acted as a reminder to the participants of how Evergreen can be used and ensures the participants did not miss any important knowledge to optimize the use of time. Then, participants were given the chance to explore Evergreen. This phase took around ten minutes (seven minutes for the walk-through and three minutes for the exploration).

After the participants had gained practical knowledge of Evergreen, they were asked to complete the following tasks, derived from the design and task requirements described in section 4.1.

- T1: Please find three visual sensitivity units that can / can not have additional modifications within the province's guidelines in terms of visual quality and list their IDs to the experimenter.
- T2: Please give an estimation of the visual sensitivity class of visual sensitivity units A and B and list the values to the experimenter.

- T3: Please give an estimation of the visual sensitivity class, biophysical rating, viewing condition, viewer rating, and visual absorption capability of visual sensitivity units A and B and list the values to the experimenter.
- T4: Please find one viewpoint from which visual sensitivity unit A has low / medium / high visibility and list its ID and viewing distance to the experimenter.
- T5: Please find one viewpoint from which visual sensitivity units A and B are both visible / both not visible / partially visible and list its ID to the experimenter.
- T6: Please give an estimation of the importance of viewpoints A and B and list the values to the experimenter.
- T7: Please find one visual sensitivity unit from which viewpoints A and B are both visible / both not visible / partially visible and list its ID to the experimenter.

T1, T2, T3, and T6 included two trials, and T4, T5, and T7 included six trials. This is because T4, T5, and T7 are based on visibility and can be further broken down into 3 subtrials, for visible, not visible, and partially visible. For all trials, two sets of two polygons and two viewpoints were selected and represented as visual sensitivity units A and B and viewpoints A and B, instead of a randomized data set. These sets of polygons and viewpoints are objects placed at similar locations throughout the evaluation as the main focus of the study is to evaluate Evergreen in regards to its visualization. By doing this, we could ensure that participants spend minimal time searching for the target objects, as it is sufficient to evaluate the exploration of the 3D environment once, when the sets were first mentioned in the tasks.

After all trials for a task had been completed, the participants answered the following five questions on five-point Likert scales, with three being the neutral option:

- Q1: Please rate the level of confidence of your answers for the task.
- Q2: Please rate the level of difficulty of completing the task using this system.
- Q3: Please rate the level of relevance of the task for completing visual impact assessments.
- Q4: Please rate the level of importance of the task for completing visual impact assessments.
- Q5: What are your impressions of using this system for completing the task?

The experimenter read the questions to the participants and entered their responses in a Google Form. Participants were also asked for the reasoning behind their answers to retrieve deeper insights. No additional personal information was recorded into the Google form apart from a unique participant ID assigned to the participants to comply with the confidentiality of the study.

To assist in the evaluation, a study helper class was implemented in Evergreen solely for that purpose. It provides a semi-automated mechanism for communicating the tasks to the participants and allows them to complete the tasks at their own pace. Each trial is broken down into three sub-phases using the study helper class. The study helper class is almost fully controlled by the participants, with the only researcher intervention being in the last sub-phase.

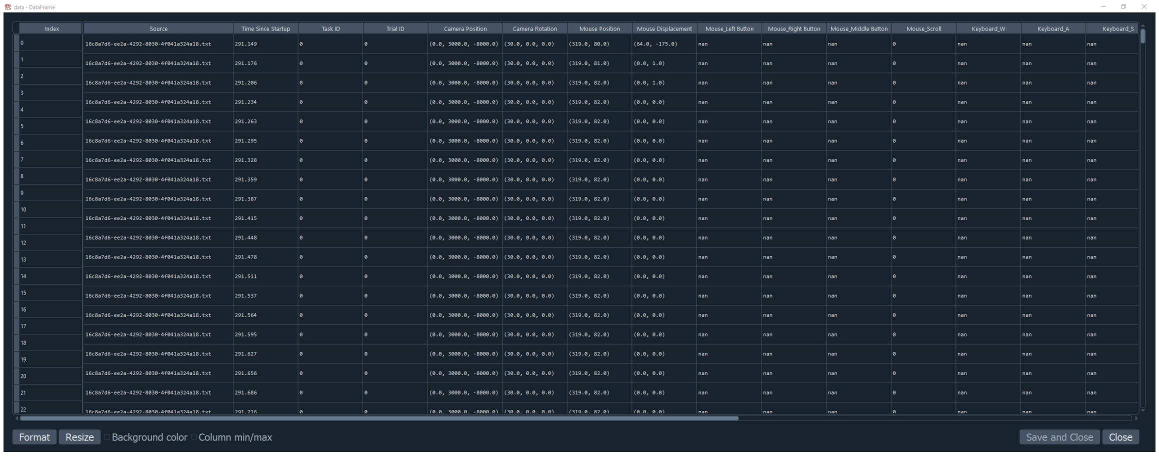
First, the participants are provided with the full description of the task, which, apart from the aforementioned descriptions, also includes additional details such as the categories or levels of the parameters the task asks for. This is to ensure the evaluation is not affected by inconsistent usage of words. For example, some foresters refer to visual sensitivity units as polygons and viewpoints as key observation points. The participants are allowed to take as much time as they need to fully understand the tasks during this sub-phase and are allowed to ask questions related to the wording of the tasks only. To continue on to the next sub-phase, a button is available to the participants.

Next, the participants are taken to the 3D environment in Evergreen and allowed to freely explore the system. This is the main part of the evaluation where the participants will complete the given tasks. When a task is completed, the participants are asked to provide the answers to the task directly to the experimenter and, regardless of the correctness of the answer, to click on the button that takes them to the next sub-phase. A simplified version of the task descriptions is provided at the bottom of the system, which displays the full descriptions provided in the previous sub-phase as a tooltip when hovered over.

All actions the participants take are recorded in this sub-phase for every task. The recorded data includes the following:

- the time in seconds since the start of the application,
- the ID of the current task and trial,
- the internal camera's position and rotation,
- the mouse's position,
- the mouse's displacement since the last frame, and
- mouse and keyboard actions, including mouse clicks and scrolls and keyboard presses.

This data is collected for the purpose of evaluating Evergreen quantitatively, in terms of the amount of time used and the number of user actions required to complete each task. It is also useful as a backup option for reconstructing the user's workflow in case the screen recording is unclear. Figure 5.1 shows a screenshot of the recorded data.



Index	Source	Time Since Startup	Task ID	Trial ID	Camera Position	Camera Rotation	Mouse Position	Mouse Displacement	Mouse_Left Button	Mouse_Right Button	Mouse_Middle Button	Mouse_Scroll	Keyboard_W	Keyboard_A	Keyboard_S
0	16c8a7d6-ee2a-4292-8030-4f041a324a18.txt	291.149	0	0	(0.0, 3000.0, -8000.0)	(30.0, 0.0, 0.0)	(319.0, 80.0)	(64.0, -175.0)	nan	nan	nan	0	nan	nan	nan
1	16c8a7d6-ee2a-4292-8030-4f041a324a18.txt	291.176	0	0	(0.0, 3000.0, -8000.0)	(30.0, 0.0, 0.0)	(319.0, 81.0)	(0.0, 1.0)	nan	nan	nan	0	nan	nan	nan
2	16c8a7d6-ee2a-4292-8030-4f041a324a18.txt	291.206	0	0	(0.0, 3000.0, -8000.0)	(30.0, 0.0, 0.0)	(319.0, 82.0)	(0.0, 1.0)	nan	nan	nan	0	nan	nan	nan
3	16c8a7d6-ee2a-4292-8030-4f041a324a18.txt	291.234	0	0	(0.0, 3000.0, -8000.0)	(30.0, 0.0, 0.0)	(319.0, 82.0)	(0.0, 0.0)	nan	nan	nan	0	nan	nan	nan
4	16c8a7d6-ee2a-4292-8030-4f041a324a18.txt	291.263	0	0	(0.0, 3000.0, -8000.0)	(30.0, 0.0, 0.0)	(319.0, 82.0)	(0.0, 0.0)	nan	nan	nan	0	nan	nan	nan
5	16c8a7d6-ee2a-4292-8030-4f041a324a18.txt	291.295	0	0	(0.0, 3000.0, -8000.0)	(30.0, 0.0, 0.0)	(319.0, 82.0)	(0.0, 0.0)	nan	nan	nan	0	nan	nan	nan
6	16c8a7d6-ee2a-4292-8030-4f041a324a18.txt	291.328	0	0	(0.0, 3000.0, -8000.0)	(30.0, 0.0, 0.0)	(319.0, 82.0)	(0.0, 0.0)	nan	nan	nan	0	nan	nan	nan
7	16c8a7d6-ee2a-4292-8030-4f041a324a18.txt	291.359	0	0	(0.0, 3000.0, -8000.0)	(30.0, 0.0, 0.0)	(319.0, 82.0)	(0.0, 0.0)	nan	nan	nan	0	nan	nan	nan
8	16c8a7d6-ee2a-4292-8030-4f041a324a18.txt	291.387	0	0	(0.0, 3000.0, -8000.0)	(30.0, 0.0, 0.0)	(319.0, 82.0)	(0.0, 0.0)	nan	nan	nan	0	nan	nan	nan
9	16c8a7d6-ee2a-4292-8030-4f041a324a18.txt	291.415	0	0	(0.0, 3000.0, -8000.0)	(30.0, 0.0, 0.0)	(319.0, 82.0)	(0.0, 0.0)	nan	nan	nan	0	nan	nan	nan
10	16c8a7d6-ee2a-4292-8030-4f041a324a18.txt	291.448	0	0	(0.0, 3000.0, -8000.0)	(30.0, 0.0, 0.0)	(319.0, 82.0)	(0.0, 0.0)	nan	nan	nan	0	nan	nan	nan
11	16c8a7d6-ee2a-4292-8030-4f041a324a18.txt	291.478	0	0	(0.0, 3000.0, -8000.0)	(30.0, 0.0, 0.0)	(319.0, 82.0)	(0.0, 0.0)	nan	nan	nan	0	nan	nan	nan
12	16c8a7d6-ee2a-4292-8030-4f041a324a18.txt	291.511	0	0	(0.0, 3000.0, -8000.0)	(30.0, 0.0, 0.0)	(319.0, 82.0)	(0.0, 0.0)	nan	nan	nan	0	nan	nan	nan
13	16c8a7d6-ee2a-4292-8030-4f041a324a18.txt	291.537	0	0	(0.0, 3000.0, -8000.0)	(30.0, 0.0, 0.0)	(319.0, 82.0)	(0.0, 0.0)	nan	nan	nan	0	nan	nan	nan
14	16c8a7d6-ee2a-4292-8030-4f041a324a18.txt	291.564	0	0	(0.0, 3000.0, -8000.0)	(30.0, 0.0, 0.0)	(319.0, 82.0)	(0.0, 0.0)	nan	nan	nan	0	nan	nan	nan
15	16c8a7d6-ee2a-4292-8030-4f041a324a18.txt	291.595	0	0	(0.0, 3000.0, -8000.0)	(30.0, 0.0, 0.0)	(319.0, 82.0)	(0.0, 0.0)	nan	nan	nan	0	nan	nan	nan
16	16c8a7d6-ee2a-4292-8030-4f041a324a18.txt	291.627	0	0	(0.0, 3000.0, -8000.0)	(30.0, 0.0, 0.0)	(319.0, 82.0)	(0.0, 0.0)	nan	nan	nan	0	nan	nan	nan
17	16c8a7d6-ee2a-4292-8030-4f041a324a18.txt	291.656	0	0	(0.0, 3000.0, -8000.0)	(30.0, 0.0, 0.0)	(319.0, 82.0)	(0.0, 0.0)	nan	nan	nan	0	nan	nan	nan
18	16c8a7d6-ee2a-4292-8030-4f041a324a18.txt	291.686	0	0	(0.0, 3000.0, -8000.0)	(30.0, 0.0, 0.0)	(319.0, 82.0)	(0.0, 0.0)	nan	nan	nan	0	nan	nan	nan
19	16c8a7d6-ee2a-4292-8030-4f041a324a18.txt	291.716	0	0	(0.0, 3000.0, -8000.0)	(30.0, 0.0, 0.0)	(319.0, 82.0)	(0.0, 0.0)	nan	nan	nan	0	nan	nan	nan

Figure 5.1: A screenshot of the recorded data

Finally, a buffer screen is shown to the participants. This allows the participants to take a moment of rest while allowing the researcher to switch to the aforementioned interviews when all trials for a task are completed. After this is completed, the participants can freely click on a button that takes them to the next trial, iterating the study helper class back to the first sub-phase.

To conclude the evaluation, a semi-structured interview consisting of eleven questions is conducted after all of the tasks have been completed. This is to collect qualitative data from the participants in regards to the overall system. The interview consisted of the following questions.

- Q1: Is it easy to learn the visuals in this system? Why?
- Q2: Is it easy to learn the interactions in this system? Why?
- Q3: Is it easy to learn how to use this system? Why?
- Q4: Is it easy to use the visuals in this system? Why?

- Q5: Is it easy to use the interactions in this system? Why?
- Q6: Is it easy to use this system? Why?
- Q7: Would you be willing to include this system into your workflow of completing visual impact assessments? Why?
- Q8: Would using this system save time for completing visual impact assessments? Why?
- Q9: Would using this system improve the quality of completing visual impact assessments? Why?
- Q10: What are your overall impressions of using this system for completing the tasks? Why?
- Q11: What are the benefits and drawbacks of this system compared to what you are using to complete visual impact assessments currently? Why?

5.3 Data Analysis

A process similar to the data analysis of the formative study, as described in subsection 3.2.4, was conducted to analyze qualitative data retrieved from the evaluative study. Only one researcher participated in the data analysis for the evaluative study and two coding iterations were used before codes converged.

In addition to qualitative data, quantitative data were also collected during the evaluation. A Python script was written to process the raw data into time used and clicks used data. However, as the quantitative data was meant to be used as a complementary data source to the qualitative data, no formal quantitative analysis was conducted and we only use the data to provide an initial idea of how Evergreen was used by the participants.

5.4 Findings

In this section, we describe the findings of the evaluative study, with the focus placed on qualitative data. Reports are organized by task and, for each task, results are presented in the following order:

- the level of confidence of the participant's answer for the task,
- the level of difficulty of completing the task using this system,
- the level of relevance of the task for completing VIAs,
- the level of importance of the task for completing VIAs, and
- the participant's impressions of using this system to complete the task.

At the end of this section, we present the results related to the overall experience of using Evergreen.

5.4.1 Task 1

Task 1 asks the participants to find three visual sensitivity units that can or can not have additional modifications within the province's guidelines in terms of visual quality. To complete the task, the participants must complete the following subtasks:

- navigate the 3D terrain and place the camera near the polygons,
- understand the visual encodings used and determine which polygons fit the criteria of the task, and

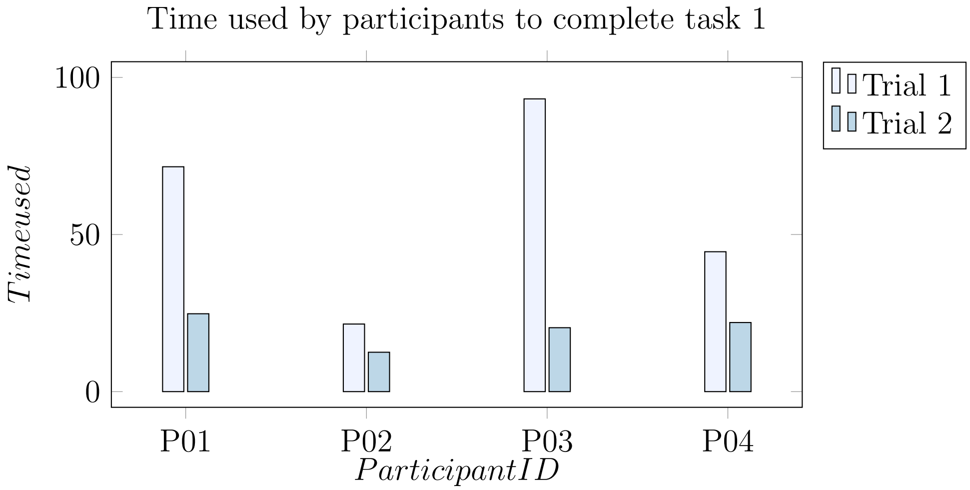


Figure 5.2: Time used by participants to complete task 1

- retrieve the selected polygon's ID.

Participants used an average of 38.80 seconds to complete the task, with a min time of 12.53 seconds, a max time of 93.17 seconds, and a median time of 23.39 seconds.

CONFIDENCE and DIFFICULTY: Participants reported being confident (1) and extremely confident (3) in their answers for the task. They found the task easy (2) and extremely easy (2) to complete.

Participants found the polygons and their selected visual encoding to be simple to understand and quick and easy to read. For example, participant B stated *"there are only three options and it's clearly color-coded... it shows you exactly what the polygon is."* However, one participant initially confused "can have" and "may have" additional modifications, stating that the green-blue color was not as noticeable compared to the other two colors. This is likely due to "can have" being the dominant value within the forest and the similarity of the green-blue color for the polygon and the color of trees on the terrain. Participant D stated *"It kind of blends in with the trees a bit so I kind of forgot about it and it feels more like a border to the forest rather*

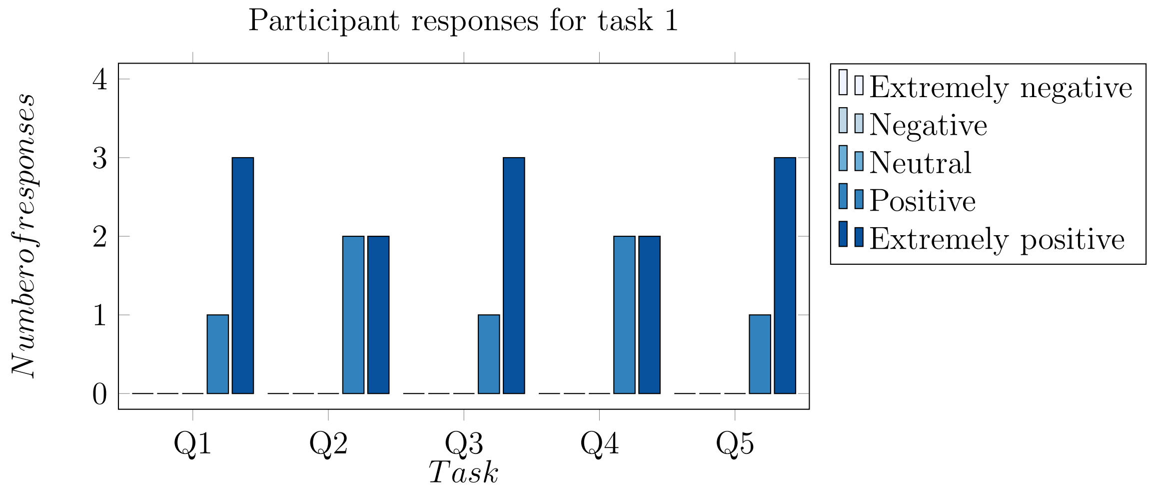


Figure 5.3: Participant responses for task 1, in the order of confidence, difficulty, relevance, importance, and impression.

than a polygon for modification."

RELEVANCE and IMPORTANCE: Participants found the task to be relevant (1) and extremely relevant (3). They found the task to be important (2) and extremely important (2) for completing visual impact assessments.

Participants stated that the task provides basic knowledge that enables the users to know and understand the polygons being assessed. For example, participant A stated *"You want to know what polygon you're accessing. You want to make sure that you're identifying the right polygon, otherwise, you're working for nothing."* The task also acts as a starting point for stakeholders, with participant D stating *"it will be very fast for managers to determine which areas that they should even put time into looking into."* However, participant B noted that the polygons are still missing information, stating that *"you need to know how much area is allowed to be cut, not just if it's allowed."*

IMPRESSIONS: Participants reported their impressions of using Evergreen to complete this task as extremely positive (3) and positive (1). They stated it is fast to use, easy to navigate, and easy to understand. For example, participant A said *"It's easy... you're just sitting there and you can see it."*

5.4.2 Task 2

Task 2 asks the participants to give an estimation of the visual sensitivity class of specific polygons. To complete the task, the participants must complete the following subtasks:

- navigate the 3D terrain and place the camera near the target area,
- locate the target polygon within the target area,
- annotate the high-level bar of the target polygon, and

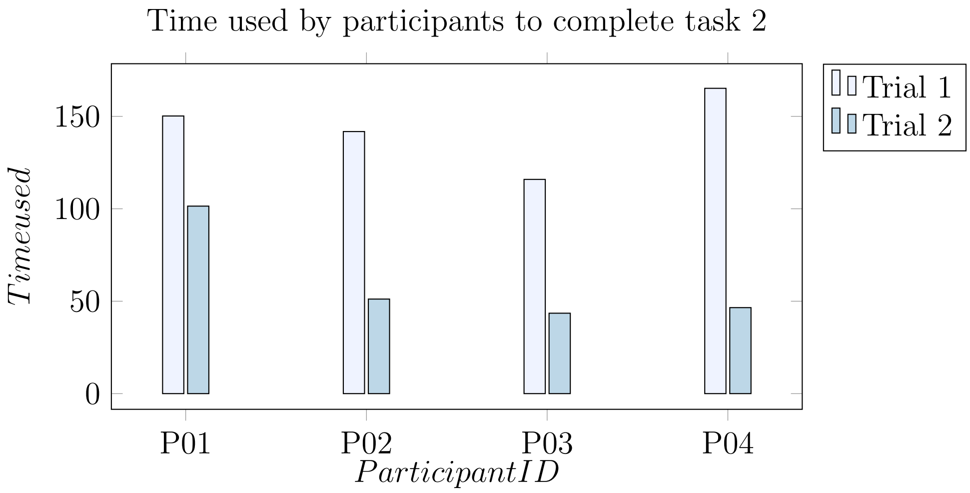


Figure 5.4: Time used by participants to complete task 2

- understand the visual encodings used and retrieve the value of the high-level bar.

Participants used an average of 101.97 seconds to complete the task, with a min time of 43.51 seconds, a max time of 165.19 seconds, and a median time of 108.67 seconds.

CONFIDENCE and DIFFICULTY: Participants reported being confident (4) in their answers. They found the task to be of neutral difficulty (1), easy (2), and extremely easy (1).

Participants contributed the drop in confidence and the rise in difficulty to be from estimating the value of the high-level bar, which has nine possible values. However, participants noted that the difficulty of estimating the value decreases as they completed more trials. It was also observed the most common strategy the participants used for estimation is by comparing known values, whether it is bars or reference images from the cheat sheet. For example, participant B stated *"Initially, I'm not sure if something is five or six. The next one, I can see where something is higher. So the more experience you get, the easier it is to read the bars."* Participant D also stated

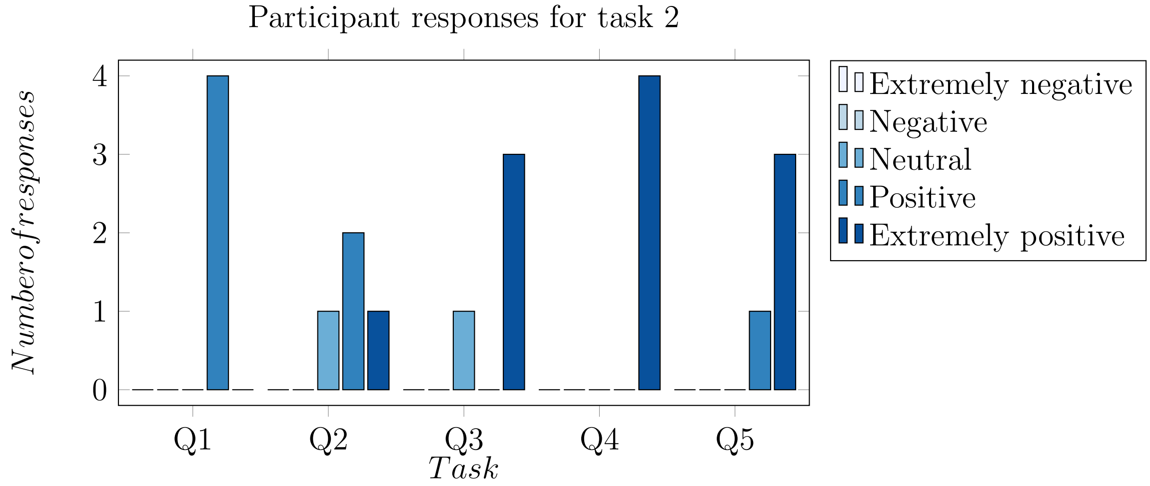


Figure 5.5: Participant responses for task 2, in the order of confidence, difficulty, relevance, importance, and impression.

"It's a bit hard to determine in between those numbers (0, 4, and 8)... I think once I saw a few of them it was a bit easier to get a scale of differences between them."

Apart from the estimation, participants identified the other subtasks as easy to complete, with the main difficulty being the estimation of the bars. For example, Participant A stated *"It's really easy to identify the polygon, and then you click on it, you just make the bars appear."*

RELEVANCE and IMPORTANCE: Participants found the task to be of neutral relevance (1) and extremely relevant (3). They all found the task to be extremely important (4) for completing visual impact assessments.

Participants stated that knowing the visual sensitivity class, which is encoded into the high-level bars, is both relevant and important. This is because it goes into the calculation of determining the size of the area foresters are allowed to modify. For example, participant B stated *"It's not as important as knowing practically how much area you have left to cut, but it is the most important information that goes into deciding that."*

Participants also recognized that high-level bars are useful for quickly retrieving preliminary information about an area. For example, participant C stated *"Once the managers are seeing those visual sensitivity classes, they have a first impression about which polygon to deal with first."*

IMPRESSIONS: Participants reported having a positive (1) and extremely positive (3) experience of using Evergreen to complete this task.

Participants noted that it was easy to complete the task with the only hurdle being estimating the values but praised other functionalities of Evergreen. For example, Participant A stated *"The teleport [to] point is really nice. It allows you to be closer to the bar and be able to have a better estimation of the number."* Participant D also stated *"I'm glad when I click on the polygon, it (the context menu) tells me what*

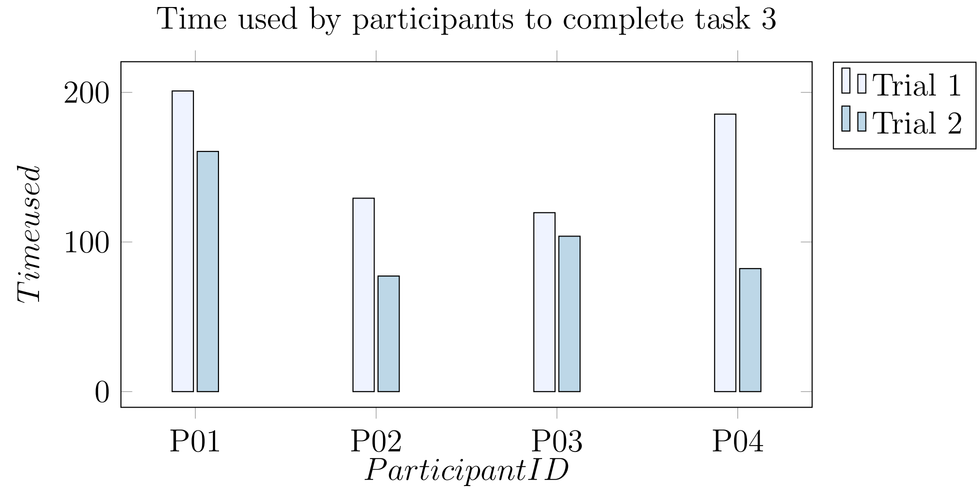


Figure 5.6: Time used by participants to complete task 3

information will come up."

5.4.3 Task 3

Task 3 asks the participants to give an estimation of the visual sensitivity class, biophysical rating, viewing condition, viewer rating, and visual absorption capability of specific polygons. To complete the task, the participants must complete the following subtasks.

- navigate the 3D terrain and place the camera near the target area,
- locate the target polygon within the target area,
- annotate the high-level bar of the target polygon,
- annotate the low-level bars of the target polygon, and
- understand the visual encodings used and retrieve the value of both the high and low-level bars.

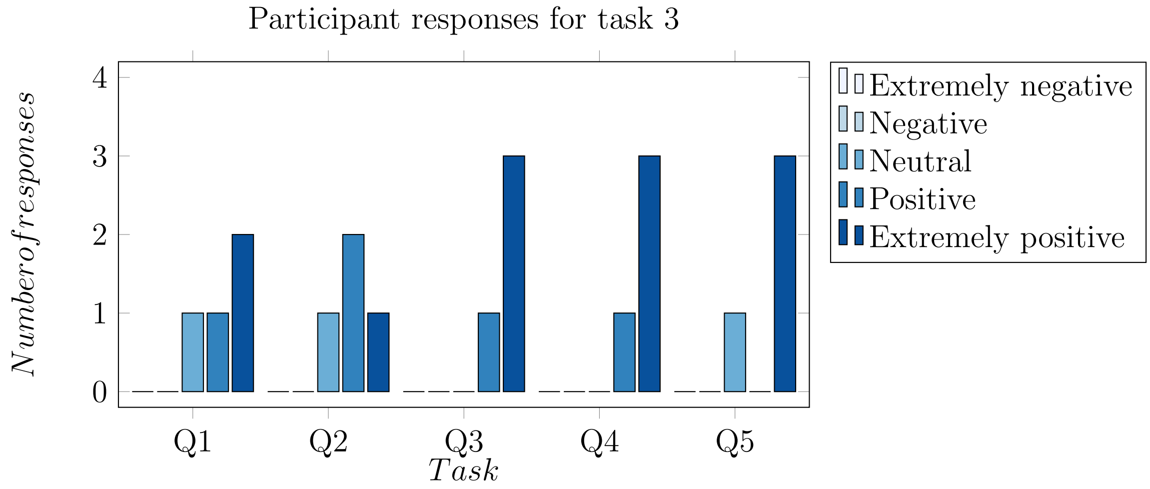


Figure 5.7: Participant responses for task 3, in the order of confidence, difficulty, relevance, importance, and impression.

Participants used an average of 132.39 seconds to complete the task, with a min time of 77.24 seconds, a max time of 200.95 seconds, and a median time of 124.43 seconds.

CONFIDENCE and DIFFICULTY: Participants reported being of neutral confidence (1), confident (1), and extremely confident (2) in their answers. They found the task to be of neutral difficulty (1), easy (2), and extremely easy (1).

Participants found the low-level bars easier to interpret than high-level bars, due to there being only four possible values. For example, participant A stated *“For the smaller bars, it’s easier because there are only four possibilities.”* Participants also reported a decrease in difficulty reading the high-level bars when low-level bars are enabled, which acts as a scale for the larger bar. For example, participant B stated *“Yes, so that (low-level bars) makes that (high-level bars) easier to read.”*

However, participants also reported some issues with the design. One participant noted initial confusion with the scale for the low-level bars and the up-side down bar that visualizes visual absorption capability. They soon understood the design and visual encoding after some time. Participant D stated *“I was uncertain about* *what scale they were on since the previous one was from zero to eight. And the visual absorption capacity (capability) is from zero to three but reversed."* Another participant noted that the bars were difficult to read when the camera is not zoomed in or is not at a suitable angle. For example, participant B stated *"Especially when you're not zoomed in... depends on the angle of the columns (bars), it can be very hard to see how the color section, how far up it goes."* However, the same participant also stated *"It's a little bit frustrating at times to try to see the bar, but once you zoom in it seems to be better."* This issue of distortion and occlusion likely exists for both high and low-level bars but is brought up only during task 3 due to the higher amount of objects within the scene required to complete the task.

RELEVANCE and IMPORTANCE: Participants found the task to be relevant (1) and extremely relevant (3). They found the task to be extremely important (1) and extremely important (3) for completing visual impact assessments.

Although the four low-level parameters are not essential to the VIA process, participants recognized their use for fine-tuning modifications. For example, participant B stated *"It's not totally essential because you can figure out how much you're allowed to log there without it, but if you're trying to decide between areas that both are allowed to log and you have some values you want to manage where in particular, then you can decide between them by zooming in to the components."* Participants also the low-level bars are useful for stakeholders who already have some idea of what they are looking for within the forest. For example, participant C stated *"This software fits more objectives because someone might be looking for biophysical ratings specifically and some might be looking for the others."*

IMPRESSIONS: Participants reported having a neutral (1) and extremely positive (3) experience of using Evergreen to complete this task.

Participants noted the simplicity of the system while providing necessary information. For example, participant C stated *"Just the simplicity of how the software is designed, how user friendly it is... being simple doesn't mean it doesn't provide the users with enough information."* Participants also enjoyed the visuals, describing them as standing out well and being easy to read. For example, participant A stated *"I like the colors, it's visually attractive... It's easy to read."*

5.4.4 Task 4

Task 4 asks the participants to find one viewpoint from which a specific polygon has low, medium, or high visibility and retrieve the viewing distance from the selected viewpoint. To complete the task, the participants must complete the following subtasks.

- navigate the 3D terrain and place the camera near the target area,
- locate the target polygon within the target area,
- annotate the links of the target polygon,
- understand the visual encodings used and determine which viewpoints fit the criteria of the task,
- retrieve the selected viewpoint's ID,
- navigate the 3D terrain and place the camera near the selected viewpoint where it simulates a person's viewport, and
- retrieve the viewing distance from the selected viewpoint to the target polygon.

Participants used an average of 112.269 seconds to complete the task, with a min time of 30.304 seconds, a max time of 633.262 seconds, and a median time of 51.703 seconds.

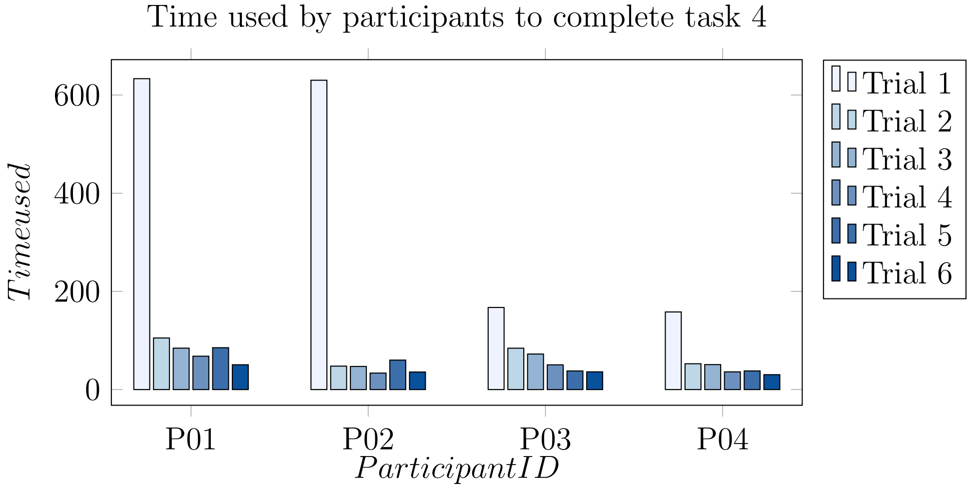


Figure 5.8: Time used by participants to complete task 4

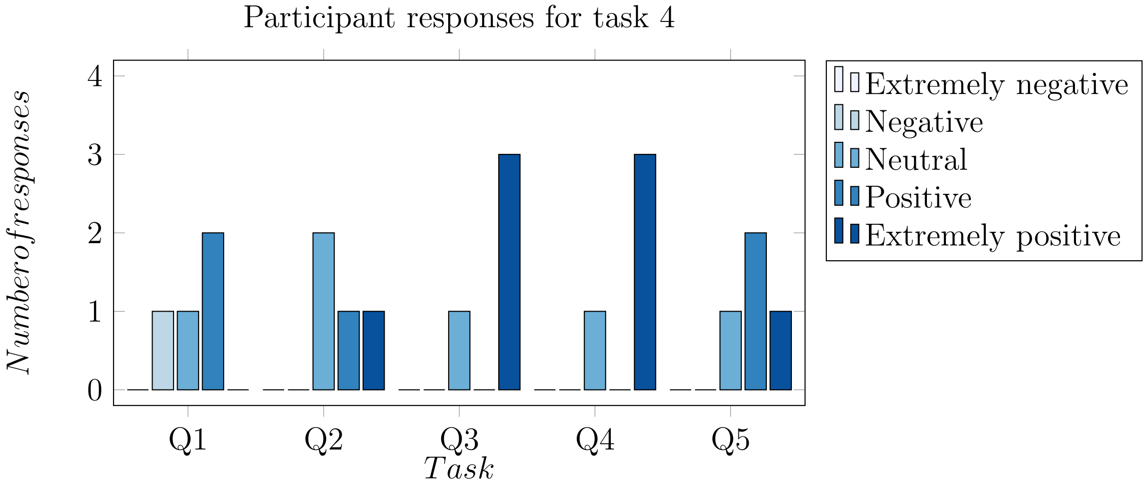


Figure 5.9: Participant responses for task 4, in the order of confidence, difficulty, relevance, importance, and impression.

CONFIDENCE and DIFFICULTY: Participants reported being not confident (1), of neutral confidence (1), and confident (2) in their answers. They found the task to be of neutral difficulty (2), easy (1), and extremely easy (1).

To complete this task, participants must interact with both links and viewpoints. For the links, participants described a learning curve when interpreting the links. For example, participant D stated *"It took me a second to think of which links lead to which visibility rating of the viewpoint. I think I got more used to it at the end."* Participants also noted that the color of the links is difficult to identify. For example, participant B stated *"The shades of green, that's kind of hard to tell."* This is likely due to the effects of rendering the links within a 3D environment, such as lights and shadows. However, the redundant encoding used within the links helped with this issue. For example, participant A stated *"There was some green that was not too (distinguishable)... It was a bit confusing but it did its job with the dashes."*

Another issue pointed out by one participant occurred when an excessive amount of links are displayed, describing the view to be overwhelming. Participant A stated *"The lines (links) feels a bit overwhelming."* The same participant also pointed out, under that condition, the association between polygons, bars, and links within the 3D environment can sometimes be overlooked without triggering additional interactions. For example, participant A stated *"It's a bit hard to find which one it is at the top of the bar from the polygon."* However, they noted that *"It might just be a matter of getting used to."*

For the viewpoints, participants reported that most of their uncertainty came from this portion of the task, compared to the links. For example, participant D stated *"I'm not very sure about the definitions for visual distancing, but with the IDs (links), I'm confident."* This is because, since viewing distance is a subjective value and relies on professional knowledge to derive, this information is not visually encoded and participants must rely on interactions within the system to complete the task. For example, participant B stated *"There's no way to quantify it."* There were also participants who misunderstood the question, as within assessments, viewing distance can be reported in meters or qualitative values, foreground, middleground, or background. For example, participant B was attempting to find a ruler tool and stated *"I can't draw a line from here to where I am on the screen."*

When using the first-person view functionality, a different participant pointed out the same issue reported in task 1. The participant noted that it was difficult to see polygons with green-blue color, due to their similarity with the color of the trees. For example, participant B stated *"The colors of the polygons isn't the best against the color of the trees... Having at least an outline [would help]."* This issue is likely amplified in first-person view, depending on the camera's location within the system. This is because the users do not have access to the overhead view in this mode, which may cause objects to look squished together, especially when the user is far away from the target area. It was observed some participants also required additional time to regain their heading and find the target area when switching to the first-person view. For example, participant B stated *"I went into first-person and it doesn't even point me towards the right direction it seems."*

RELEVANCE and IMPORTANCE: Participants found the task to be not relevant (1) and extremely relevant (3). They found the task to be of neutral importance (1) and extremely important (3) for completing visual impact assessments.

Participant A was one of the participants to find the task extremely relevant and extremely important, stating *"You have to know if the people can see the area you're trying to assess"* and *"It's really important to determine what was the distance and what is visible or not from where you're trying to assess."* Participant B was the more reserved participant, stating *"You already have the bars, you already have the* *importance of the viewpoint, so I'm not sure if looking at it from the viewpoint is all that useful."* However, they noted the usefulness of the links, stating *"Even though that's already included in the rating as well, but it breaks it down further."* when asked about solely the visibility portion of the task.

Participants also recognized the potential of saving resources when conducting fieldwork using the first-person view. For example, participant C stated *"The function of enabling you to view as the field person from the viewpoint, it just saves the traveling time to those viewpoints."*

IMPRESSIONS: Participants reported having a neutral (1), positive (2), and extremely positive (1) experience of using Evergreen to complete this task.

Participants praised the convenience of directly viewing the visibility of entities within the 3D environment without the need for additional navigation. For example, participant A stated *"It was easy to use, easy to complete the task because you felt confident doing it. It's nice to have that view without having to move to every point on the landscape to see if you can see it."* Participant B also reiterated the main source negativity stems from the first-person view, stating *"Seeing the line connections (links) is pretty nice. Looking at the first-person view, it's not a very great view."*

5.4.5 Task 5

Task 5 asks the participants to find one viewpoint from which two specific polygons are both visible, both not visible, or partially visible. To complete the task, the participants must complete the following subtasks.

- navigate the 3D terrain and place the camera near the target area,
- locate the target polygons within the target area,
- annotate the links of the target polygons **or** enable the visibility filters of the

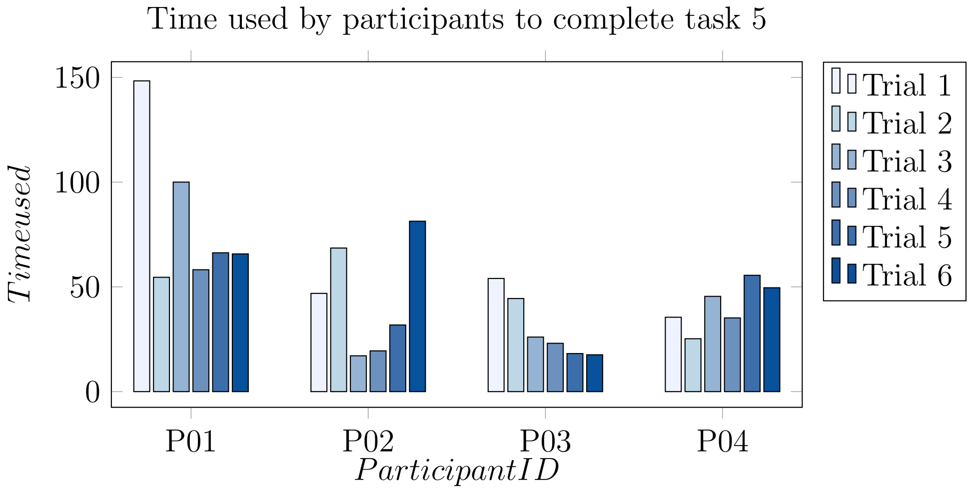


Figure 5.10: Time used by participants to complete task 5

target polygons,

- understand the visual encodings used and determine which viewpoints fit the criteria of the task, and
- retrieve the selected viewpoint's ID.

Participants used an average of 49.5058 seconds to complete the task, with a min time of 17.099 seconds, a max time of 148.353 seconds, and a median time of 46.184 seconds.

CONFIDENCE and DIFFICULTY: Participants reported being confident (2), and extremely confident (2) in their answers. They found the task to be easy (1), and extremely easy (3).

Participants found the task more complex compared to previous tasks, but easy overall. For example, participant A stated *"There's some clicking around and some steps to it, but, overall, it's easy."*

To complete this task, participants can choose to use the links or the built-in visibility filters. It was observed that most participants opted to use the links at

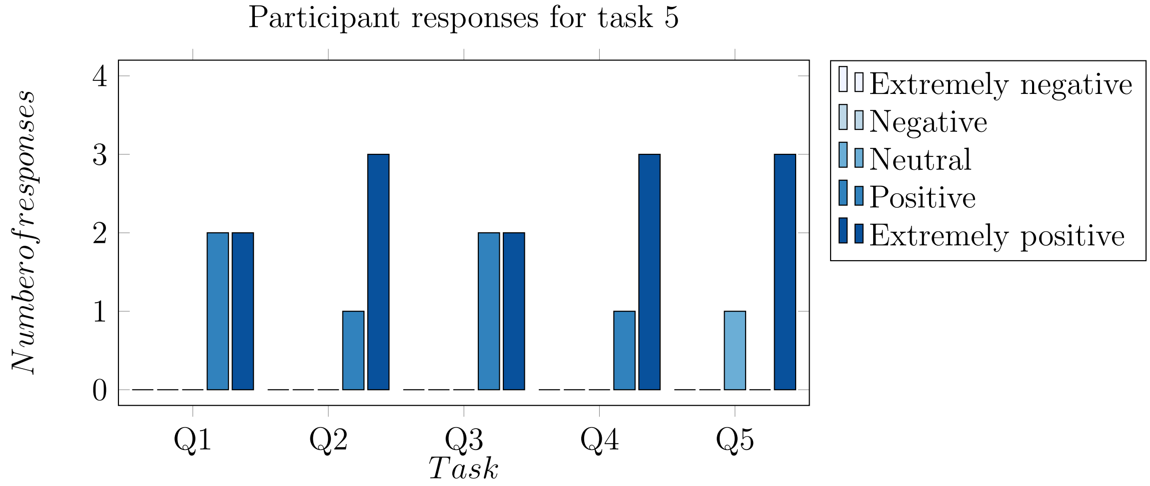


Figure 5.11: Participant responses for task 5, in the order of confidence, difficulty, relevance, importance, and impression.

this stage of the evaluation. However, one participant initially was using the links as well but switched to visibility filters during the task. When asked about the strategy change and which one they preferred, participant C stated *"Of course the second one (visibility filter) because at first I used the links trying to find overlaps and after that, I figured maybe they automatically have filters."*

In addition, some participants noted the "partially visible" statement within the task description is potentially confusing. Participant B stated *"That's not what the statement seems to mean to me. I have to find a viewpoint from which both these polygons are partially visible, which means I need to find a viewpoint which has the broken lines (links) from both polygons going to it."*

RELEVANCE and IMPORTANCE: Participants found the task to be relevant (2) and extremely relevant (2). They found the task to be important (1) and extremely important (3) for completing visual impact assessments.

Participants commented that the task is crucial when determining whether a viewpoint is already under too much pressure. For example, Participant B stated *"If I care particularly about one viewpoint, I might want to see multiple polygons and compare multiple polygons to that viewpoint."* Participant C also stated *"There are cases you have to avoid operations in those blocks (polygons) that are highly visible to viewpoints."*

Participants recognized the potential of using the links or the visibility filters as an exploration tool. For example, participant C stated *"Can be a very useful tool in the decision-making stage... Also saves field work... Just how convenient this can be applied in forestry."*

IMPRESSIONS: Participants reported having a neutral (1) and extremely positive (3) experience of using Evergreen to complete this task.

Participants described the system as easy to use. For example, participant A

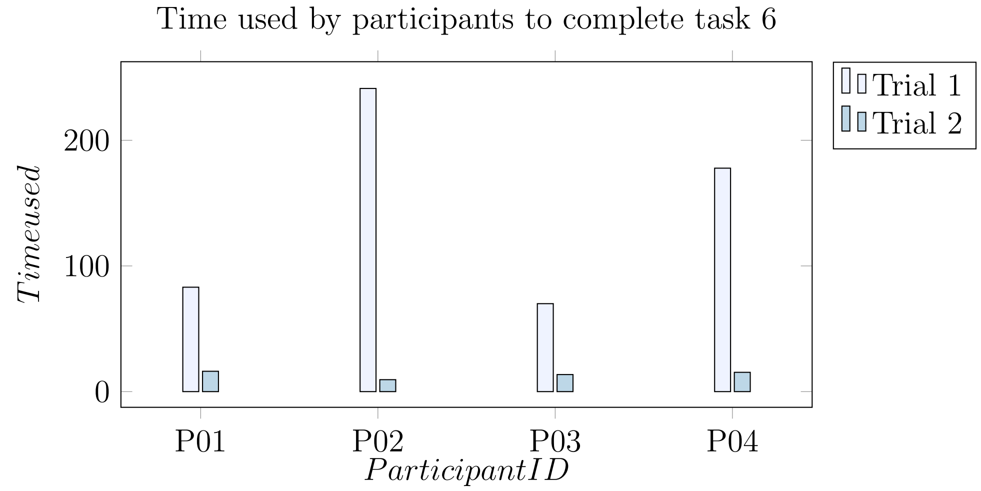


Figure 5.12: Time used by participants to complete task 6

stated *"It's easy to work around and change the view and see the other viewpoints."* and participant B simply stated *"Seems pretty easy."*

5.4.6 Task 6

Task 6 asks the participants to give an estimation of the importance of specific viewpoints. To complete the task, the participants must complete the following subtasks.

- navigate the 3D terrain and place the camera near the target area,
- locate the target viewpoint within the target area, and
- understand the visual encodings used and retrieve the value of viewpoints.

Participants used an average of 78.3321 seconds to complete the task, with a min time of 9.496 seconds, a max time of 241.211 seconds, and a median time of 43.0805 seconds.

CONFIDENCE and DIFFICULTY: Participants reported being of neutral confidence (1), confident (1), and extremely confident (2) in their answers. They found the task to be of neutral difficulty (1), and extremely easy (3).

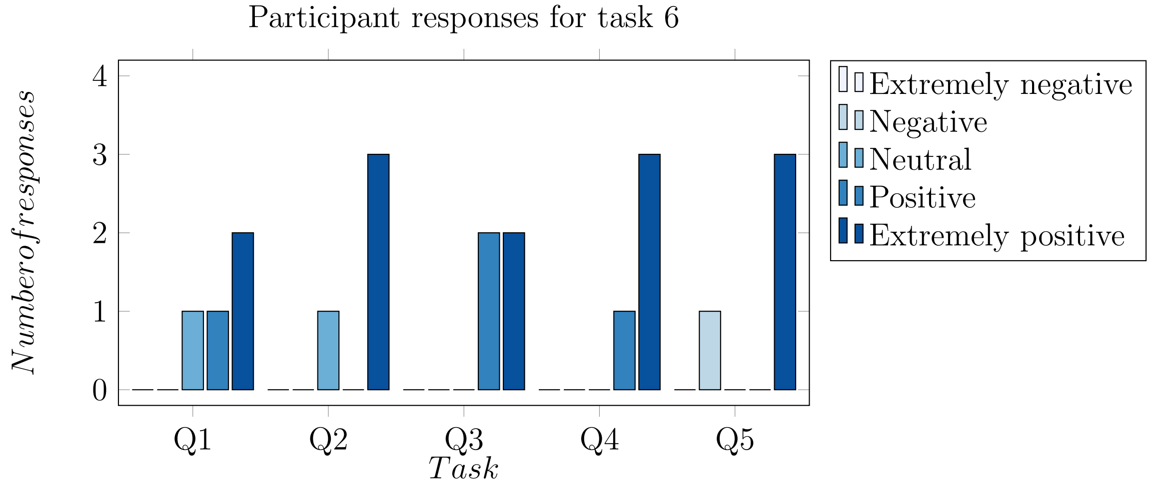


Figure 5.13: Participant responses for task 6, in the order of confidence, difficulty, relevance, importance, and impression.

Participants found the viewpoints easy to interpret, due to their low number of possible values. For example, participant A stated *"There are only three different types of bubbles (viewpoints) and it makes it easy to find high, low, or medium."*

It was observed the most common strategy the participants used for estimation is also by comparing known values. For example, participant C stated *"This is done just by comparing the sizes."* However, one participant pointed out that the size was difficult to read unless viewpoints that can be used as references were located nearby. For example, participant B stated *"[If they're not right next to each other], it's very unconfident, it seems to be changing and it's hard to compare... [If they're right next to each other], it's very confident, so I had the same scale."* They also noted the importance of having an absolute baseline for this strategy, stating *"If you don't have a large circle (viewpoint) around you, all you have is medium or low becomes very hard to know. So you know one is larger than the other, we don't know if they're medium and high or if they're low and medium."*

One participant was confused by the static property of the viewpoints' size as they were expecting depth and perspective distortion within the 3D environment. For example, participant B stated *"The distance and the location distorts the circle (viewpoint). If you're going by the size of the circle, then the distance to it and the angle of it becomes hard to know."*

RELEVANCE and IMPORTANCE: Participants found the task to be relevant (2) and extremely relevant (2). They found the task to be important (1) and extremely important (3) for completing visual impact assessments.

Participants stated that this task is essential as it allows them to prioritize different portions of the forest and understand the suitable amount of modifications an area can have. For example, participant A stated *"You want to be able to identify what polygons are visible from high importance viewpoints. It's also important to be able* *to identify the low ones, you don't want to put all the pressure on the low-importance viewpoints."* One participant noted the task's relevance and importance but details that more generalized data is already part of the calculation for visual sensitivity class. For example, participant B stated *"I might want to manage where I log to certain viewpoints based on its importance, but, again, it's all included already in the bars and accumulated values."*

One suggestion a participant provided is to increase the scale and number of possible values for viewpoint importance. For example, participant D stated *"There could be a lot of difference in between the three samples (low, medium, and high), since, for a viewpoint, it may have a bigger variety. Maybe a numerical scale could be better so that you have a larger spectrum to work with."*

IMPRESSIONS: Participants reported having a negative (1) and extremely positive (3) experience of using Evergreen to complete this task.

Participants described completing the task as easy and simple, providing a positive experience. For example, participant C stated *"Very positive, because of the simplicity."* and participant D stated *"Overall, it's very easy to use and it's very easy to identify which level of importance it (a viewpoint) is."* The negative experience stems from the confusion caused by comparing the size of viewpoints and the static size disregarding depth and perspective, as mentioned previously by participant B.

5.4.7 Task 7

Task 7 asks the participants to find one polygon from which two specific viewpoints are both visible, both not visible, or partially visible. To complete the task, the participants must complete the following subtasks.

- navigate the 3D terrain and place the camera near the target area,

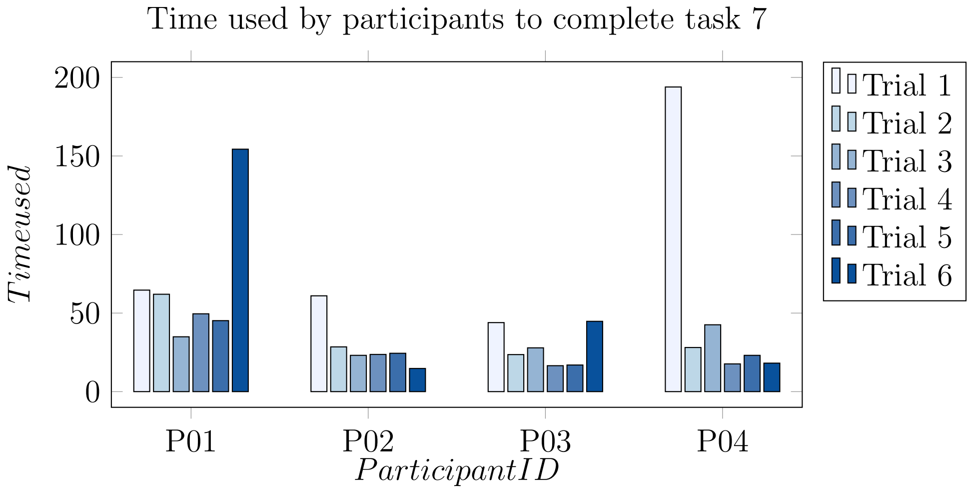


Figure 5.14: Time used by participants to complete task 7

- locate the target viewpoints within the target area,
- annotate the links of the target viewpoints **or** enable the visibility filters of the target viewpoints,
- understand the visual encodings used and determine which polygons fit the criteria of the task, and
- retrieve the selected polygon's ID.

Participants used an average of 45.116 seconds to complete the task, with a min time of 14.732 seconds, a max time of 193.914 seconds, and a median time of 28.2765 seconds.

CONFIDENCE and DIFFICULTY: Participants reported being confident (2), and extremely confident (2) in their answers. They found the task to be easy (1) and extremely easy (3).

This task is similar to task 5 and participants can choose to use the links or the visibility filters to complete it as well. Most participants opted to use the visibility filters, describing them as easy to use and easy to get results. For example, participant

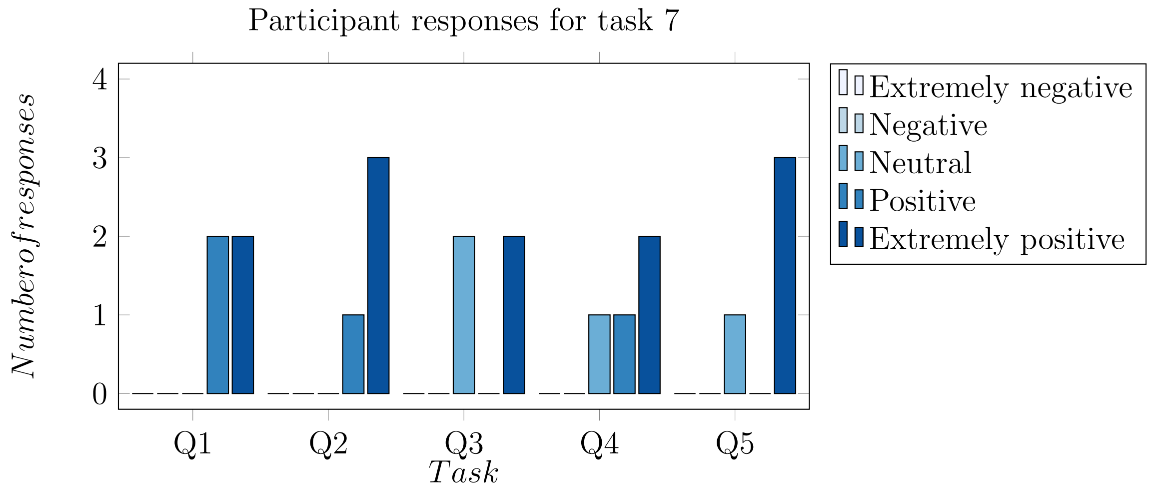


Figure 5.15: Participant responses for task 7, in the order of confidence, difficulty, relevance, importance, and impression.

D stated *"It was very easy to use and very easy to apply... Once you click the tool, the answer is in front of you basically."*

Participant B was the only one to use the links to complete this task. They noted a similar issue pointed out by participant A during task 4, in which the association between polygons, bars, and links can sometimes be unclear when an excessive amount of links are displayed. Participant B stated *"There's somewhere the line (link) doesn't reach quite to the polygon, it kind of hovers in the air, and it's hard to see which polygon it might be going to."*

When asked, participants reported preferring the visibility filters more than the links. For example, participant A stated *"The filter function is pretty useful. It's easier to see than the bars, you can see the polygon disappearing and appearing."* However, participants also noted the importance of links when looking for more detailed information. For example, participant D stated *"I prefer this one if I just want a straight answer of whether it's visible or not. I think the links are better if you want to know the scale of how it is visible from that viewpoint."*

RELEVANCE and IMPORTANCE: Participants found the task to be of neutral relevance (2) and extremely relevant (2). They found the task to be of neutral importance (1), important (1), and extremely important (2) for completing visual impact assessments.

Participants commented that the task is useful to determine which visibility relationship between viewpoints and polygons. For example, participant B stated *"Could be useful to compare polygons to see how many viewpoints are visible to it, or if particular viewpoints that are important."* This may be essential knowledge when planning modifications nearby existing operations as well. For example, participant C stated *"From that aspect, I think it's very important, so you can get the number of viewpoints that can see this polygon if any operations are going on."* Participants also provided an example of how this task may affect stakeholders during the decision-making stage. Participant D stated *"Like viewpoints 6 and 8, it's very nice to know that all the polygons are visible from those two points, so it'll be easier to choose between one or the other viewpoints. You don't need to go to both viewpoints, especially viewpoint 8, which has a lower importance, since you'll be able to see the same polygons from those two areas."*

IMPRESSIONS: Participants reported having a neutral (1) and extremely positive (3) experience of using Evergreen to complete this task.

Participants described their experience as smooth and easy. For example, participant C stated *"I feel everything is automatically calculated and selected, encoded in the software. As the user, it didn't take that long time to learn."*

5.4.8 Overall Experience

The participants responded positively when asked about the learnability and usability of Evergreen, in regards to both the visuals and the interactions.

Participants noted the navigation controls were intuitive and easy to use, with participant A stating *"I always have some sort of difficulties with, in general, moving in environments like that, or video games, but once you get used to it, it's pretty easy."* However, participants with little to no prior experience with video games and their controls indicated the teleport-to-component functionality provided an efficient alternative to navigation within the environment.

For the polygons, participants provided only positive feedback, stating that the polygons were easily accessible and that the three-class color scheme was intuitive and easy to distinguish.

Participants were more split about the viewpoints. Positive feedback includes that the viewpoints are easily accessible, that the color scheme used when its visibility filters are enabled is easily understandable, and that the size-encoded viewpoint importance is easy to read. Negative feedback includes that viewpoint importance is hard to read, as reported by one participant, that the static size which ignores depth and perspective is sometimes confusing, and that the first-person simulation supported by viewpoints is less useful and confusing in certain scenarios, such as when the viewpoint is far away from the area of interest.

For the bars, feedback revolved mostly around the high-level bars, with some that apply to low-level bars as well. Although the bars are considered to be important for the completion of visual impact assessments, participants noted it is sometimes difficult to estimate the value of the bars, as there are nine possible values, and that being within a 3D environment causes difficulty to read the bars when the camera is placed at extreme angles, due to occlusion and perspective. The latter also applies to the low-level bars as well, though the low-level bars were considered easy to estimate, due to there being only four possible values. In addition, one participant noted the color hue selected to present each of the four low-level parameters is not intuitive, although it can be remedied by referencing the manuals or through more use of the system.

Finally, the links received both positive and negative feedback as well. Positives include the links allowing users to understand complex relationships of components within visual impact assessments, such as comparing polygons or viewpoints based on visibility, and the redundant visual encoding used to encode visibility being an effective fail-safe when participants are having troubles with reading one of the encodings. Related to the positives, the negatives include the color hue and the dashes being difficult to read, depending on the participant, and the association between polygons and links being imperceptible occasionally due to the offset in height from the terrain given to the links, causing the participants difficulty when determining which link belongs to which polygon and forcing them to rely on additional interactions such as highlighting.

Overall, Evergreen is perceived positively and considered straightforward to use. Participant A stated ”There’s some simplicity to it that I like, keep it to the essentials.“

When asked whether they are willing to include Evergreen into their workflow of completing visual impact assessments, participants responded positively as well. Major points include Evergreen providing basic information at the same time and making it easily accessible, such as polygons, viewpoints, and their associated data. Participants also stated the option to break down the data and allow them to dig deeper into areas of interest for more information is useful as well.

Chapter 6

Discussion

In this chapter, we discuss the findings from the formative study and the evaluative study.

6.1 Design Decisions

6.1.1 Navigating the environment

There are two ways to navigate the environment within Evergreen, manipulating the camera using the WASD keys and mouse or teleporting to components using the implemented interactions. The teleport provides quick access to the component and the WASD keys provide fine-grained controls for the users to explore the surrounding environment. This can be observed in one participant's switch of strategy, who initially relied only on WASD keys, but shifted to the above approach after becoming more familiar with the system.

However, apart from the aforementioned participant, three participants avoided the WASD keys as much as possible, using only the teleport function to move the camera and, in some cases, kept the camera in its default position and completed the tasks from less than preferable positions. This caused issues and increased the difficulty of estimating values from components such as bars and links not only with the small size but also with occlusion and perspective. This is perhaps due to their unfamiliarity with the system and with 3D environments, as common GIS applications such as ArcGIS and QGIS are placed in 2D environments and users can use only the mouse to control camera movement. It is also observed that the participant's experience with systems with 3D environments, such as video games or simulations, correlates with the strategy they employ to explore the environment, as the only participant that actively uses both approaches to control the cameras is also the only participant that reported to be somewhat familiar with 3D environments within the demographics questionnaire.

6.1.2 Polygons

Evergreen visualizes polygons within the forest by directly applying a layer of color onto the terrain. Whether or not additional modifications can be placed within a polygon is broken down into three categories and encoded using color hue, green, orange, and red. Participants stated the polygons to be easy to access and easy to read, due to the polygons being visible as soon as Evergreen starts, the small number of classes it visualizes, and the distinguishable colors utilized.

However, two main problems exist with the approach used to visualize polygons. As the sample dataset used comes from a research forest and minimal modifications have been done to it, the majority of the forest allows additional modifications, which causes the terrain to be mostly shaded in green with little specks of orange and red. This caused confusion in some cases as, since the terrain is shaded with mostly the same color, participants were unsure where the green polygons were. This is aggravated by the choice of using green, which blends into the forest due to having similar colors. This issue can be resolved by adding boundary outlines to the polygons, which signifies the bounds of each individual polygon at the cost of performance. It can also be resolved by using real-world datasets, which are more diverse and will generate less confusing color layers.

6.1.3 Viewpoints

Viewpoints are visualized by placing custom-made models of pinpoints onto the terrain and using 2D size to encode viewpoint importance, which is a three-class ordinal data. Similar to polygons, it is also visible as soon as Evergreen starts.

There are two approaches that participants used to estimate the viewpoint importance observed during the evaluation, including directly reading the viewpoint or comparing two viewpoints, and can be used separately or intermittently. For participants that use the latter approach often, they often have difficulty estimating the encoded value as neighboring viewpoints used as baselines does not always exists, and, when not, this approach requires participants to have a mental model of the three sizes used, which further increases the mental load required.

We also believe that, initially, participants all apply the comparing approach to a degree and, as the evaluation goes on and they become more familiar with 3D objects and environments, they are more comfortable directly estimating the value without referencing other objects within the environment. The speed to which this process completes also correlates with the participant's familiarity with 3D environments. It is observed that not only is the sole participant who reported being somewhat familiar with 3D environments the most rapid at shifting their strategy, but they also did not reference neighboring viewpoints by the second trail of the task and relied only on their mental model of the environment.

This issue can perhaps be resolved by switching to another visual encoding or introducing redundant encodings for viewpoint importance. However, it is important to avoid reusing color hue, as it is already used in polygons for another data dimension and may increase stress and confusion for the participants if reused.

6.1.4 Bars

The bars are one of the components that are not visible by default and require interactions to activate. Within Evergreen, they are used to visualize forestry-related attributes of polygons and can be broken down into high-level bars and low-level bars.

There are two main issues with the high-level bars. First, as the bars are eight units in length and can have nine possible values, it is sometimes difficult to estimate their value, especially in cases where it appears to be in the middle of the range. It is observed that participants follow a similar approach to reading the bars with reading the viewpoints where the comparison method is also used as well. As such, this issue may be resolved by adding a baseline to the middle of each bar such as labels or slight alteration in color, thus allowing participants a way of confirming their estimation.

Second, different from 2D bars, occlusion and perspective may cause difficulty in estimation as well. Occlusion is when another object is placed in between the camera and the bar, causing some areas to be visually blocked. It is also possible to self-occlude, such as when the camera is positioned directly underneath the bar. Perspective is when the camera is placed at a slightly higher or lower angle which causes the bar to become distorted and thus difficult to read. The two issues revolve around camera manipulation and are perhaps non-existent for users more experienced with 3D environments. This is observed as well through the evaluation, as the participant who reported being somewhat familiar with 3D environments made no reports or complaints about occlusion or perspective distortion, perhaps due to them being comfortable using the WASD controls for fine-grained camera manipulation. However, this issue should be resolved by implementing the navigation approach described in the above subsection, which gives some control back to less experienced users.

Another issue mentioned by the participants relating to occlusion and perspective includes the contrast in the transparency of the opaque and transparent sections of the bars. One participant stated it is difficult to identify the location which divides the two portions, causing inaccurate estimations of the value of the bars. However, this may be caused by the participant's unfamiliarity with 3D systems and navigation within 3D environments, as the specific participant regularly avoids moving the camera and attempts to complete the tasks from its default location, typically far away from the target bars. Anyhow, to resolve this issue, the transparency contrast can be modified to make the two portions of the bars more visually separable, though the exact value should be determined by future studies.

For the low-level bars, four smaller bars are vertically stacked to represent the added value of the high-level bar, with the last value being subtracted, or flipped. This approach did not cause any confusion to the participants, indicating that the stacked bar approach may be a suitable method to visualize more complex relationships between parameters including addition and subtraction. Due to the low number of possibilities the low-level bars can have in terms of value, participants did not report them as difficult to estimate and achieved high accuracy when completing the tasks. However, the issues with occlusion and perspective persist with some participants stating similar complaints to the high-level bars.

6.1.5 Links

The links are the other component that is not visible by default. Within Evergreen, they are used to visualize the visibility relationship between polygons and viewpoints and categorize the visibility into three classes, low, medium, and high. Redundant encoding is used, which applies two or more visual encodings to represent the same data. In this scenario, both color value and shape, in the form of dashes with different length, is used to represent the three visibility classes.

There are two main issues with the links, one for each visual encoding selected. First, using color value, the three visibility classes, from low to high, are represented using light green, green, and dark green, respectively. However, participants reported the colors being difficult to differentiate. This may likely be due to the difference in color value being insufficient, making the three categories visually similar. However, it is also possible the lighting and rendering system within Unity caused the difficulty, as the rendered color and shadow on the components are different depending on the location of the camera and its relative position with light sources within the 3D environment.

Another issue is with the shape of the links, which uses dashes with long spaces, short spaces, and full lines to visually represent low, medium, and high visibility respectively. Similar to the approach used to read viewpoints, participants often employ the comparing approach to understand the links and their value. As such, participants pointed out it is difficult to differentiate links with low or medium visibility, especially when neighboring links are of the same value since comparison is impossible under this scenario. This issue does not exist for high-visibility links, as full lines are visually apparent. The dashes are also affected by occlusion and perspective as well, as the visual encoding is highly reliant on analyzing the length of the spaces and the ratio of dash and space to understand.

One interesting observation for the links includes that, although the participants pointed out issues with the representation used for the links, the participants are generally able to complete the task and identify the visibility correctly. This may be due to the fact redundant encoding is used, and participants are able to refer to the other visual encoding when they find one difficult to decode. This result is in line with past research which found the correct use of redundant encoding is able to increase the accuracy and readability of visualizations.

Chapter 7

Conclusions

In this chapter, we review our research questions, research approach, and research contributions. We then discuss the limitations and future work to extend this study.

7.1 Research Contributions

This thesis includes three main research contributions.

- A collection of tasks foresters carry out when conducting visual impact assessments, including the planning phase and the assessment phase. These tasks are derived from the analysis of official government guidelines and interviews with domain experts.

In chapter 3, we described the steps we took to understand the visual impact assessment process. This included going over existing literature, with a focus on government-published documents, and speaking to domain experts with various levels of experience within the field. In chapter 4 section 4.1, we provided a list of tasks that are important to the visual impact assessment process retrieved through the previously described study.

- The implementation of Evergreen, a system designed to assist foresters in conducting visual impact assessments. Evergreen is designed using the guidance of design requirements derived from the aforementioned tasks.

In chapter 4, we described Evergreen, the system designed and implemented for this thesis. We described the design requirements, the data used, and various aspects and components of the system.

- The evaluation of Evergreen with domain experts. This confirms the usefulness of Evergreen in terms of conducting visual impact assessments. The findings also suggest the direction for future work and the improvement of Evergreen.

In chapter 5, we described how Evergreen was evaluated. This includes the study procedure, the participants, and the findings of the evaluation. In chapter 6, we talked about our interpretation of the findings and suggested methods that may resolve some issues that arose during the evaluation.

7.2 Limitations & Future Work

The two studies within the thesis, including the preliminary study and the evaluation, were conducted during the COVID-19 pandemic and were required to adhere to restrictions placed by the university to ensure the protection of public health, such as limited travel and no in-person studies. As a result, both studies were conducted online and remotely using Zoom without face-to-face interactions between the participants and researchers.

For the preliminary study, although remote interviews are not uncommon, it is still different from in-person interviews to plan and execute. In addition, remote interviews provide results lacking in detail compared to in-person interviews, as researchers miss out on observing nuances such as facial expressions and body language. We also found it difficult to build rapport with participants during remote interviews and to control the flow of the discussion.

For the evaluation, the effects of conducting the research remotely have an even more obvious impact. As the evaluation also had portions of interviews, the aforementioned disadvantages also apply to it. Furthermore, as the participants were required to learn and interact with Evergreen during the evaluation, it was difficult to direct the participants and provide assistance to them as it was impossible to take over the controls of the system and have to instead rely on verbal communication. Another disadvantage is related to hardware. Evergreen is taxing to operate in regard to system requirements, as it is within a 3D environment rendered with numerous complex meshes. Network latency was also an issue, making discussions during a task difficult and the interviewers often have to wait until tasks are completed for discussion, by which time participants had to recollect feedback they wish to provide.

Another limitation of the study is the number of participants recruited. As Evergreen is targeted towards foresters and visual impact assessments, it is crucial participants for both studies are domain experts from the demography in order to gain meaningful insights. This restricted recruitment to only foresters with prior experience in conducting visual impact assessments and increased the difficulty of finding participants. In the end, only three participants were recruited for the formative study and four participants were recruited for the evaluation. This number of participants, although acceptable and did provide valuable insight towards understanding the visual impact assessment process and Evergreen, can benefit from having more participants.

Overall, conducting the studies remotely rather than in-person introduced more disadvantages than advantages. It would be beneficial to this thesis and to understanding how Evergreen can be improved to conduct similar studies in-person as well as increase the number of participants recruited to gather more elaborate data and insights.

Another interesting point for future work would be to understand in more detail how 3D benefits the users of Evergreen, what it does better, and what it does worse than 2D. From the evaluation, participants stated both liking and disliking the 3D environment depending on the task they were attempting to complete. However, from the analysis, no conclusions were reached as to which specific tasks benefits from 3D. Although preference from the participants hugely attribute to this question as well, it would be interesting to understand this and further improve Evergreen or other 3D systems based on the findings.

Finally, as mentioned in chapter 6, there are several design choices within Evergreen that can be modified, improved, and perhaps studied more thoroughly with quantitative studies. Most design choices within Evergreen have been used in past work and similar systems placed in 3D environments, with some being listed in chapter 2. However, these implementations still received both positive and negative feedback during the evaluation. It would be beneficial to Evergreen and future iterations of the system to understand these design choices and their alternatives to create a better system. Some of these design choices include the following.

- What is the maximum amount of classes that can be encoded using 2D size within a 3D component (e.g. the viewpoints using 2D size to encode viewpoint importance)?
- What is the maximum amount of values that can be encoded within 3D bars?
- What is the maximum amount of low-level bars that can be used in a stacking manner?

- How effective are dashes as visual encoding within a 3D environment and how do users interpret them?
- To what extent do lighting and shadow affect users in reading color-related visual encodings?

7.3 Conclusion

In this thesis, a 3D system, Evergreen, was created to assist foresters in conducting visual impact assessments, a government-regulated process foresters are required to complete in order to modify forests within BC.

We first learned of the domain from government documents and domain experts to understand the process better and to understand which parts of the process can be improved by adding visualization to the workflow, in terms of both quality and time. Using our understanding of the process, we derived tasks and design requirements that guided the design phase of Evergreen.

Evergreen is then prototyped and implemented using Unity, a game engine capable of building 3D environments. We looked at several existing work and literature within the 3D visualization space to understand what has already been done and what designers and users prefer to use. Using the knowledge gained, we designed Evergreen to support the derived tasks with both learnability and usability in mind.

Finally, we evaluated Evergreen with domain experts. During the evaluation, emphasis was placed on whether Evergreen would assist them during visual impact assessments as well as whether our implementation and various design choices are easy to understand. We learned several advantages and disadvantages of Evergreen from the participants that would serve as guidance for future iterations of the system.

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Appendix A

Appendix

A.1 Prototyping

To guide the design and implementation of Evergreen, we conducted a prototyping phase in which design ideas were generated based on the established design and task requirements and knowledge of the available data.

In this chapter, we describe the prototyping process and rationale for the methods we employed. Next, we talk about some of the generated prototypes, including how to read the prototype, the design decisions, the requirements it supports, the data it utilizes, and its advantage and disadvantages.

A.1.1 Procedure

Due to time constraints, the prototyping phase consists only of low-fidelity prototyping. Although low-fidelity prototyping, compared to mid and high-fidelity prototyping, is limited in terms of the details the prototypes provide, it is able to support rapid prototyping and provide a medium for communication [73].

As one of the main purposes of Evergreen is to provide foresters access to the related data through visualization within the context of the area they are interested in, it is important that Evergreen is built on top of the terrain. To gain an accurate understanding of how the ideated designs may look when implemented, it is crucial to include the terrain in the prototyping phase as well.

Two different methods were employed during the prototyping phase. At the start of the phase, we created screenshots and printed random areas of the terrain from various heights and angles, which served as the basis on which the sketches were created. However, this method has several disadvantages such as the sketches being difficult to perceive, only providing limited perspective of an idea unless it is recreated onto another screenshot, inflexible, and time-consuming to generate, which defeats the purpose of low fidelity prototyping.

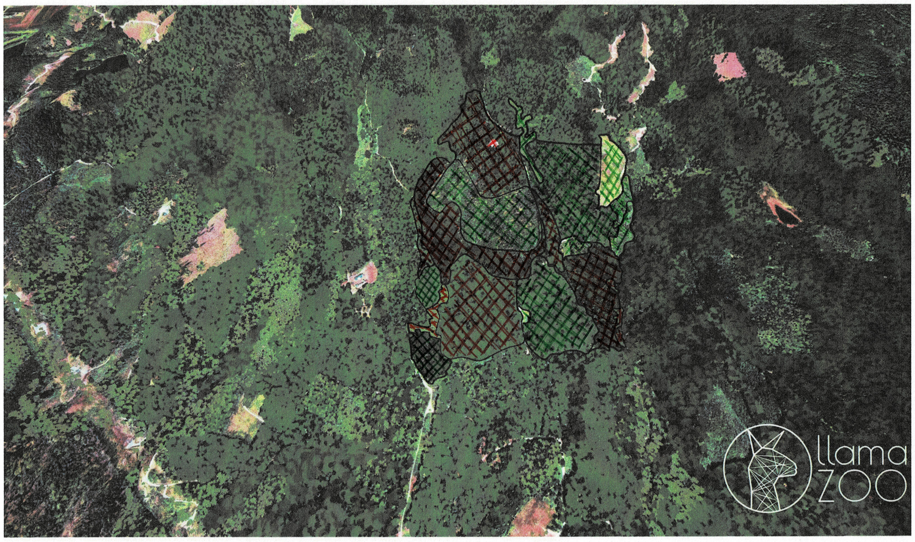
To resolve the above issues, some modifications were made to the process. For the later parts of the prototyping phase, instead of directly sketching onto the screenshots, sketches were generated by overlaying tracing paper onto the screenshots and sketching on them. This allows for a more flexible prototyping phase as the designs can now be examined on different landforms by simply exchanging the overlaid screenshots.

The sketches generated during this phase all focus on supporting just one or two requirements. Several meetings were held with researchers in the research team to evaluate the prototypes against the requirements they support in terms of expressiveness, effectiveness, and general readability of the proposed visualization. The advantages and disadvantages of each prototype are noted and used to improve future sketches. The iterative process took around one month with weekly discussions.

A.1.2 Prototypes

The following are some of the relevant prototypes ideated during the prototyping phase. These prototypes either highly support the design and task requirements of

Evergreen or contain at least one design that is implemented in Evergreen. The prototypes are listed in the order in which they were ideated.



Color hue on transparent overlays to encode whether VSC exceeds EVC (whether a new cut block plan will be approved)
Filters should support calculations with VSC and EVC (eg. show only VSC - EVC ≥ 10%)

Figure A.1: Prototype A

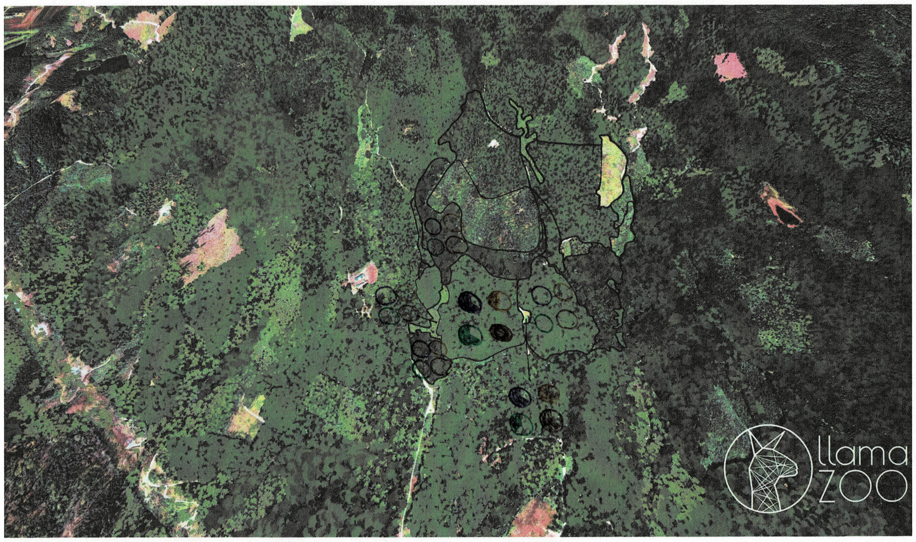
Prototype A (Figure A.1) uses an overlay on the terrain to display whether the polygons can have additional modifications in terms of visual quality by layering them with specific color hues. This is determined by comparing the polygon's visual sensitivity class and existing visual condition and can be categorized into the following three categories.

- the visual sensitivity class is greater than the existing visual condition, which means additional modifications can be added
- the visual sensitivity class is equal to the existing visual condition, which means additional modifications can maybe be added
- the visual sensitivity class is lesser than the existing visual condition, which

means additional modifications can not be added

As this is categorical data with only three categories, it is suitable to encode the data using color hue, which retains the expressiveness and effectiveness of the data. In the design, we used the colors green, orange, and red, respectively. For example, if a polygon is overlaid with green, it will mean that additional modifications can be added to it. On the contrary, if a polygon is overlaid with red, it will mean that it can not have any additional modifications.

This design supports only R1 as it does not provide any information other than whether a polygon can have additional modifications.



Colour hue to encode what parameter it is (VAC, BR, VC, VR)
Angle to encode ordinal level (High, Moderate, Low)

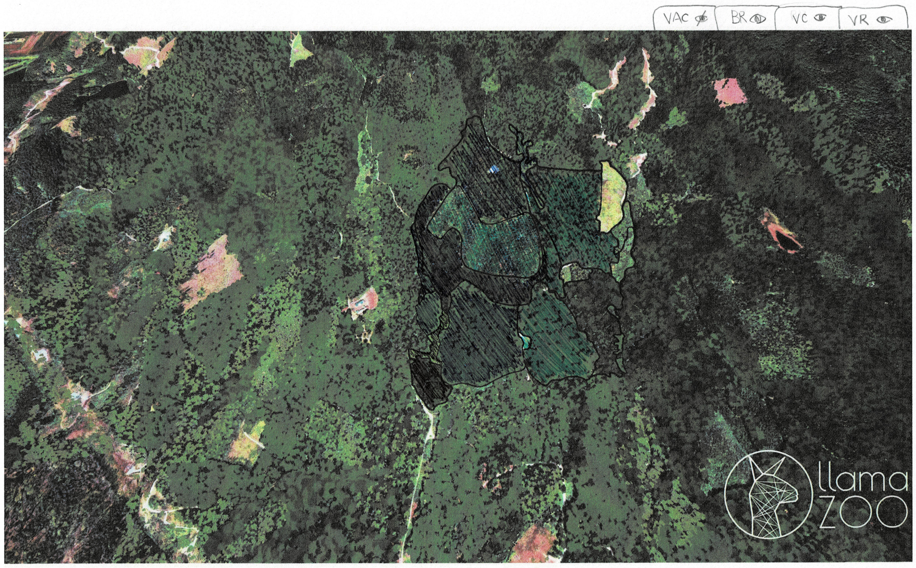
Highlighting support for Interactions.

* small polygons would need some sort of compensation

Figure A.2: Prototype B

Prototype B (Figure A.2) focuses on R2 and on visualizing the four low-level parameters: visual absorption capability, biophysical rating, viewing condition, and viewer rating. There are four pie charts inside each polygon, representing the four low-level parameters respectively.

To differentiate between the different pie charts, spatial region and color hue have been used to encode what parameter is visualized, which is categorical. As the parameters are ordinal and have a minimum value of one and a maximum value of three, it is suitable to represent the data using pie charts, which use angle as the encoding.



Color hue to encode what parameter it is (VAC, BR, VC, VR)
Color value to encode ordinal level (High, Moderate, Low)

Interactions should Include drag & drop, toggle visibility,
reordering of layers,
transparency control.

Figure A.3: Prototype C

Similar to prototype B (Figure A.2), prototype C (Figure A.3) focuses on R2 and the four low-level parameters as well. However, instead of utilizing multiple pie charts inside the polygons, it uses an overlay system similar to prototype A (Figure A.1). Prototype C (Figure A.3) visualizes only one of the four parameters at once, with interactions tab-like structures on the top right to transition the parameter that is being visualized. Although not apparent in the sketch, the tab-like structures should support interactions such as drag and drop, reordering, and toggle visibility and transparency, imitating the manipulation of physical slides.

In this example, color hue is used to encode what parameter is being visualized, similar to prototype B (Figure A.2). However, instead of using angle, prototype C (Figure A.3) utilizes color value to encode the value of the parameters. As this is ordinal data with only three levels, it is also acceptable to replace color value with color chroma, depending on preference.

Figure A.4: Prototype D

Prototype D (Figure A.4) is the first sketch that incorporates a design that supports both R1 and R2. It is able to show whether a polygon can have additional modifications and visualize its associated attributes. Bars are offset on top of each polygon and display the polygon's visual sensitivity class. An object is placed beside each bar indicating the polygon's existing visual condition. As visual sensitivity classes are not on the same scale as existing visual conditions, visual sensitivity classes have eight levels and existing visual conditions have six levels, additional conversion is required and the range indicating existing visual conditions may not always translate to one bar unit within the visualization. Similar to prototype A, color hue is used to visualize whether the polygon can have additional modifications. However, instead of overlaying the color hue onto the terrain, it is displayed on the bars.

To visualize the four low-level parameters, the bars can be selected to toggle four smaller stacked bars, as shown on the bottom left of prototype D (Figure A.4). As visual sensitivity class, represented by the larger bars, is computed using the four low-level parameters, the use of stacked bars in this scenario is intuitional. It is worth noting that as visual absorption capability is subtracted from the results, it is placed separately and flipped over.

In the prototype, position on a common scale is used to encode the values of visual sensitivity class, existing visual condition, and the four low-level parameters. Similar to prototype A, color hue is used to encode whether the polygon can have additional modifications.

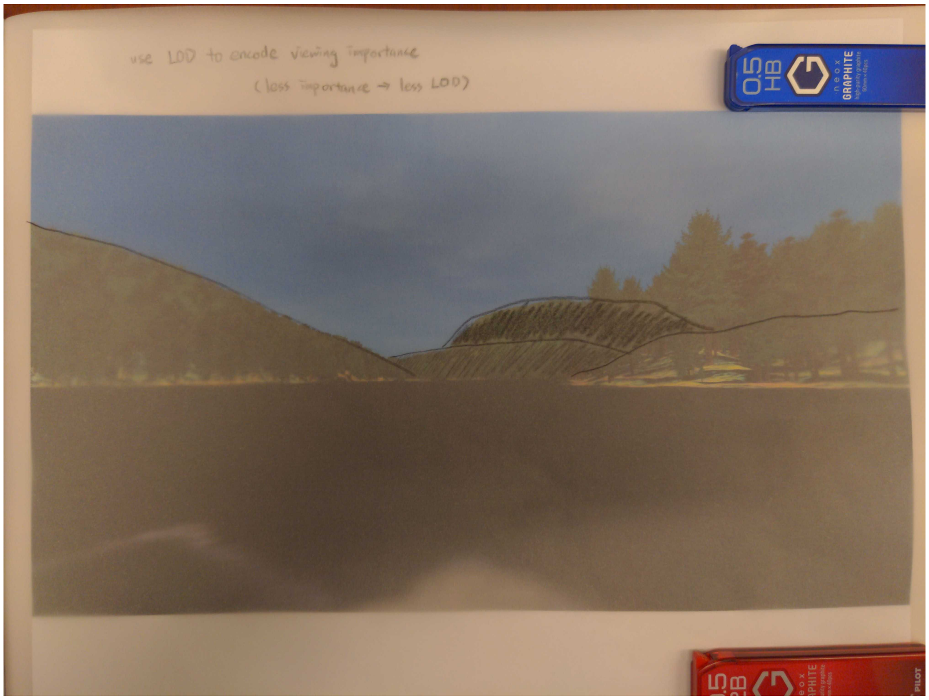


Figure A.5: Prototype E

Similar to prototype A (Figure A.1), prototype E (Figure A.5) focuses solely on whether the polygons can have additional modifications as well. It uses level of detail as the visual variable. For example, if a polygon is displayed with high quality, it will mean that additional modifications can be planned. On the contrary, if the polygon has a low level of detail, it will mean that the polygon has already reached its maximum capacity for modifications.

Although level of detail is not an effective visual variable, it is sufficient in this case as there are only three categories within the data. In addition, using level of detail is intuitive as the users' focus will be shifted to polygons with the highest details, which is beneficial as those are the polygons that allow for modifications.

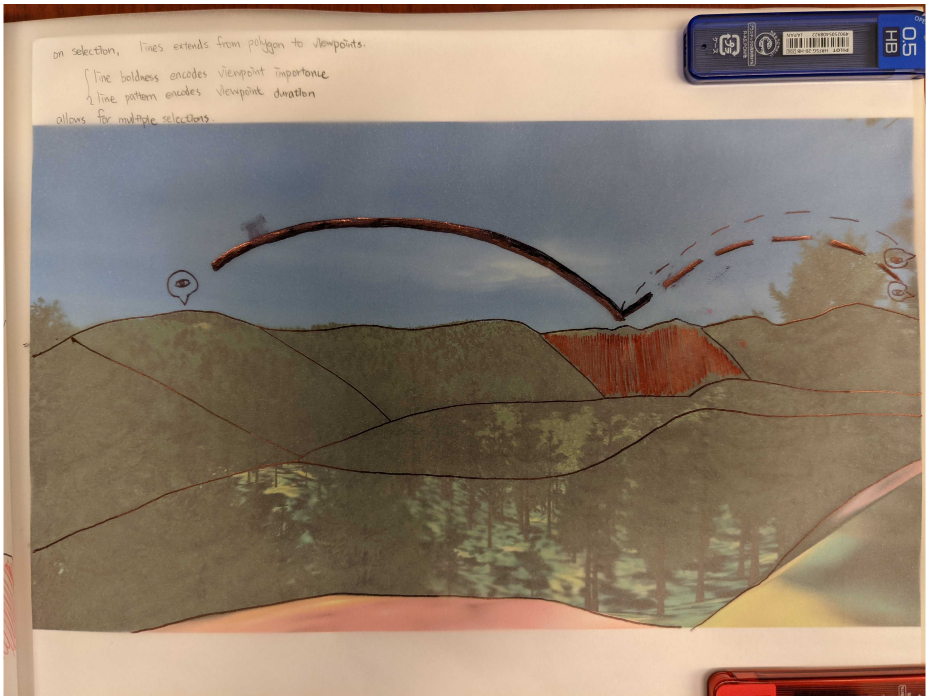


Figure A.6: Prototype F

Next, prototype F (Figure A.6), G (Figure A.7), and H (Figure A.8) are designs focusing on providing support for R3 and R4. Although seemingly different, the three prototypes visualize viewpoint data and their relationships with polygons. A design similar to prototype A (Figure A.1) is used in the three prototypes, encoding whether

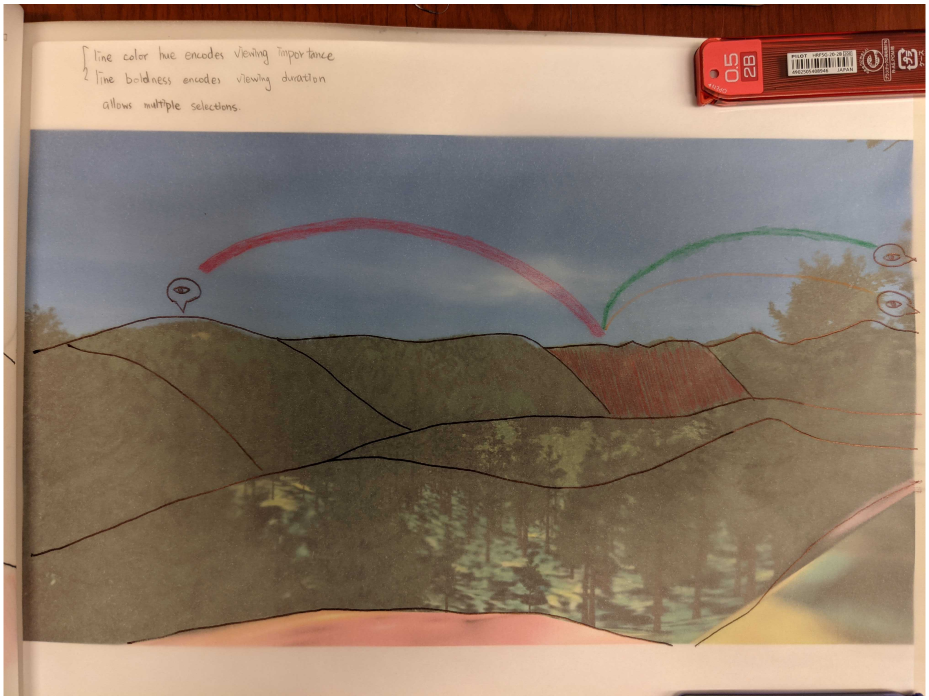


Figure A.7: Prototype G

the polygon can have additional modifications using color hue. The three prototypes are interactive and the sketched representations are assuming the users have selected a polygon they want to explore, which is the one with visible color overlays. On selection, curved lines are extended from the polygons to the viewpoints that are visible from the selected polygons.

The three prototypes use a combination of size, in the form of line thickness, color hue, color value, and dashes to encode viewpoint importance and viewing duration. It is worth noting that since color hue is already used for the polygons, it is a less effective choice in comparison to other visual variables.

Prototype I (Figure A.9) and H (Figure A.8) also focuses on R3 and R4, although from a different approach. Different from the prototypes that utilize lines to visualize the relationship between viewpoints and polygons, prototype I and H utilizes color value to describe the visibility of the polygons. The viewpoints simulate a light

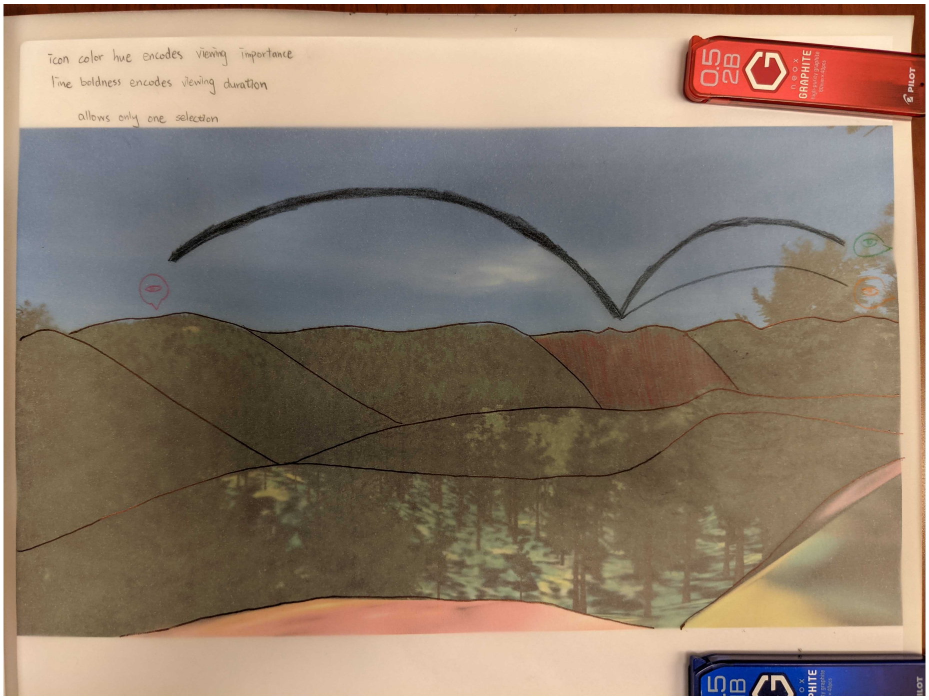


Figure A.8: Prototype H

source in which the more visible a polygon is, the brighter it will become. For example, if a polygon is highly brightened, it means that it has high visibility from the surrounding viewpoints. This is combined with color hue, which, similar to prototype A (Figure A.1), uses color hue to represent whether the polygon can have additional modifications.

Prototype H (Figure A.8), although follows a similar design to prototype I (Figure A.9), depicts the interactions in which the viewpoints can be toggled, acting like a mechanism similar to that of a switch.

Finally, prototype K (Figure A.11) also focuses on R3 and R4, following an approach more similar to prototypes F (Figure A.6), G (Figure A.7), and H (Figure A.8). However, instead of lines, the relationship between viewpoints and polygons is represented using triangles, or shapes. Each viewpoint includes several triangles that are pointing outwards, towards visible polygons and scales with the distance between

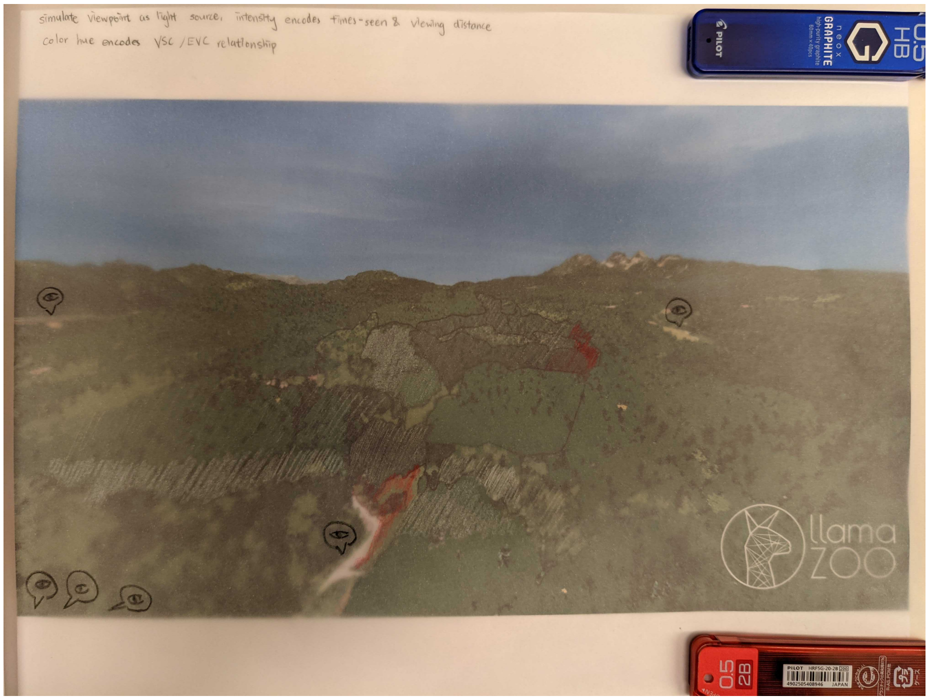


Figure A.9: Prototype I

the viewpoint and the target polygon. In this prototype, angle encodes the direction of viewing and length encodes the viewing distance. It is also worth noting that although in the prototype, color hue also encodes viewpoint importance. However, this approach has a similar problem as described above.

A.2 Non-Visualization Components

The compass and the altimeter provide directional information and aim to assist the user in navigating the three-dimensional terrain within Evergreen by providing a sense of direction in regard to location and pathfinding, indicating the orientation and height of the camera respectively. The two components are commonly used in real-world navigation and orientation devices, as well as real-world applications such as video games. In Evergreen, the compass is a horizontal line that includes the four letter labels (N, S, E, W) and vertical dashes in between the labels to represent the

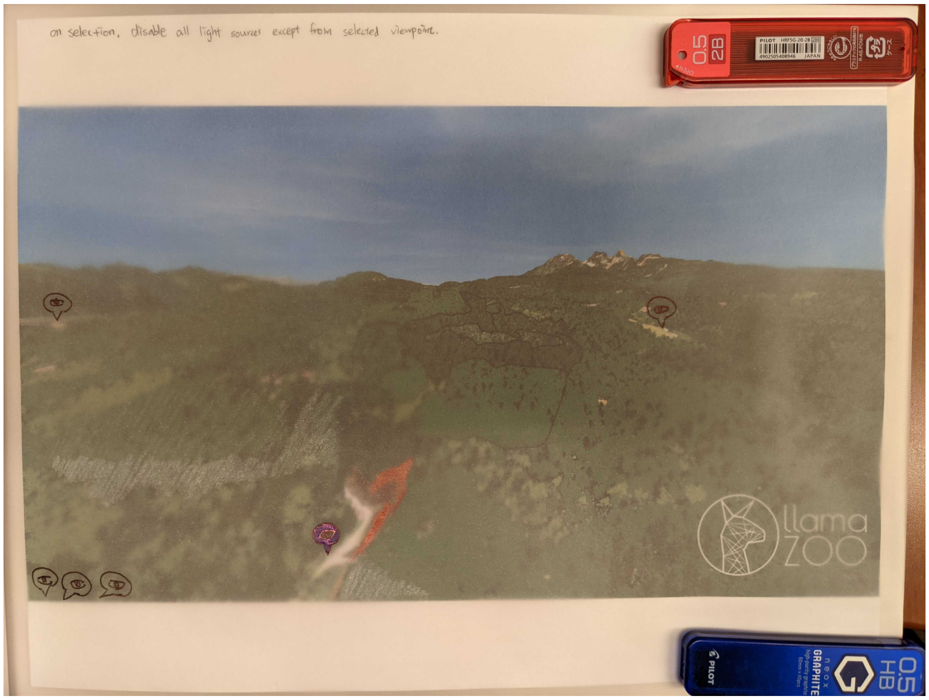

on selection, disable all light sources except from selected viewpoint.

Figure A.10: Prototype J

dials of a physical compass, set to repeat every ten degrees. The labels are colored in orange and set to have a larger font size and the dashes are white and smaller, making the labels more prominent to view. This is important as the labels provide the user with a general sense of direction while the dashes are used only for fine-tuning. The compass is set to have a viewing angle of 150 degrees and centered in the middle with 75 degrees at both sides. Visuals outside of that range are hidden from the display. The altimeter is a vertical line that includes a solid rectangle in the middle. The position of the solid rectangle indicates the current height of the camera. Both sea level elevation and ground level elevation are visualized using the altimeter, represented using the lower and upper bounds of the solid rectangle, depending on which value is larger. For example, the higher the solid rectangle is, the higher the current elevation, and, the longer the solid rectangle is, the larger the difference between sea-level elevation and ground-level elevation. To help the user identify critical information from the altimeter, two icons indicating sea level

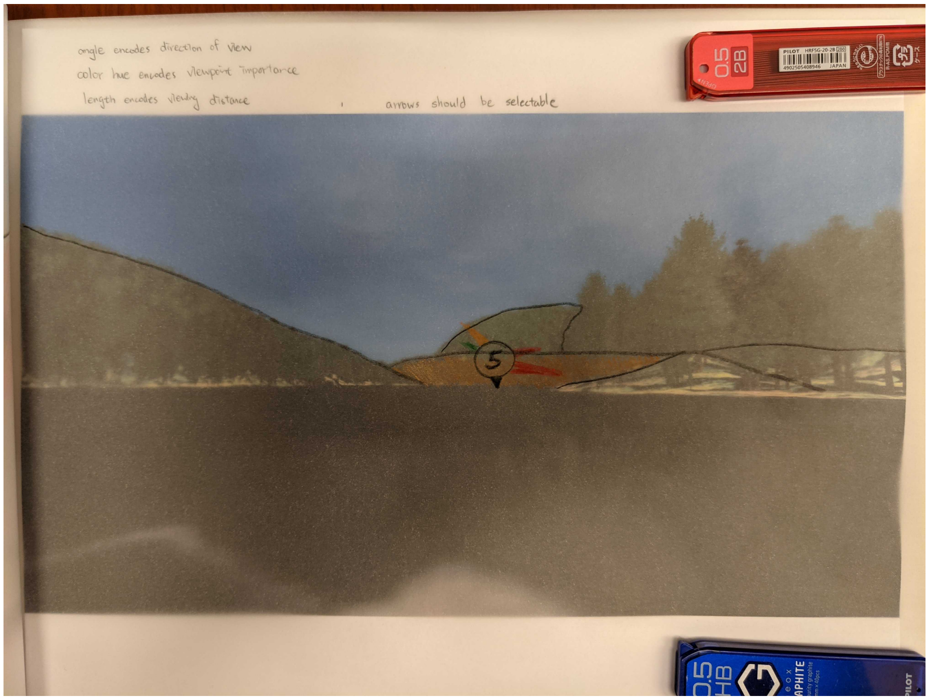


Figure A.11: Prototype K

elevation and ground level elevation are placed on the right side of the solid rectangle and numeric labels indicating the height in meters are placed on the left.

As it is unclear when the user may require navigational information, the two components are implemented as part of the user interface, which is always on top. However, as both components do not provide information that is critical for visual impact assessments and is only navigation aid, they should be as undistracting as possible. To achieve this, the two components can not be directly interacted with by the user, only passively when the camera is moved or rotated by the user. The mainly white color scheme used by the two components is also part of the effort to lower their visibility of them when navigational information is not needed by the user. It is worth noting that although the compass and the altimeter provide effective navigational information as a simple aid, it does not provide information outside of the camera. For example, the user will not be able to calculate the distance between themselves and a target location using solely the two components.

The distance filter is a game object placed at target positions by the user. Visually, it is also a pinpoint-like model pointing down toward the target position. As viewpoints and distance filters follow a similar concept, both representing a position within the terrain, the appearance of the two components is designed to be easily distinguishable. Numeral labels are placed on the distance filters to indicate their ID, determined by the order in which they are created. When activated, it filters viewpoints or polygons or both, depending on the user's settings, based on their distance with the position of the distance filter and supports filtering selected components within or outside the set range. In the case where the user created two or more distance filters, the logical AND operation is used to calculate which components to display. Although the distance filter does not support directly filtering other visualization components excluding viewpoints and polygons such as the bars and links, the state of these components relies on their associated viewpoint or polygon. For example, bars are hidden when their associated polygon is filtered and links are hidden when either their associated viewpoint or polygon is filtered.

The above components, the compass, the altimeter, and the distance filter, can not be controlled directly by the user. The compass and the altimeter update passively whenever the camera is moved or rotated. The distance filter can be activated and updated as part of the functionality additional user interface components provides.

There are four additional user interface components:

- Filters
- Add
- Edit
- Help

The filters option provides an additional method for the user to examine data based on their criteria. The filters included within the user interface allow the user to set Evergreen to display only viewpoints and polygons containing specific values for its forestry-related associated parameters. For viewpoints, this includes viewpoint ID and viewpoint importance. For polygons, this includes the ID and both high and low-level parameters. The filters support the input of multiple criteria, whether it is multiple values from the same parameters or one value from multiple parameters, and calculates the final filtering criteria using the logical AND operation.

The add and edit option provides some control over the components within Evergreen and, in turn, the data behind the visualization to the user, wherever it makes sense. The add option allows users to add custom viewpoints and distance filters, retaining all functionality and interactivity of the components explained previously, and edit associated parameters of the components added using this method. The edit option allows users to edit the associated parameters of existing viewpoints, polygons, and distance filters. Once modified, the edited component will immediately update to reflect the change in value within the visualization. However, the edit option only supports the editing of alphanumeric values and does not support editing data that is encoded using a different method other than alphabets or numbers. For example, the user can not edit the shape of a polygon or the location of a viewpoint using solely the edit option provided.

Finally, the help option provides the user with easy access to the documentation of Evergreen within the system. This allows the user to retain their attention within the system and the task they are completing and confirms how Evergreen may be used without exiting or switching applications. The documentation provided includes the four visualization components, how to read them, and how to use them. This is the only additional user interface component that does not require additional actions from the user to use, make modification to the visualization, and is read-only.

The four components are initially displayed as smaller rectangular buttons placed at the corner of the display with distinguishable labels that are descriptive of their use. The help button is placed separately at the bottom right corner of the display from the other buttons, which are at the top right corner of the display and side by side horizontally, since the help option is the only of the four that is read-only. The size of the help button is also smaller to be less distracting to the user, as the documentation is only useful to new users and its usefulness declines as the user gains knowledge and grows more accustomed to the system. The other three components, although placed at the same region of the display, contain additional grouping as well. Filtering is considered to be different from add and edit, as it does not affect the data behind the visualization and only affects what information can be seen on the top by the user. To implement the grouping, the margin, or the space outside the border of the component, of the filter button is increased, which enhances the learning of natural concepts and implies the sense of categorization to the user [92].

Due to the number of components each button controls, the tabular structure is applied to provide a form of organization and make them less overwhelming for the user to learn and use. For example, the edit button controls three components, viewpoints, polygons, and distance filters. As such, when the user selects the edit button, a second-level menu appears consisting of the three options, which in turn takes the user to the window that provides the actual editing when selected.

A.3 Additional Considerations For Evaluation Procedure

Option 1: downloading a standalone application of Evergreen. First, we built and exported Evergreen from Unity into a standalone project that is then uploaded to a private cloud drive. Measures were adopted to ensure security and privacy, including encrypting the project and setting various security-sharing options on the cloud drive. The participants were then provided with a single-use link and password that can be used to gain access to the uploaded files.

Option 2: using a cloud computing service and a remote desktop streaming service. For participants without easy access to personal computers, we utilized Paperspace and Parsec, a cloud computing service and a remote desktop streaming service respectively. A machine with sufficient specifications to run Evergreen was created on Paperspace and linked to a single-use Parsec account created for each session. To access Evergreen using this option, the participant can choose to either use the Parsec application or a web client of their choosing. As Parsec is optimized for low ping, the two options theoretically provide a similar user experience to the participants. In addition, the participants are not required to provide any additional personal information solely for the purpose of using the second option, thus making it suitable for the purpose of an evaluative study.

Although the first option is straightforward for both the researchers and the participants, it has some underlying issues. First, participants are asked to execute the project on their personal machines, which some may find uncomfortable doing. Next, Evergreen is built to run only on Windows operating systems. Although the project exporter built into Unity supports cross-platform operations and is able to export projects to operating systems such as Windows, MacOS, Linux, and even Android and iOS, as Evergreen is developed and tested on Windows, we felt it unsuitable to provide options other than Windows, in case operating system specific bugs or errors arise. Finally, as Evergreen is built using Unity and includes complicated 3D graphics, it is taxing on computers and requires mid to high-level specifications in order to achieve 30 frames per second [36].

The second option fixes all of the above problems. However, using this option requires additional time and money resources from the research team. Both services used in this option are commercial, with Paperspace charging per hour and Parsec charging per month. In addition, to ensure the confidentiality of the participants, different setups are required for each participant that chooses to participate in the evaluation using this option. Due to this, the first option was used by default and the second method was only used if issues would arise.

A.4 Cheat Sheet

The following is the cheat sheet that documents how to use Evergreen provided to participants prior to each evaluation session.

Cheat Sheet

The Only Instructions You Will Need

Camera & Navigation

How To Use

- W key: Move forward
- S key: Move backward
- A key: Move left
- D key: Move right
- E key: Move up
- Q key: Move down
- Shift key: Hold to accelerate
- Space key: Hold to disable up & down
- Right mouse: Hold & drag to rotate camera

Viewpoints

How to read

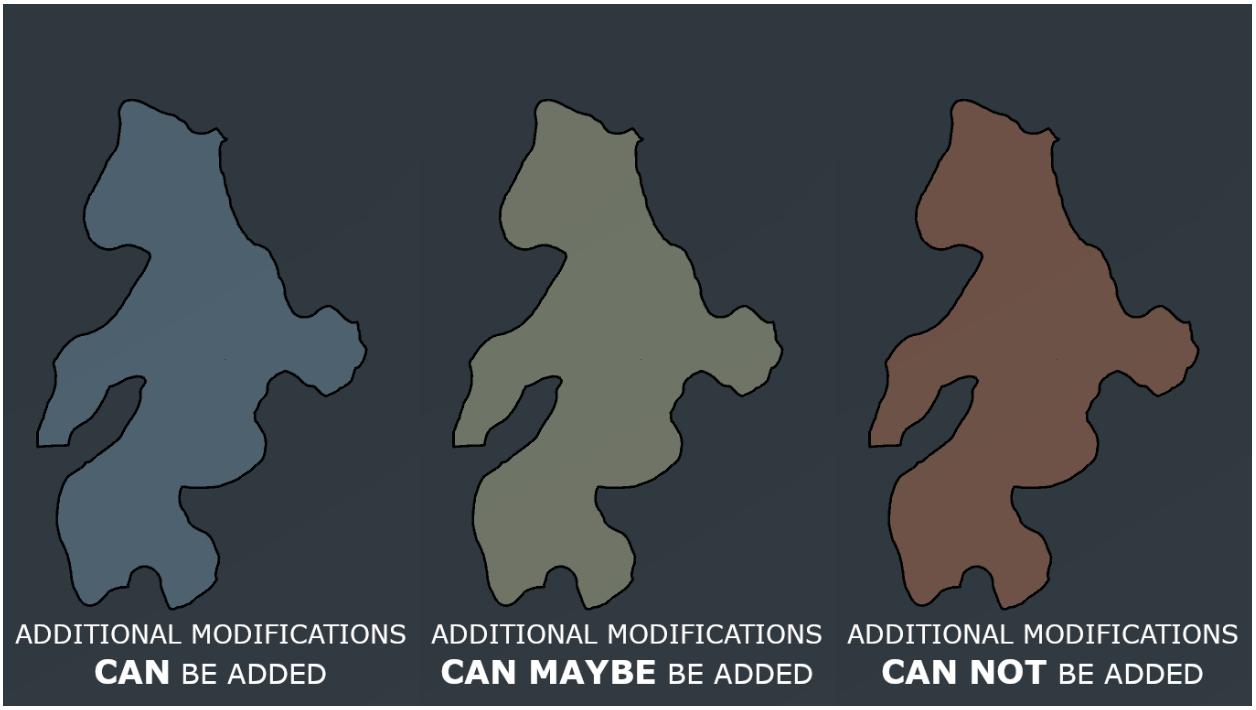
- Size encodes **Viewpoint Importance**

    Small : **low** importance
    Medium : **medium** importance
    Large : **high** importance

How to use

- Left click (Long): Show visible polygons from this viewpoint
- Right click (Long): Show invisible polygons from this viewpoint
- Middle click (Short): Teleport to this viewpoint
- Middle click (Long): Enter first-person view mode (Fieldwork simulation)
- Scroll up: Show additional details (Links)
- Scroll down: Hide additional details (Links)

Polygons



How to read

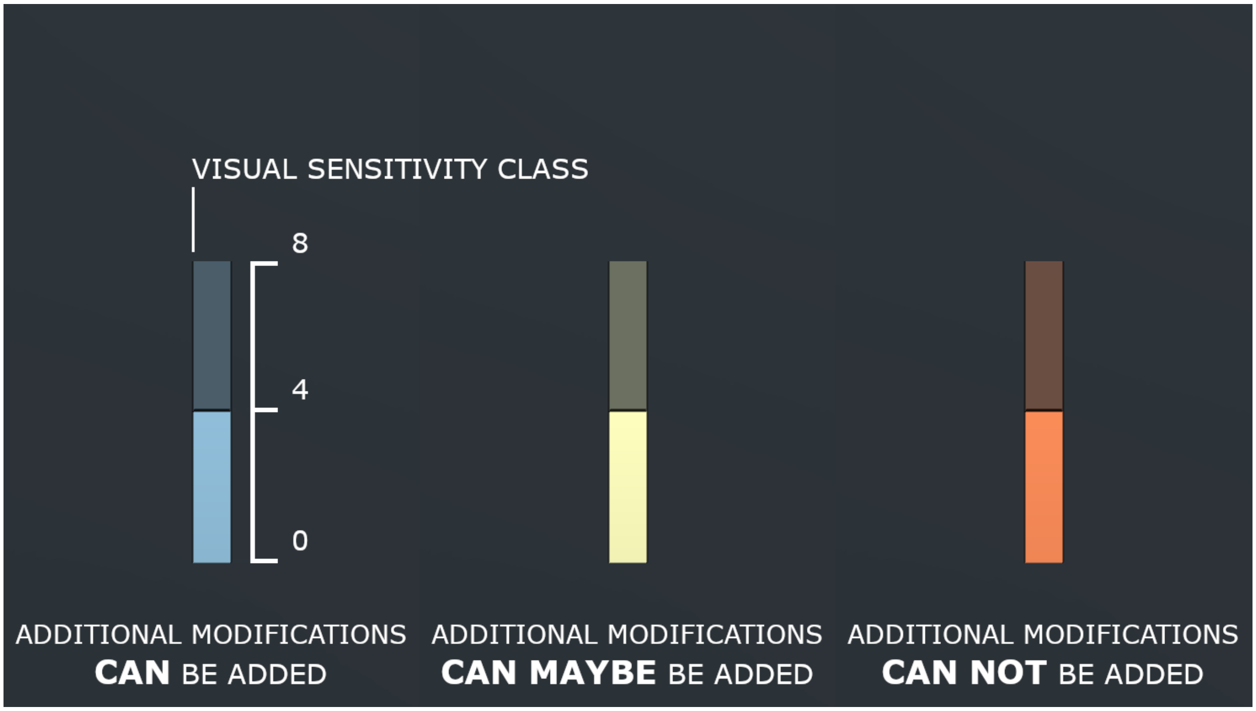
- Color encodes whether **additional modifications can be added**
    - Blue : **can** be added
      (Visual Quality Class > Existing Visual Condition)
    - Yellow : **can maybe** be added
      (Visual Quality Class = Existing Visual Condition)
    - Red : **can not** be added
      (Visual Quality Class < Existing Visual Condition)

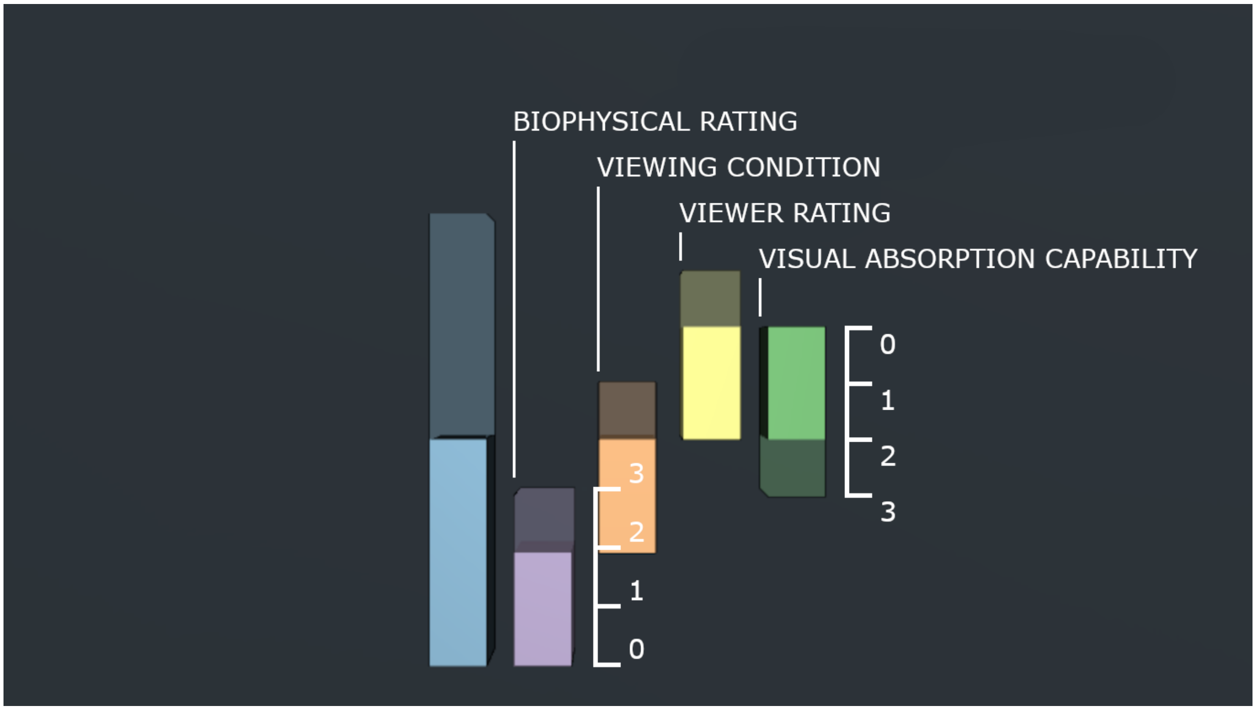
How to use

- Left click (Long): Show viewpoints from which this polygon is visible
- Right click (Long): Show viewpoints from which this polygon is invisible
- Middle click (Short): Teleport to this polygon
- Scroll up: Show additional details (Bars & Links)
- Scroll down: Hide additional details (Bars & Links)

Bars

(Used to display various parameters of forest-cover polygons)





How to read when details (small bars) are hidden

- Color encodes whether **additional modifications can be added**

    Blue : **can** be added
    (Visual Quality Class > Existing Visual Condition)
    Yellow : **can maybe** be added
    (Visual Quality Class = Existing Visual Condition)
    Red : **can not** be added
    (Visual Quality Class < Existing Visual Condition)
- Height of opaque bar encodes **value of Visual Sensitivity Class**
- Height of full bar encodes **maximum value of Visual Sensitivity Class**

How to read when details (small bars) are shown

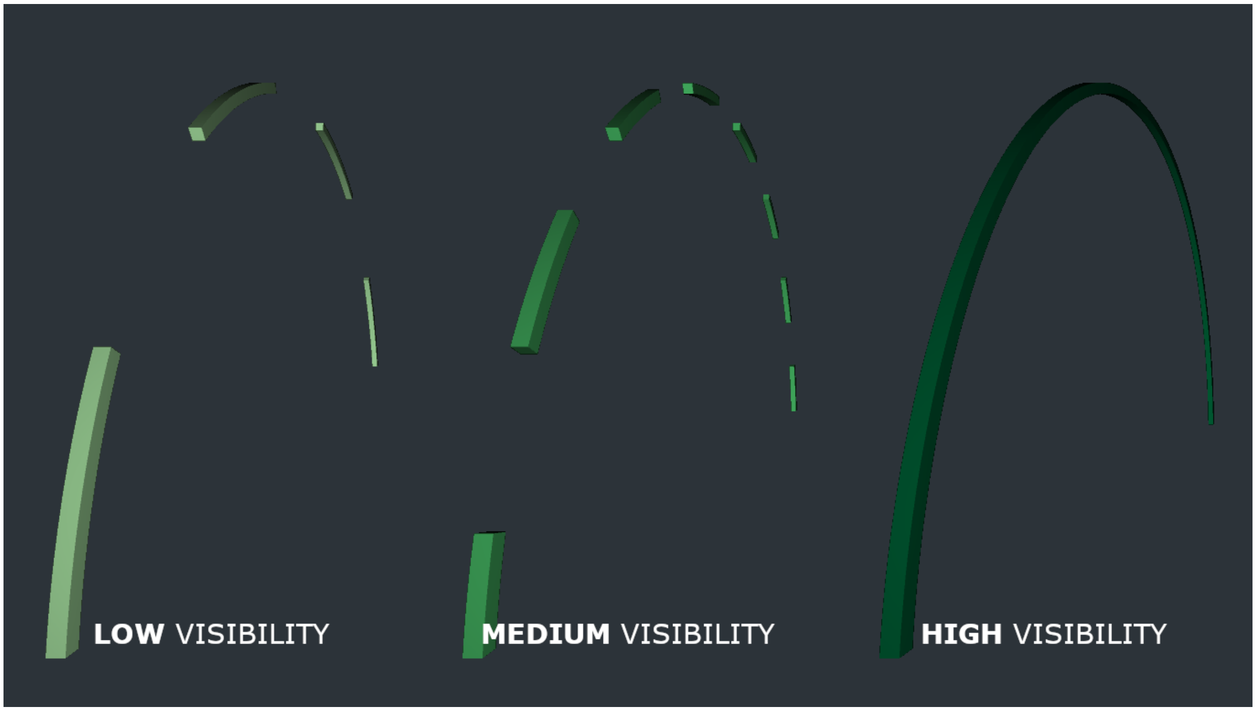
- Color encodes parameter type
    Purple : **Biophysical Rating**
    Orange : **Viewing Condition**
    Yellow : **Viewer Rating**
    Green : **Visual Absorption Capability**
- Height of opaque bar encodes **value of parameter type**
- Height of full bar encodes **maximum value of parameter type**
- Direction encodes **operator** in Visual Quality Class calculation
    (Visual Sensitivity Class = BR + VC + VR - VAC)
    Upright = **Add** operation
    Inverted = **Subtract** operation

How to use

- Left click (Short): Toggle additional details (Small Bars)
- Middle click (Short): Teleport to component

Links

(Used to display relationships between viewpoints and forest-cover polygons)



How to read

- Color encodes **visibility** of polygon from viewpoint

Light green :	**low** visibility
Green :	**medium** visibility
Dark green :	**high** visibility

- Dashes encodes **visibility** of polygon from viewpoint

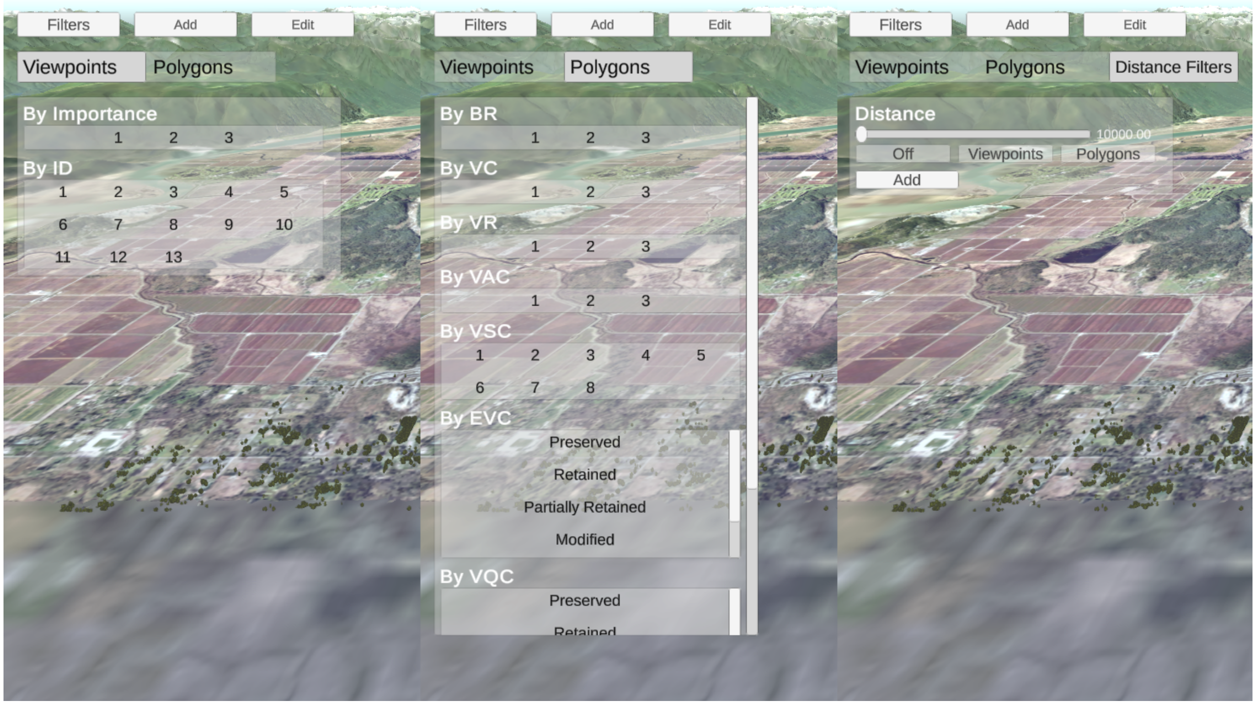
Sparse dashes	(-- -- -- --) :	**low** visibility
Dense dashes	(- - - - - - -) :	**medium** visibility
Full line	(-------------) :	**high** visibility

(If a Red bar appears instead, it means the polygon is **not visible** from any viewpoints.)

How to use

- Left click (Short):	Teleport to associated viewpoint
- Left click (Long):	Teleport to associated polygon
- Middle click (Short):	Teleport to component

Filters



How to use viewpoints

- Filter by **ID**
- Filter by **Importance** (Numeric values from **1** to **3**)

How to use polygons

- Filter by **ID**
- Filter by **Biophysical Rating** (Numeric values from **1** to **3**)
- Filter by **Viewing Condition** (Numeric values from **1** to **3**)
- Filter by **Viewer Rating** (Numeric values from **1** to **3**)
- Filter by **Visual Absorption Capability** (Numeric values from **1** to **3**)
- Filter by **Visual Sensitivity Class** (Numeric values from **0** to **8**)
- Filter by **Existing Visual Condition** (**6** categorical values)
- Filter by **Visual Quality Class** (**6** categorical values)

How to use distance filters

- Left settings
    - **Off**: Turn off filter
    - **Include**: Filter components within range

    Exclude: Filter components out of range

- Middle settings
    - **Toggle** filter for viewpoints
- Right settings
    - **Toggle** filter for polygons
- Add
    - 1. (optional) Pre-select desired settings
    - 2. Click on the **Add** button
    - 3-A. Click **left mouse** to add on terrain
    - 3-B. Press **ESC key** to cancel action