FACULDADE DE ENGENHARIA DA UNIVERSIDADE DO PORTO

Bioimages Platform: Development of a spatiotemporal information visualization platform on the ecology of images

Hugo Reis de Castro

U.PORTO

FEUP FACULDADE DE ENGENHARIA UNIVERSIDADE DO PORTO

Mestrado em Engenharia Informática e Computação

Supervisor: Tiago Assis

Second Supervisor: Alexandre Valle

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Abstract

To understand the ecological impact of image production, from early analog photography to contemporary digital media, it is necessary to interpret complex relationships between materials, people, and processes over time and space. However, existing semantic data platforms often lack intuitive visual tools that can effectively support this exploration by non-technical users.

This dissertation was developed within the scope of the Bioimages project, which explores how image-making affects the environment and society. It aims to address the challenge of how to present structured and time-evolving information in a visual, accessible, and engaging way that facilitates analysis and storytelling about the sustainability of images.

The goal of this work is to propose and evaluate a web-based platform that supports the interactive visualization of entities and their connections across space and time. The system integrates semantic data from a Wikibase and employs a map-based interface enriched with a timeline slider, semantic filters, and graph-based visualizations using React, D3.js, and React-Leaflet.

To validate the platform, an experimental protocol was conducted involving participants from the fields of art and design education. The evaluation was composed of a task-based usability testing and a System Usability Scale questionnaire. The results validated the conceptual validity of the proposed interface and demonstrated high task accuracy in direct exploration tasks. However, the study also identified areas for improving usability, specifically in the responsiveness of filters and the clarity of interactions.

These findings support the use of graph-based, spatiotemporal visualizations as effective tools to explore rich and dynamic datasets, with potential applications extending beyond image ecology into other domains involving historical, cultural, or environmental data.

Keywords: Information Visualization, Spatiotemporal Information Visualization, Graph-based Visualization, Timeline, Human-Computer Interaction, Image Ecology

UN Sustainable Development Goals

The United Nations Sustainable Development Goals (SDGs) provide a global framework to achieve a better and more sustainable future for all. It includes 17 goals to address the world's most pressing challenges, including poverty, inequality, climate change, environmental degradation, peace, and justice.

This project contributes meaningfully to SDGs, particularly by promoting awareness and responsible practices in the intersection of digital technologies, ecological sustainability, and art education.

The specific Sustainable Development Goals mentioned have the following names:

SDG 4 Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all

SDG 12 Ensure sustainable consumption and production patterns

SDG 13 Take urgent action to combat climate change and its impacts

SGD	Target	Contribution	Performance Indicators and Metrics
4	4.7	The project promotes innovative pedagogical strategies in art education that incorporate ecological awareness, and encourage critical thinking about sustainability, resource extraction, and the effects of image production on the environment.	Number of educators, researchers, and students engaging with the platform; feedback on ecological awareness gained by using the platform.
12	12.8	The platform helps users comprehend the material and toxic footprint behind media technologies, by bringing to light the invisible environmental cost of producing digital images. Through educational visualization, it promotes responsible decision-making.	Platform usage data; number of visualizations explored; inclusion in educational programs.
13	13.3	The project helps students, teachers, and the general public change their behaviour by exposing the environmental effects of unsustainable technological practices.	Engagement with narratives related to extractivism and toxicity; survey-based metrics on shifts in user perception.

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I am also grateful to my family, who have always supported me throughout this academic journey. In particular, my father, mother, and brother, who have been closest to me through both good and bad moments, have always offered a kind word and made countless sacrifices to ensure I had all the conditions necessary to study so far away from home. Thanks to them, I have become the person I am today.

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Finally, I am thankful to my friends from the island, whose support was fundamental, never letting me down even in the most challenging moments. Their friendship has always made me want to return to Terceira, where I invariably feel welcomed and at home.

Hugo Castro

*“Como homens, estamos soldados historicamente ao povo de onde viemos
e enraizados pelo habitat a uns montes de lava que soltam
da própria entranha uma substância que nos penetra.”*

Vitorino Nemésio

Contents

List of Figures

List of Tables

List of Listings

Abbreviations and Symbols

API	Application Programming Interface
ANOVA	Analysis of Variance
CSV	Comma-Separated Values
df	Degrees of Freedom
F	F-statistic (test statistic of ANOVA)
IRI	Internationalized Resource Identifier
ID	Identifier
HCI	Human-Computer Interaction
HSD	Honestly Significant Difference (from Tukey HSD post-hoc test)
HTTP	Hypertext Transfer Protocol
JSON	JavaScript Object Notation
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
ρ	Spearman's Rank Correlation Coefficient
p-value	Probability Value
MS	Mean Square
SPARQL	Query language and protocol for accessing RDF data
SS	Sum of Squares
SSL	Secure Sockets Layer
SUS	System Usability Scale
SVG	Scalable Vector Graphics
RDF	Resource Description Framework
UI	User Interface
UX	User Experience
WBS	Wikibase Suite
WDQS	Wikidata Query Service

Chapter 1

Introduction

1.1 Context and Motivation

The Bioimages project aims to promote new pedagogic practices based on sustainable and ecological principles within the field of Artistic Education [24]. This project offers a dataset with information about the history of the ecology of image and scientific-didactic materials. The data includes spatiotemporal content about image production and registration processes, as well as the extraction of natural resources and the environmental toxicity associated with.

Key examples encompass the extraction of silver utilized in photographic processing and lithium for the batteries that power today's digital devices, which form the infrastructure of current image production. By integrating data from early photographic records with the contemporary mass proliferation of digital images, the project facilitates the development of spatiotemporal visualizations that reveal the relationships between resource extraction, image production, and environmental impact over time.

Researchers involved in the project play an important role by actively entering these data into the system, ensuring the accuracy and comprehensiveness of the information. Additionally, they are interested in visualize and analyze the dataset, through visual representations of the spatiotemporal relationships between resources and image production, enabling comparative studies in the emerging field of image ecology, from the earliest photographic records to the modern proliferation of digital images.

1.2 Problem

Information Visualization involves transforming data, information, or knowledge into visual formats to make it easier for people to understand and analyze [10]. Although the process may often go unnoticed, it plays a significant role in everyday life, particularly in areas such as human-computer interaction, visual design, and data science [32].

Spatiotemporal data represents both space and time information [38]. Representing this knowledge and visualizing it in a meaningful and intuitive way presents a challenge due to its complexity.

The work involves to combine both time, location, and user-specific factors, along with additional attributes such as value or category. Additionally, the research team is used to input data into a user-friendly front-end. However, semantic database ecosystems like MediaWiki [34], use complex data entry mechanisms, such as CSV tables, and data visualization is usually produced using SPARQL queries, which makes it impractical for the research staff. The challenge is to explore a method to visualize the spatiotemporal information given, and, if its possible, validate it in an ecosystem of semantic data with a user-friendly interface to fulfill the needs of the research team.

1.3 Aim and Goals

The aim of the project is to propose an intuitive and user-friendly information visualization platform that allows the visualization of people, events, and processes of image production to understand the sustainability of images and harmful processes for the environment and society. The work is composed by technical, technological and scientific objectives.

The technical and technological objectives rely on design and develop a data visualization pipeline capable of processing and displaying spatiotemporal relationships in an engaging and interactive way. This includes creating an interface that integrates with semantic databases like MediaWiki and effectively uses adequate techniques to transform complex data into insightful visual representations.

The scientific goal of the project is to propose, and experiment an approach regarding spatiotemporal visualization. This involves the development and the testing of visualization techniques that can effectively transform complex spatiotemporal data in ways that enhance comprehension.

1.4 Research Questions

The outlined challenges span technical, technological, and scientific dimensions, from designing visualizations to integrating with a semantic database. To ensure the success of the project, it is necessary to define research questions that guide the investigation:

Q1: What are the primary project visualization goals?

Q2: How should multimedia spatiotemporal data be displayed in an efficient and effective way?

Q3: What effective visualizations can be considered for the defined goals?

Q4: How can the proposed approach be validated?

Chapter 2

Literature Review

This chapter presents the methodology used to find existing research relevant to the field of Spatiotemporal Information Visualization and related disciplines, such as Human-Computer Interaction (HCI) and user interface design.

2.1 Methodology

To ensure a systematic and unbiased approach, a structured method was followed guided by the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework [40], aiming to identify the most relevant studies that inform this research. A PRISMA flow diagram was included, as shown in Figure 2.1, to document and visualize the process of study selection. The review process began with a paper collection, then undertake the screening phase, and, finally, an eligibility and selection process.

2.1.1 Paper Collection

This process started with the identification of the data sources intended to search for relevant information. Following this, selection of search strings to effectively query these data sources. Lastly, the references were collected and organized within a reference manager.

The procedure began by pinpointing the data sources intended for extracting pertinent information. Following this, search strings were selected to effectively query these data sources. Finally, the references were gathered and organized within a reference manager.

2.1.1.1 Data Sources

The data sources used for this research include IEEE Xplore, Scopus, and the ACM Digital Library. These platforms were chosen due to their comprehensive access to peer-reviewed publications and availability of resources relevant to the theme. It is important to mention that the University of Porto provides a subscription that covers all of these platforms.

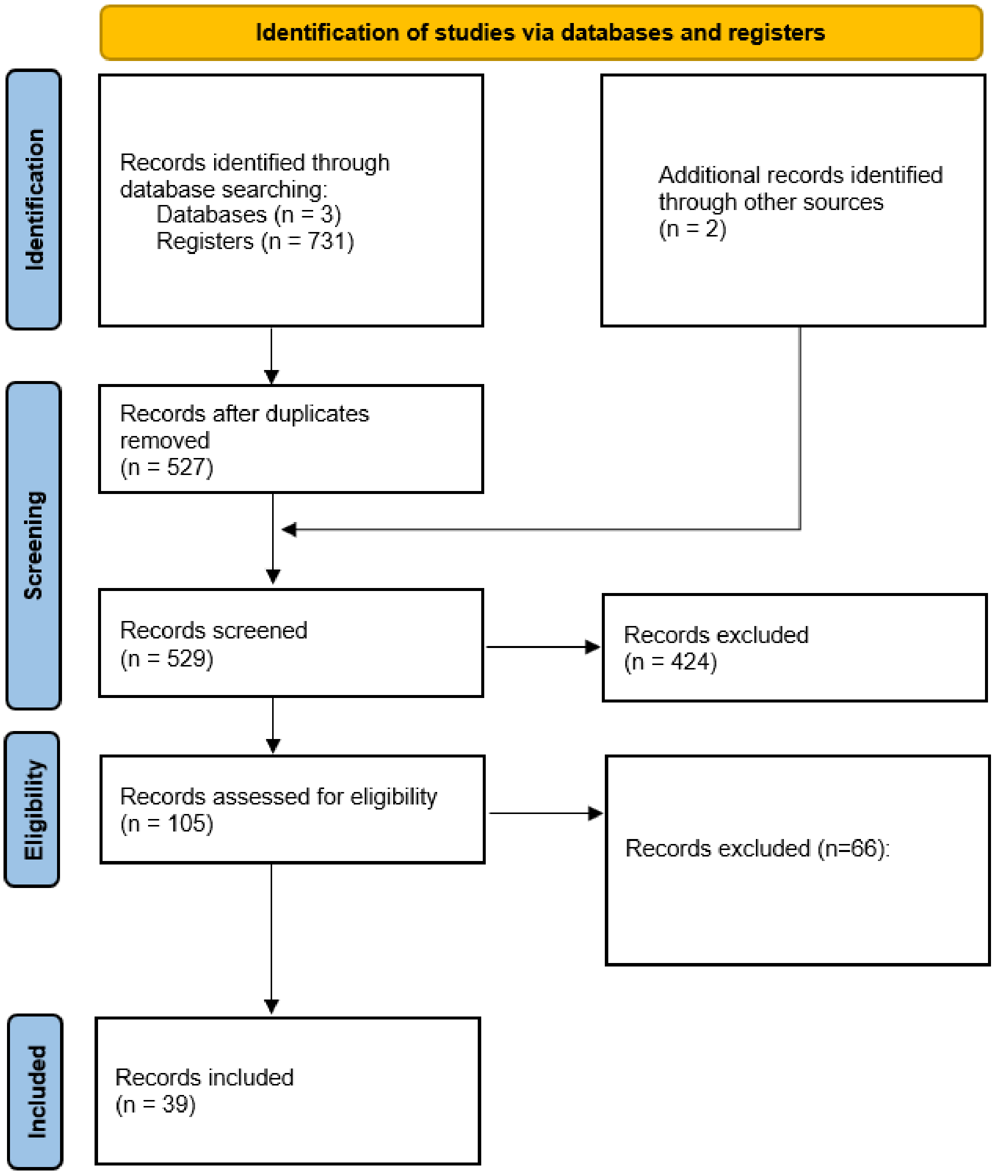


Figure 2.1: PRISMA Flow Diagram

2.1.1.2 Search Strings

The selection of the search strings began with the identification of terms relevant to the project, including *Information Visualization*, *Human-computer Interaction*, and *Spatiotemporal Visualization*, as outlined in Table 2.1. Due to the simplicity and opening of search strings, the number of content retrieved from all data sources was huge, as shown in Table 2.2.

For that reason, it was necessary to refine the search strings to achieve greater specificity. There is a common topic related to information visualization. To best combine the terms, intersection (AND) and union (OR) operators are used, as well as the wildcard (?), to take into account the British English spelling, resulting in the search string QS1 in Table 2.3. Additionally, the

Table 2.1: Initial search strings

QS1	information visuali?ation
QS2	human-computer interaction
QS3	spatiotemporal visuali?ation
QS4	spatial-temporal visuali?ation

Table 2.2: Number of items retrieved for initial search strings

Data Source	**QS1**	**QS2**	**QS3**	**QS4**	Total
ACM Digital Library	125 991	245 774	3 764	28 795	404 324
IEEE Xplore	77 964	37 675	2 395	4 302	122 336
Scopus	105 735	124 922	4 022	7 328	242 007
Total	309 690	408 375	10 181	40 425	768 671

search string "Human-computer interaction" was modified to refine the search results and focus on more relevant literature, Table 2.3. This adjustment was made to target studies that address the foundational concepts behind HCI, rather than general overviews of the field.

Next, it was applied an inclusion criteria, adapted according to the functionalities of each data source. These criteria restricted the selection to articles, conference papers, and books on the topic of *Spatiotemporal Information*, *Spatiotemporal Data*, *Visual Information*, *Human-computer interaction*. Additionally, for QS1 the criteria restricted the selection to publications from 2020 onward, to include only recent publications. The total number of content retrieved is presented in Table 2.4.

Table 2.3: Refined search strings

QS1	(spatiotemporal OR spatial-temporal) AND information AND visuali?ation
QS2	(human-computer interaction) AND (principles)

Table 2.4: Number of items retrieved for refined search strings

Data Source	Q1	Q2	Total
ACM Digital Library	6	156	162
IEEE Xplore	191	68	259
Scopus	122	188	310
Total	319	412	731

2.1.1.3 References Collection and Organization

To ensure an efficient approach to managing references, Zotero [54] was utilized, an open-source reference management tool. Zotero has the capability of collecting, organizing, and annotating references, and advanced features such as duplicate reference detection and the ability to search for and attach full text documents significantly streamlined the reference management process.

2.1.2 Screening

The screening process was crucial for filtering the initial set of collected resources down to the most relevant to the project's objectives. This phase started with the removal of duplicate entries using the Zotero's capabilities. The initial dataset comprised 731 records, which was reduced to 527 after eliminating 204 duplicated items.

The next step was to inspect the title, abstract and keywords of the records to exclude the ones that do not match the criteria. During this review, a special attention was given to keywords and tags associated with each record. Surprisingly, many records were related to artificial intelligence algorithms, as well as audio and video recognition. Moreover, the keywords were often unrelated to the intended criteria, including terms such as "*3D Convolutional Neural Network*", "*Feature Extraction*", "*Video Recognition*", "*Audio Features*".

This process led to a substantial reduction in the number of articles, with 424 items excluded, leaving 103 records. This allowed the focus to shift towards those most likely to offer meaningful insights.

2.1.3 Eligibility

In the eligibility phase it was necessary to ensure that each selected record had full-text accessibility. Full-text access was primarily obtained using Zotero's "*Find Full Text*" tool, which simplified the process. This step led to the exclusion of 33 articles due to the unavailability of full-text versions.

2.1.4 Selection

This phase was essential to evaluate the relevance and quality of each work. Once full-text versions were available, each paper was reviewed to confirm alignment with the project's goals, particularly in terms of their contributions to spatiotemporal information visualization and human-computer interaction. Table 2.5 briefly describes the research purpose of the selected papers. It was noticed that a significant number of articles were identified as focusing on artificial intelligence detection algorithms, which fell outside the scope of the project's objectives and were consequently excluded from the selection.

Table 2.5: Research purpose description for selected studies

References	Research purpose	Approach/domain
[30]	Analyze and visualize the spread of COVID-19 in real-time, specifically focusing on human mobility patterns originating from East Asian countries.	Spatiotemporal data visualization; epidemiology, and human mobility analysis.
[15]	Categorize and summarize existing research in competitive sports data visualization.	High-Dimensional Data Visualization; Time-Series Visualization; Graph Visualization; Glyph Visualization.
[33]	To introduce a platform that monitor spatiotemporal impacts, evaluate citizen well-being and facilitate decision-making.	2D and 3D visualization; temporal data integration; user-friendly interface.
[37]	Presents an innovative approach to visualize data regarding occupancy trends during the pandemic.	Spatiotemporal data analysis.
[7]	Tool that provides a low-memory storage component that enables real-time visual interactions with spatiotemporal data.	Density Dictionary Learning; Real-Time Visual Querying.
[9]	Online resource designed to improve access to cultural heritage objects by visualizing them on interactive spatiotemporal maps.	Geo location and Temporal Filtering; Interactive Mapping.
[50]	Develop a visualization method that integrates time and location, aiming to reduce line crossovers for clarity.	Timeline-Based Visualization.
[44]	Explores various techniques for visualizing spatial and spatio-temporal data, with a specific focus on COVID-19 datasets.	Choropleth Maps; Heat Maps; Bubble Maps.
[31]	Provide a platform that allows researchers to examine the spatiotemporal evolution of infectious diseases, integrating ecological data.	Spatiotemporal Mapping; Interactive visualization.

Table 2.5: Research purpose description for selected studies (cont.)

References	Research purpose	Approach/domain
[2]	Development of online archiving platform enabling the examination of narratives that have shaped the perception of the creative child.	Interpolation in a timeline.
[32]	Web platform to visualize multimedia data and management of spatiotemporal information.	Interactive maps; Timeline.
[11]	A novel approach to visually represent spatiotemporal phenomena through the automated generation of static and interactive visual narratives.	Information visualization and geospatial data analysis.
[46]	Develop an intuitive visualization method for space–time series data that effectively conveys spatiotemporal information related to terrain surface movements.	Spiral Graphs; Proportional Point Symbol Maps.
[12]	A standalone web-based application designed to enhance public health surveillance by integrating genomic, geographical, and temporal data.	Spatiotemporal Mapping; User-friendly interface.
[23]	Develop a method that effectively encodes and visualizes temporal changes in spatial data, facilitating the analysis of spatiotemporal phenomena.	Temporal Topology Density Map.
[42]	To introduce a structured framework for creating interactive visualizations that effectively represent spatiotemporal data.	Analyzes design processes; Proposes a conceptual model.
[53]	Prototype system designed to enhance the exploration of spatiotemporal data through immersive virtual reality experiences.	Immersive analytics and spatiotemporal data visualization.
[16]	a visualization tool designed to represent and analyze movement trajectories within social network datasets.	Origin-destination maps; Heat maps; Graph representations; Time abstraction; word clouds.

Table 2.5: Research purpose description for selected studies (cont.)

References	Research purpose	Approach/domain
[43]	Examine the role of interactivity in spatiotemporal data visualization.	Applies a generic interaction taxonomy.
[19]	Tool to visualize geospatial data, supporting multiple data types, providing customization visualization.	Choropleth maps; Heat maps; Scatter plots; Time-series visualization; 3D surface plots.
[18]	To systematically review usability, barriers, and provide recommendations for improving clinical decision support systems (CDSS) from a Human-Computer Interaction perspective.	Clinical Decision Support Systems (CDSS) usability; Human-Computer Interaction (HCI); healthcare systems.
[5]	To outline principles and methodologies for crafting effective and impactful user experiences.	User experience (UX) design; General HCI principles and UX methodologies.
[21]	To establish design strategies and models for Human-Computer Interaction interfaces based on user experience.	Human-Computer Interaction (HCI) design; User experience-driven interface strategies and models.
[3]	To analyze the historical development of Human-Computer Interaction, tracing its evolution and milestones over time.	Historical development of HCI; Evolution of HCI concepts and frameworks.
[25]	To study methods and outcomes of feedback research in HCI, highlighting how feedback mechanisms improve user interaction and system performance.	Feedback mechanisms in HCI; Research methods for evaluating interaction outcomes.
[28]	To explore the role of microinteractions in HCI, identifying design principles, types, and their impact on user experience.	Microinteractions in HCI; Design principles for small-scale interactions and their UX implications.

Table 2.5: Research purpose description for selected studies (cont.)

References	Research purpose	Approach/domain
[45]	To investigate usability needs through the lens of HCI patterns, aiming to design interfaces that meet diverse user requirements.	Usability research in HCI; Pattern-driven design approaches for interface usability.
[1]	To provide strategies for designing user interfaces with a focus on effective HCI principles and methods.	User interface design; HCI strategies and frameworks.
[17]	To explore processes and principles for designing Human-Computer Interfaces with an emphasis on usability and user experience.	HCI process design; Principles for creating user-centered interfaces.
[20]	To explore usability test methods and design principles to enhance the effectiveness of Human-Computer Interface design.	Usability testing in HCI; Design principles for user-centered interface creation.
[41]	To propose and discuss the concept of Human-Engaged Computing, emphasizing a future direction for HCI focused on deeper engagement and interaction.	Future trends in HCI; Human-Engaged Computing and user interaction advancements.
[13]	To examine the foundations of HCI and introduce new paradigms that can shape the future of the field.	HCI foundations; Exploration of emerging paradigms and concepts in interaction design.
[47]	To introduce students to the concept and application of User Interface (UI) patterns, emphasizing their importance in design education.	Education in HCI; UI pattern teaching methodologies.
[29]	To explore innovative approaches to HCI research and design specifically for decision-aiding systems.	Decision support systems; Novel HCI research and design strategies.
[48]	To design and study Human-Computer Interaction modes tailored to meet the needs of elderly users.	HCI for aging populations; User-centered design for elderly accessibility.

Table 2.5: Research purpose description for selected studies (cont.)

References	Research purpose	Approach/domain
[39]	To examine sustainable information system design and explore the contributions of Sustainable HCI to environmentally conscious technology development.	Sustainable HCI; Eco-friendly information system design.
[51]	To explore the interplay between the user model and system model in user-centered software development, emphasizing their complementary roles.	User-centered software development; Interaction between user and system models.
[27]	To investigate how principles from architecture can inform and inspire HCI design, drawing parallels between the two disciplines.	Cross-disciplinary design; Applying architectural principles to HCI design.
[52]	To explore methods for integrating Human-Computer Interaction principles into a Web Technologies course, enhancing students' understanding of HCI in web development.	HCI education; Integration of HCI principles in web technologies and development.

2.2 Conclusions

The initial collection of 731 records was filtered through multiple stages, including duplicate removal, screening for relevance, and eligibility checks for full-text access. Each phase employed criteria to focus on publications addressing spatiotemporal data visualization and human-computer interaction, culminating in a final set of records. By refining search strings, applying inclusion criteria, and using reference management tools like Zotero, the process effectively minimized irrelevant content while retaining essential studies.

The selected literature covers diverse domains, including public health (eg. spreading of COVID-19 disease), cultural heritage, urban planning, and decision support systems. It also covers diverse visualization techniques, such as heat maps, timeline-based visualizations, and graph-based methods, which demonstrates the versatility of spatiotemporal visualization. The integration of HCI principles in the reviewed studies shows the importance of creating systems that prioritize usability, accessibility, and user engagement. Additionally, many studies applied foundational HCI techniques, such as iterative design, usability evaluation, and feedback mechanisms, to refine the user interfaces and system functionality.

While existing studies often address specific applications, there is little research on standardized approaches that can be adapted across diverse domains. Another gap lies in the development of real-time adaptive systems. Few studies integrate real-time user interaction data into the iterative design process, although these systems have the potential to adapt dynamically according to user interactions and contextual changes, to improve usability and decision-making.

Other gap is the integration of sustainability principles in spatiotemporal visualization design, because there is little research on practical approaches to creating environmentally conscious systems. There are opportunities to design tools that minimize energy consumption and material waste while promoting user engagement in sustainable practices. Furthermore, accessibility and inclusive design remain not addressed adequately. Ensuring that visualization tools are accessible to diverse user groups is essential to promote universal usability.

Chapter 3

State of the Art

This chapter presents the State of the Art in Information Visualization, specifically in Spatiotemporal Information Visualization, and Human-Computer Interaction. By examining key innovations and identifying gaps, this chapter aims to establish a foundation for the proposed solution while showing the interdisciplinary aspects of this research.

3.1 Spatiotemporal Information Visualization

Spatiotemporal information represents events that occur in a specific location and at certain time points or periods, such as weather patterns, traffic flows, disease outbreaks, or historical events. The terms spatial and temporal refer to space and time, respectively, thus the terms spatial-temporal or spatiotemporal are used in data analysis to infer about data that has both space and time features [44].

The rapid advance of power processing and device storage capacity have allowed the creation of large data collections, specifically spatiotemporal data [23]. Analyzing this data effectively, particularly in relation to uncovering and comprehending their significance through trends and patterns is essential for enabling informed decision-making [23].

However, to be capable of analyzing the data, we have to know how to present the information, which is the main purpose of visualization [42]. This task is quite challenging, since each project demands a unique design tailored to elements like the dataset, communication goals, target audience, context, technical constraints, and visual style and conventions [42].

3.1.1 Spatiotemporal Visualization

Spatiotemporal visualization is essential to analyze data with both spatial and temporal dimensions, leveraging human natural ability to interpret spatial relationships and temporal patterns [44]. By combining spatial data with temporal elements, such as animations, color gradients, or interactive sliders, these visualizations make it intuitive to identify patterns and observe changes over time [44].

The versatility of spatiotemporal visualization is evident across many domains. For example, in public health, visualizations such as interactive maps, network graphs, and timelines have been used to track and analyze the spread of COVID-19 disease [44], [30], [31], enabling decision makers to identify hotspots and allocate resources effectively [37]. Tools like *Crowdmap* [37], illustrated in Figure 3.2, integrate spatial overlays with temporal dynamics to monitor the density of the crowd in real time, while *PhyloView* [31] combines phylogenetic relationships with spatial data to monitor the evolution and spread of diseases.

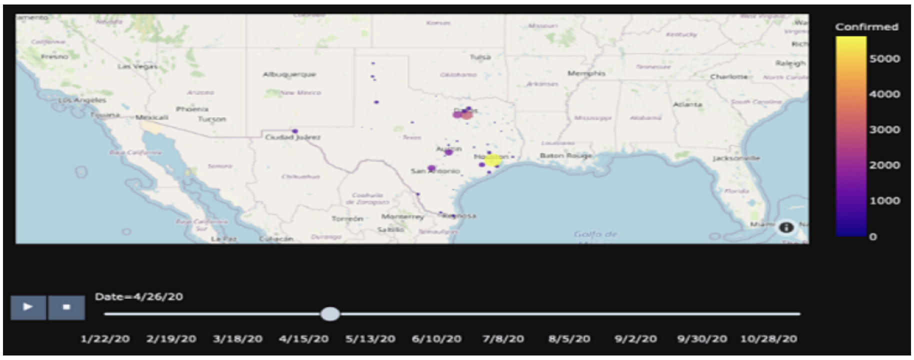


Figure 3.1: Bubble Map extended to visualize spatiotemporal data for confirmed COVID-19 cases in Texas [44]

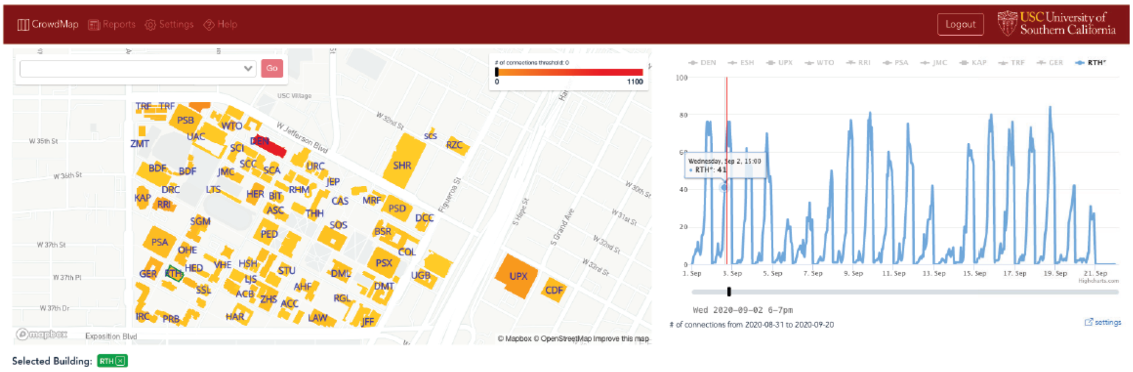


Figure 3.2: CrowdMap front-end showing daily building aggregates of active connection counts on the USC campus [37]

In cultural heritage, interactive spatiotemporal maps enhance accessibility, exploration, and navigation of collections, allowing users to trace the evolution artifacts, events, and locations [9]. These tools use timelines alongside spatial representation, creating interesting pathways for understanding historical phenomena.

In the context of real-time data exploration, *DDLVis* [7] framework employs density dictionary learning to represent data density distributions interactively, allowing users to query specific patterns or anomalies in real-time. A distinguishing characteristic of these methodologies is the synthesis of cartographic representations with a temporal dimension as depicted in Figures 3.1, 3.2, 3.3 and 3.4, facilitating the visual depiction of variations over time alongside spatial patterns.

This combination allows users to interact with dynamic phenomena in an interactive manner, providing insights into temporal trends and spatial distributions simultaneously.

Figure 3.3: Bubble map integrated with temporal scale [9]

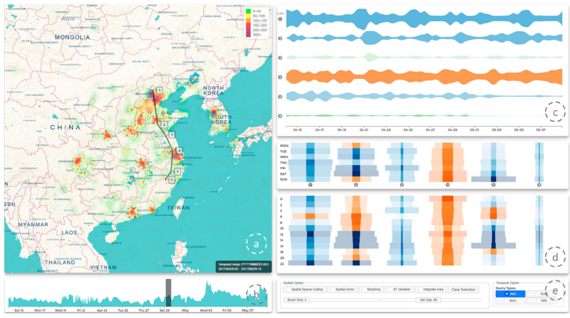


Figure 3.4: DDLVis system interface [7]

TrajectoryVis [16] explores different styles, such as line maps and heat maps, with the goal of illustrating movement trajectories to analyze the paths and behaviors of moving entities. Line maps, in Figure 3.5, illustrate individual trajectories as paths on a geographic map, with icons to indicate origin and destination locations. Heat maps, Figure 3.6, display aggregated trajectories, highlighting density flows in space. Similarly, *Lavanya et al.* [30] use this technique to monitor the spread of COVID-19 disease as it illustrates the paths of travelers traveling from China and neighboring airports, and *Le et al.* [31] the spread of the same disease in the United States.

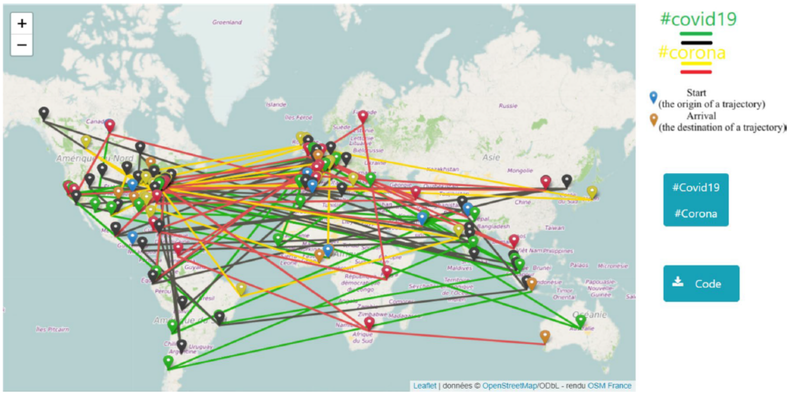


Figure 3.5: Line map representing trajectories of hashtags #Covid19 from 1 to 15 May [16]

The *VTGeo* [19] tool was conceived to explore and analyze complex geospatial data. This tool employs four different methods to display information: Area Maps, Road Maps, Scatter Plots Maps and Heat Maps, see Figures 3.7, 3.8 and 3.9. These visualizations are particularly suited for urban planning, where understanding interactions between various urban factors (e.g., traffic, population density, and land use) is essential.

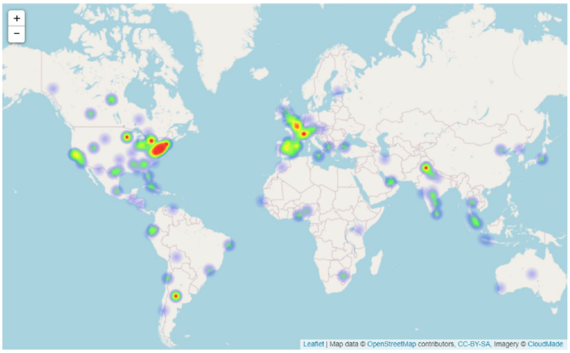


Figure 3.6: Trajectory visualization of #Covid19 and #Corona hashtags using heat map [16]

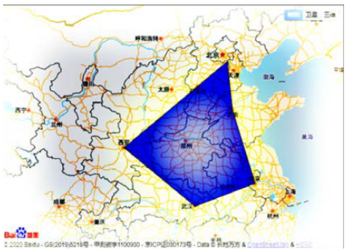


Figure 3.7: Area Map in *VT-Geo* tool [19]

Figure 3.8: Road Map in *VT-Geo* tool [19]

Figure 3.9: Scatter Plot in *VTGeo* tool [19]

3.1.2 Graph-based Visualizations

Graph-based approaches provide powerful tools for representing and analyzing spatiotemporal data. These methods utilize visual structures like diagrams, spirals, and networks to uncover patterns and relationships that may not be immediately evident on traditional maps. For instance, *Struhár et al.* [46] introduce a spiral graph visualization to represent land deformation data, combining spatial information with a temporal spiral structure, capturing periodic patterns over time, as depicted in Figure 3.10. The spiral design is effective to analyze repetitive phenomena, such as seasonal land deformation, and provides an intuitive way to compare temporal trends in different geographic areas.

Similarly, *TrajectoryVis* [16] uses graph-based visualizations to complement its trajectory maps. The tool uses interactive graph structures to represent movement dynamics, such as connections between key locations over time. These graphs help users identify movement clusters, bottlenecks, or other significant spatial relationships, as shown in figures 3.11, 3.12, 3.13.

Lavanya et al. [30] have also shown the usefulness of graph-based visualizations in understanding the spread of infectious diseases. The approach creates mobility graphs that link geographic locations based on travel patterns, illustrating how movement between regions contributes to the disease's propagation. Another example, in this field, is *PhyloView* [31], uses tree-like graph structures to represent evolutionary relationships among pathogens while integrating geographic and temporal data.

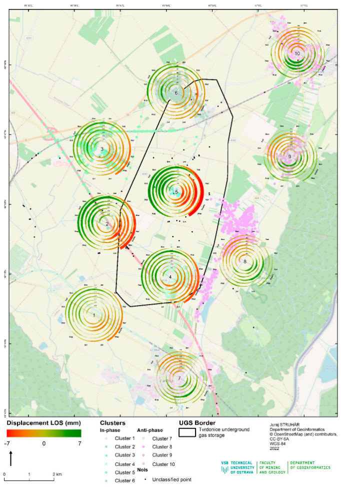


Figure 3.10: Spiral graphs combined with map to visualize time series [46]

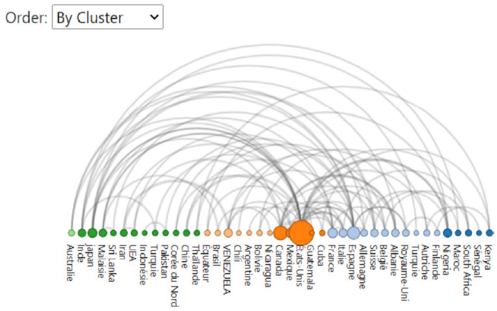


Figure 3.11: Arc diagram in TrajectoryVis [16]

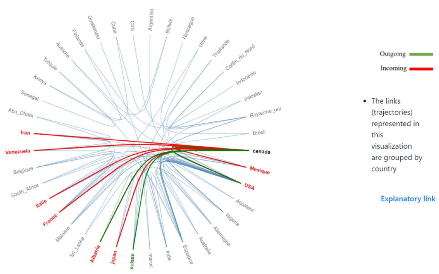


Figure 3.12: Edge-Bundling in TrajectoryVis [16]

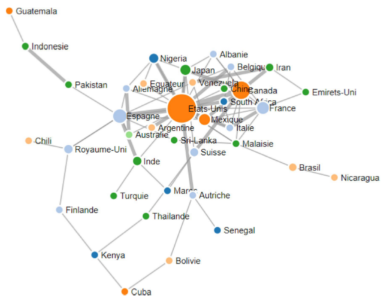


Figure 3.13: Graph in TrajectoryVis [16]

Building on these approaches, *SPREAD* [12] offers a dashboard for spatiotemporal epidemiological analysis. This tool integrates graph-based methods to visualize relationships between pathogens, outbreaks, and transmission events. Furthermore, SPREAD incorporates temporal analysis tools, allowing users to identify critical time windows for interventions and dynamically track the progression of epidemics, as shown in Figure 3.14.

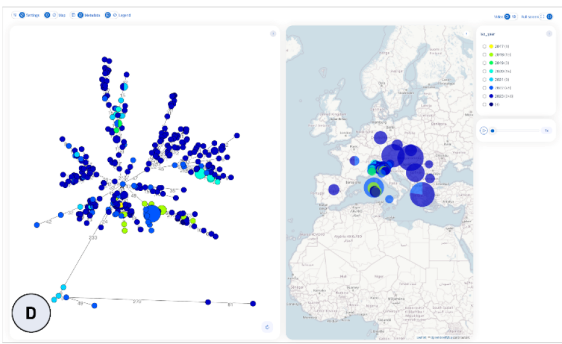


Figure 3.14: *SPREAD* dashboard fragment [12]

3.1.3 Timeline-based Visualization

Timeline-based visualizations provide an essential approach for displaying spatiotemporal data, as they offer a straightforward and intuitive method to illustrate chronological events and their temporal and spatial connections.

In cultural heritage, the *CREAT_ED* [2] online platform was designed to explore the historical construction of the creative child in education. This platform combines timelines with multimedia data to archive and interpolate historical events in a structured way [2], allowing users to explore the evolution of historical artifacts and narratives. *Magalhães* [32] integrates temporal and spatial information into a unified interface, as shown in Figure 3.15. Events are interconnected through multimedia elements where the focus is on building a smooth narrative where multimedia data is embedded directly within the timeline.

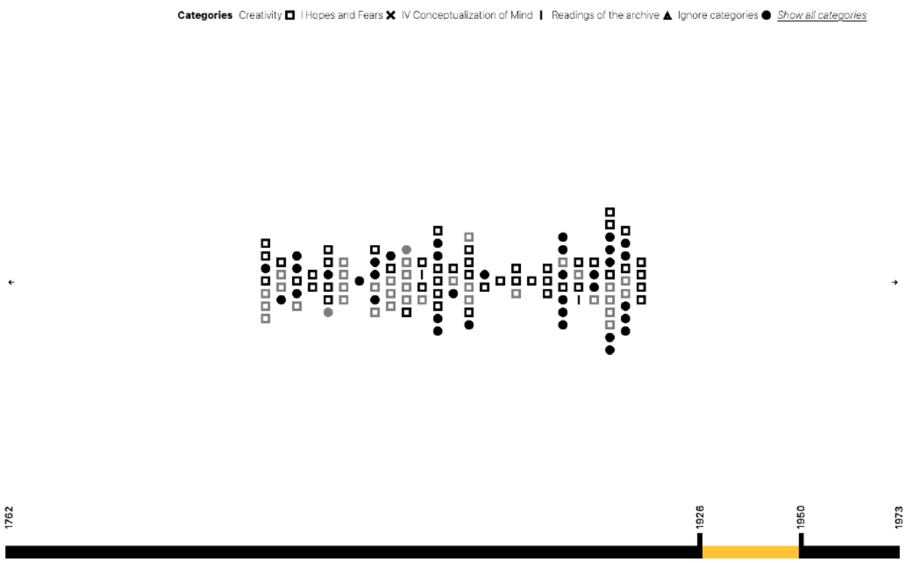


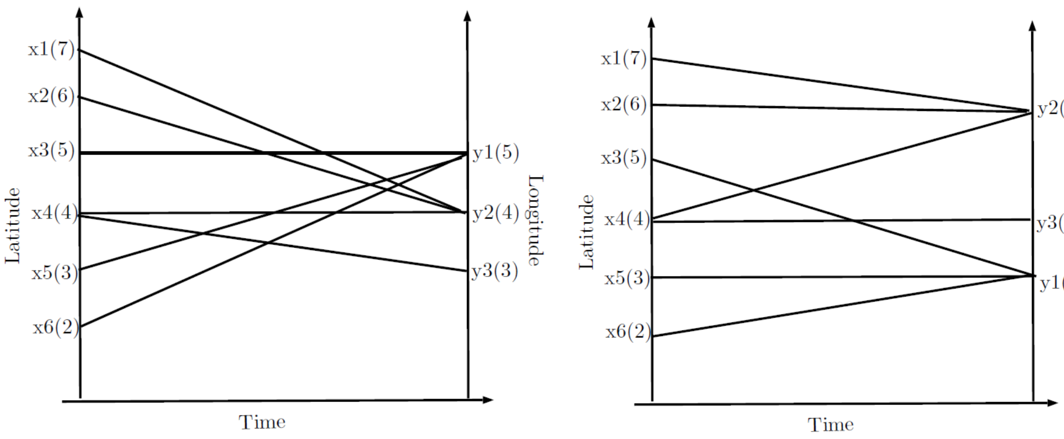
Figure 3.15: CREAT_ED timeline showing events [32]

3.1.4 Narrative-Based Visualization

Narrative-based visualizations combine visual elements with storytelling techniques to convey data insights in a structured and engaging manner. These visualizations are particularly effective in guiding viewers through complex spatiotemporal phenomena by emphasizing connections between events, locations, and time.

He et al. [50] introduce a method to visualize storylines of entities over time and space, with minimal overlap and intersection of lines, as illustrated in Figure 3.16. Storyline visualizations are particularly effective for analyzing scenarios involving multiple interacting entities, such as in social networks or historical narratives.

In addition, *Marques* [11] employs static visual narratives to decompose complex spatiotemporal data into engaging visual representations. These static narratives are very useful to summarize events and trends, making them accessible to diverse audiences, while preserving the critical insights, as illustrated in Figure 3.17.



(a) Layout of the storygraph without reducing line crossings (b) Layout of the storygraph after reducing line crossings

Figure 3.16: A storygraph example [50]

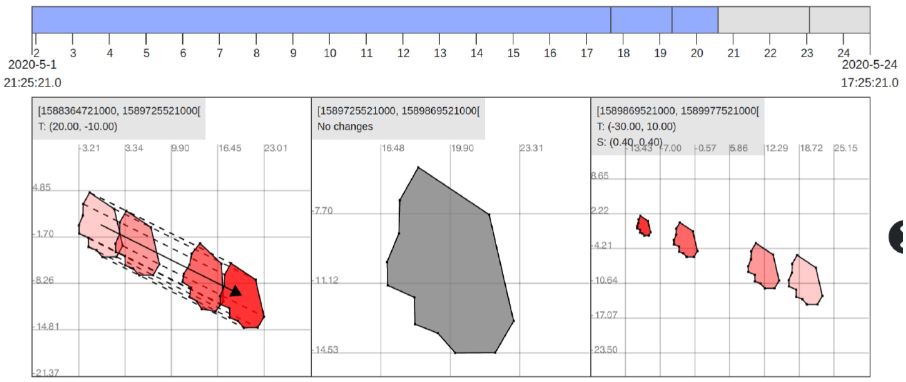


Figure 3.17: Example of a translation [11]

3.2 Human-Computer Interaction

Human-Computer Interaction (HCI) has evolved significantly and emerged as a response to the growing need for more efficient, intuitive, and accessible methods of interacting with computer systems [3]. Early HCI research was focused on basic command-line interfaces, where users needed specialized knowledge to operate computers effectively, over time, this evolved into more sophisticated graphical user interfaces and touch systems, transforming human-machine interaction [3]. It is important to understand user needs, context, and cognitive processes involved in interaction, promoting user-centered design strategies to create more accessible and efficient systems [1].

3.2.1 Interface Design

The foundational principles of user interface design are rooted in cognitive psychology and human perception, which guide the creation of intuitive and user-friendly interfaces [13]. *C. Gong et al.* defends that "Designers should abide by the following principles so that the design of the interface is well guided." [21], defining three principles: Visibility, Usability, and Interaction, as illustrated in Figure 3.18. The principle of visibility includes being visually pleasant, having a reasonable layout, harmony of colors, and the aesthetics of the interface. The principle of interaction contains: learnability, flexibility, memorability, predictability, tolerance of fault-operation and feedback. Lastly, the principle of usability consists in consistency, simplicity, usability and pertinence.

HCI has historically been interdisciplinary, however it has not been extensively involved with other design principles like architecture [27]. Architectural design elements are compared with information architecture in website design and conclude that principles such as spatial organization, user flow, and context can inform the creation of more intuitive and effective user interfaces.

In the context of HCI education, it is important to teach UI patterns to students [47]. Workshops and pattern analysis exercises are effective methods to build foundational skills in interface design.

Techniques for simplifying the interface and improving accessibility are crucial for specialized user groups, such as elderly users [48]. *Shen and Zhou* address the challenges elderly users face when interacting with technology, specifically input devices such as mouse, stylus, and touchscreen, concluding that the elderly benefited more from touchscreen use than younger participants, indicating its potential for more accessible user experiences for older adults.

In the domain of sustainability, *Nystrom et al.* [39] integrate the sustainability principles with HCI design, proposing a theoretical framework to create sustainable systems. The paper emphasizes the need for designers to rethink their approach to incorporate sustainability in a more holistic manner, focusing not only on material and energy efficiency, but also on social and user involvement.

3.2.2 Iterative Design and User Feedback

Iterative design is a crucial aspect of user-centered software development, where design improvements are made based on user feedback [51]. The work of *Bertino et al.* [5] emphasizes iterative design processes and the importance of user feedback due to improvements in efficiency, customer satisfaction and overall product performance. The authors add that user experience (UX) principals should guide design decisions, fostering empathy for the user and creating solutions that are not only functional but also enjoyable.

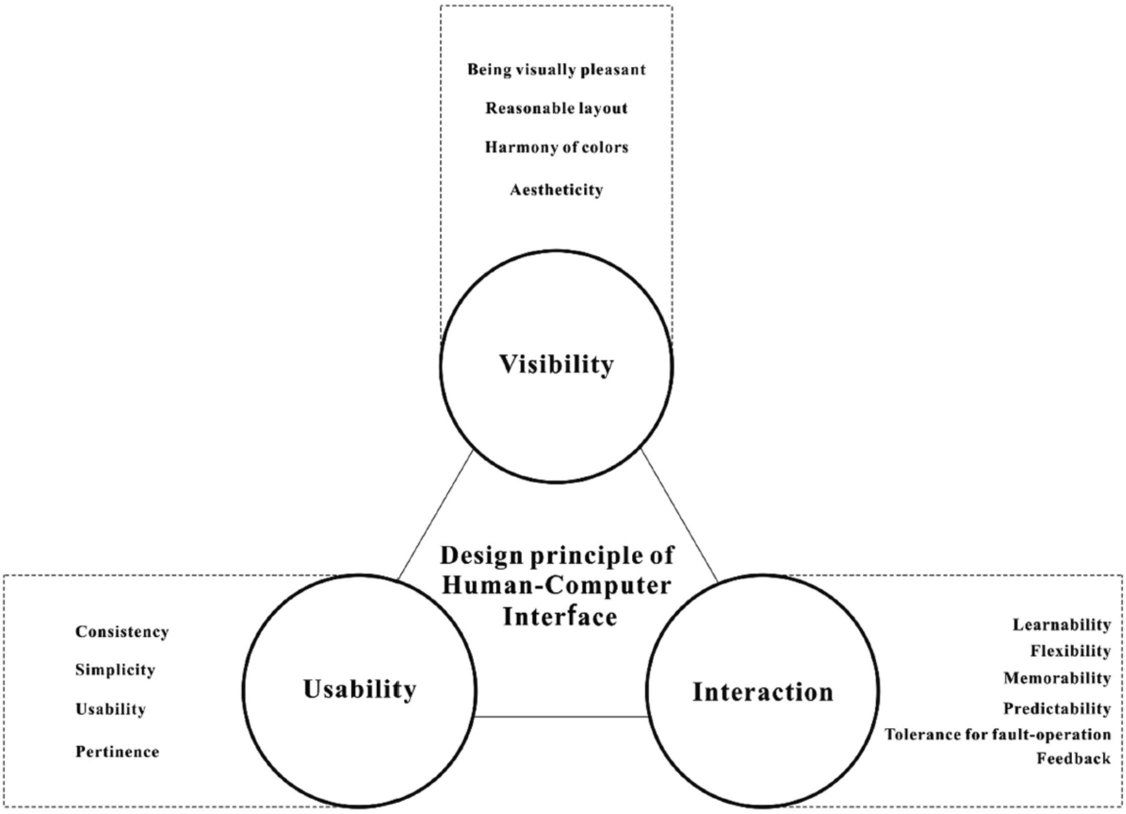


Figure 3.18: Principles and strategy of software interaction interface design [21]

Similarly, *Markus Specker and Ina Wentzlaff* [45] propose a method to support identifying and specifying usability requirements in software development, introducing a pattern-based development method that integrates usability principles from HCI design patterns into software analysis frameworks called "HCI Frames".

Kolte and Rao [28] delve into microinteraction design. Defined as focused tasks that take less than four seconds, they minimize disruption to the user's primary task by providing immediate feedback, making them essential for a smooth user experience. Moreover, feedback mechanisms explored by *Zhang and Zhong* include real-time error detection and corrective suggestions, improving the quality of the interaction and system performance by enabling users to rectify errors promptly [25].

Additionally, *Ren et al.* [41] discuss iterative design in the context of Human-Engaged Computing (HEC), where systems recognize and adapt to user emotions and behaviors in real-time. Iterative methods are used to fine-tune the mechanism of emotion recognition and interaction, ensuring that the system provides context-aware responses.

On the other hand, Ehrhart [29] highlights iterative design as a means of improving decision support systems. The iterative process allows designers to refine interactive visualizations by incorporating user feedback at each stage.

Expanding on this, *Xu* [52] emphasizes the importance of iterative design in education, showcasing how real-world projects incorporate iterative feedback cycles improve both students learning experience and the usability of their final products.

3.2.3 Usability Evaluation Methods

Usability evaluation methods are valuable for ensuring system effectiveness and user satisfaction. *Gong Chao* elaborates usability test methods aligned with design principles [17]. This includes user testing, by directly observing users as they interact with the system to identify practical usability challenges. Think-Aloud protocols to encourage users to verbalize their thoughts while navigating the interface to uncover hidden usability issues. And comparative analysis to evaluate multiple interface designs to determine which best meets user needs and expectations. In addition, heuristic evaluation and task analysis are core techniques for identifying interface issues early in development [20].

Usability evaluation can address domain-specific challenges. Scenario-based design and cognitive walkthroughs ensure the system aligns with the critical workflows and time-sensitive decision making, highlighting the importance of understanding the user context and the potential consequences of design flaws in high-stakes environments [18].

3.3 Conclusions

Spatiotemporal data visualization has demonstrated its importance in various domains, including public health, urban planning, and cultural heritage. Tools and techniques such as bubble maps, trajectory maps, DDLVis, and VTGeo have proven valuable in enabling users to identify patterns, trends, and anomalies effectively. However, the increasing complexity and volume of data require scalable solutions that can balance computational efficiency with user interactivity. Furthermore, many visualization tools depend on the intuition of the user to interpret patterns, which can lead to misinterpretations.

The evolution of Human-Computer Interaction has influenced the design and development of interactive visualization tools. Key principles such as visibility, usability, and interaction have guided the creation of user-friendly systems. Iterative design approaches, along with continuous user feedback, have improved system usability and adaptability.

Chapter 4

Proposed Solution and Implementation

The proposed solution aims to address the challenges in the stated problem, designing and proposing a platform that is both intuitive and effective for the research team. This solution is composed by a requirements elicitation, approach, and specific details about the implementation of the prototype.

4.1 System Requirements

Given the nature of the problem, it was necessary to carry out a detailed elicitation of system requirements. This process ensured that the platform would satisfy the research team's functional expectations and comply with relevant technical and operational limitations.

This section outlines the identified requirements, organized into three parts: user characteristics, functional requirements, and non-functional requirements. The analysis of user roles clarifies how various stakeholders interact with the system, while the functional and non-functional requirements define the necessary capabilities and quality attributes for effective system performance and user experience.

4.1.1 User Characteristics

The system's development includes three user roles, each with distinct responsibilities and access permissions. Understanding these stakeholders is essential to ensure the system meets their needs while upholding security and efficiency. The following table 4.1 identifies and describes the primary stakeholder groups: *Viewers*, *Editors*, and *Administrators*.

Stakeholder	Interests	Constraints
Viewers	• Access structured data through the platform. • Explore and interact with all the platform's features.	• Cannot edit data. • Dependent on the completeness of published items.
Editors	• Create and edit items, properties, and statements. • Contribute to the structured knowledge database.	• Must authenticate to the Wikibase instance. • Limited by data modeling constraints and property usage policies.
Administrators	• Maintain the Wikibase instance and manage users. • Ensure system integrity.	• Responsible for user rights management and system configuration.

Table 4.1: User/Stakeholder profiles

4.1.2 Functional Requirements

The list below outlines the core functional requirements of the system, which define the expected behavior and features from a user perspective. These requirements were derived based on the system's objectives and the interactions expected from stakeholders.

FR1 The system shall display items and their relationships on an interactive map.

FR2 The system shall group items when the view is too far.

FR3 The system shall show the number of grouped items in the group.

FR4 The user shall be able to view items and their relationships in a specified time range.

FR5 The system shall list all properties and visible items.

FR6 The user shall be able to search for specific items or properties.

FR7 The user shall be able to filter items and connections based on properties.

FR8 The user shall be able to locate an item upon selecting it in the search list.

FR9 The user shall be able to select a narrative, axis, and vocabulary filter that filters the visible data.

FR10 The system shall display colored properties.

FR11 The system shall show detailed item information upon clicking on it.

FR12 The system shall show detailed connection information upon hovering over it.

FR13 The system shall show only the item's connections upon hovering over it.

FR14 The system shall display items with an associated image using a Polaroid-style visual.

FR15 The system shall render clusters containing items as Polaroid-style visual representing the group.

FR16 On load, the map shall attempt to center on the user's geolocation.

4.1.3 Non-Functional Requirements

Non-functional requirements define the quality attributes and operational constraints of the system, they are essential to ensure that the system performs effectively and meets user expectations.

NFR1 The system shall be developed primarily for desktop environments.

NFR2 The system shall use a local Wikibase instance as its backend.

NFR3 The system should be accessible anywhere and anytime.

NFR4 The system has to be intuitive and support complex and quick filtering, exploration, and navigation.

4.2 Approach

The State of the Art reviewed in Chapter 3 highlighted essential principles and techniques for designing effective spatiotemporal visualizations, in domains that demand semantic interpretation, temporal exploration, and user-centered interaction.

One of the primary conclusions from the literature emphasizes the integration of spatial and temporal dimensions into a unified visualization interface. Combining maps with timelines makes it possible to represent evolving spatial phenomena effectively. This understanding guided the decision to integrate a geographic map with a timeline slider in this solution, allowing users to explore data distributions and relationships across both space and time.

The research in dynamic graph visualization and arc diagrams delved into the use of colored arcs to visualize the connections. These curved representations simplify the complexity of densely connected items while enabling interaction mechanisms such as hover tooltips and color encoding. Therefore, in the context of the problem, where interconnected items are complex, the implementation of arc connections is an effective solution.

Based on these considerations from the literature and the requirements elicited from the research team, the proposed solution is a map-based spatiotemporal visualization platform. Figure 4.1 represents the first mockup of the platform. The main component is a map that displays items and their relationships. The items will be shown using polaroid-style icons when an image is available or simple labeled boxes otherwise. While relationships will be represented as connections using curved arcs, colored according to the property they represent.

Both items and connections have clicking and hovering actions associated. Firstly, clicking on an item reveals full information about it, including all properties associated with that item, while hovering over it highlights only the connections associated with that specific item. Secondly, clicking on a connection moves the map to the furthest node involved, while hovering over it reveals a tooltip with information about that specific relationship, including name, target, and qualifiers.

To enable temporal exploration, the platform features a timeline slider that filters items and connections according to a specific year range defined by the user. This control remains persistently accessible in the interface and updates the map content in real time. The slider allows for exploratory browsing of historical periods and is useful for examining the evolution of materials, institutions, or actors over time.

Additionally, the platform supports a set of filters, corresponding to semantic properties in the dataset, to better analyze and explore the data, represented in Figure 4.1. Users can combine these filters to constrain the view and explore more targeted subsets of the dataset.

Finally, the system integrates a search interface that provides property and item search. Property search allows users to isolate specific types of connections by selecting them from a list, where each property is shown with a color matching the connection styling. In contrast, item search enables users to locate specific entities already visible in the current view.

All these elements are composed within a grid layout that gives prominence to the central map while maintaining accessibility to filters and search panels. This structure, combined with the interactive visualization logic, makes a user-friendly environment for exploring spatiotemporal and semantic relationships across this complex historical data.

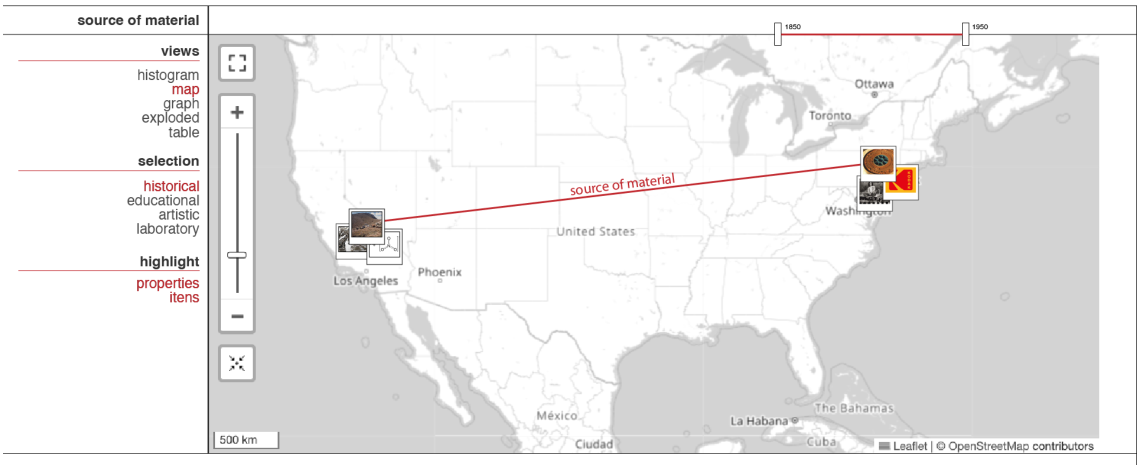


Figure 4.1: First mockup of platform structure

4.3 Prototype Implementation

The system is composed of two main layers: a backend powered by Wikibase Suite [35], and a frontend implemented using React [36] and JavaScript libraries such as React-Leaflet [8] and D3 [6]. Data is retrieved from Wikibase through both the SPARQL endpoint and the MediaWiki Application Programming Interface (API), and processed in the frontend to enable interactive visualizations. The figure 4.2 presents a high-level overview of the project architecture. Additional details of the implementation of each component are addressed in subsequent sections.

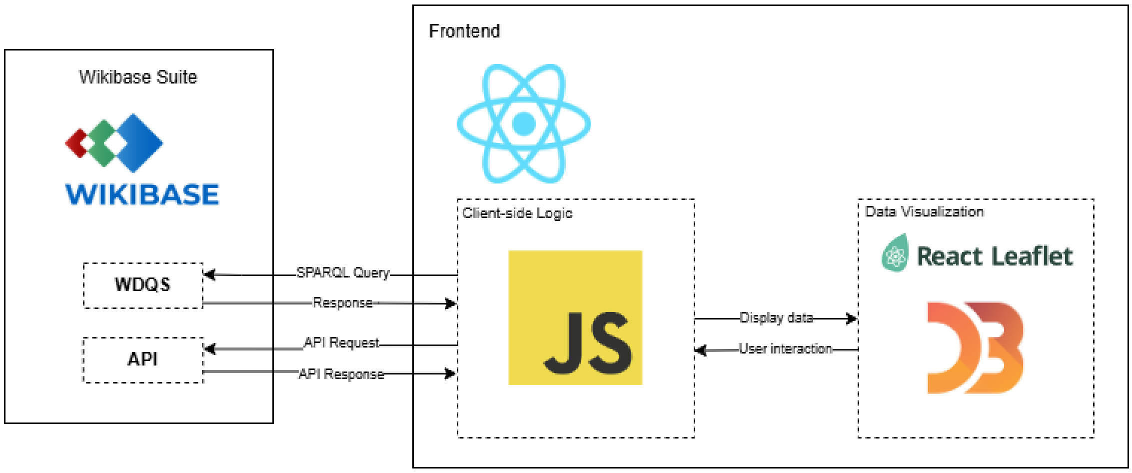


Figure 4.2: Prototype's data flow and architecture

4.3.1 Wikibase Suite

To manage and store structured knowledge, the platform uses a local deployment of the Wikibase Suite. The deployment includes the core Wikibase engine along with auxiliary components such as the Query Service (WDQS) to process SPARQL queries, QuickStatements to import and manipulate large amounts of data, and ElasticSearch for full-text search support. This was deployed using Docker [14] and orchestrated with Docker Compose, where each service runs in its own container and communicates over a shared network. A reverse proxy is configured to route HTTP requests and provide SSL support when necessary.

The deployment enables authenticated users to create and edit entities, such as items and properties, using a MediaWiki interface. Each item and property is represented by a unique IRI and can include multilingual labels, descriptions, and claims. Additionally, the frontend can retrieve data via two main interfaces:

- **MediaWiki API:** used to retrieve metadata on items and properties via de wbgentities action;
- **WDQS:** used to semantically query the knowledge base.

4.3.2 Data Retrieval

The system retrieves structured data from the Wikibase instance. The dataset includes a wide range of entities that represent key components of the ecological and sustainable dimensions of image-making practices, such as *institutions*, *creators*, *materials*, *chemical processes*, and *tools*.

Data retrieval involves communicating with WDQS to first obtain the ID of each item or property and then communicating with the API to gather all the information about the entity in question. The structure of the JSON object retrieved from the API is presented in Listing 4.1.

```
{
    "pageid": 195,
    "ns": 120,
    "title": "Item:Q105",
    "lastrevid": 511,
    "modified": "2025-04-22T18:32:59Z",
    "type": "item",
    "id": "Q105",
    "labels": {
        "en": {
            "language": "en",
            "value": "Cerro Gordo Mines"
        }
    },
    "descriptions": {
        "en": {
            "language": "en",
            "value": "abandoned mines located in the Inyo Mountains, California"
        }
    },
    "aliases": {},
    "claims": {
        "P3": [
            {
                "mainsnak": {
                    "snaktype": "value",
                    "property": "P3",
                    "hash": "d74e7cdcf3321425d3647ee4e1ddaf8fd5930ac3",
                    "datavalue": {
                        "value": {
                            "entity-type": "item",
                            "numeric-id": 106,
                            "id": "Q106"
                        },
                        "type": "wikibase-entityid"
                    },
                    "datatype": "wikibase-item"
                },
                "type": "statement",
```

```
                "id": "Q105$E09628B0-FF47-4A29-80B8-04B91A56978F",
                "rank": "normal"
            }
        ],
       // other properties
    },
    "sitelinks": {}
}
```

Listing 4.1: Example of a JSON item retrieved from the API

The JSON structure shown above corresponds to a single Wikibase entity. Each entity includes metadata fields such as a unique identifier (`"id"`), human-readable `"labels"` and `"descriptions"`, and a list of `"claims"` that represent semantic statements made about the item. Claims are composed of properties and values. Each claim can also include qualifiers and references, which add contextual information such as time, location, or source.

These items are semantically linked through properties that describe their origin, transformation, and impact. Properties include relationships such as *creator*, *source of material*, *product or service provided*, *has effect*, and *associated hazard*. The Listing 4.2 shows the structure of the JSON object retrieved from the API for a property.

The JSON structure presented in Listing 4.2 represents a Wikibase property. Properties in Wikibase define the types of statements that can be made about items. Each property includes metadata such as its `"id"`, `"label"`, `"description"`, and its `"datatype"`. Unlike items, properties typically do not contain extensive claims themselves, instead, they are used to define the structure of claims in other entities.

```
{
    "pageid": 7,
    "ns": 122,
    "title": "Property:P6",
    "lastrevid": 7,
    "modified": "2025-04-22T15:26:06Z",
    "type": "property",
    "datatype": "commonsMedia",
    "id": "P6",
    "labels": {
        "en": {
            "language": "en",
            "value": "image"
        }
    },
    "descriptions": {
        "en": {
            "language": "en",
```

```
            "value": "image of relevant illustration of the subject; if available, also use more specific properties (sample: coat of arms image, locator map, flag image, signature image, logo image, collage image)"
        }
    },
    "aliases": {},
    "claims": {}
}
```

Listing 4.2: Example of a JSON property retrieved from the API

4.3.3 Technology Selection

When assessing technologies for developing the prototype, the primary consideration was the alignment between the platform's technical requirements and the capabilities of the available libraries. The system required support for interactive map rendering, dynamic filtering, temporal control, and visual representation of semantic connections between items. It was essential that the chosen technologies provided high modularity, performance, and compatibility with web standards, particularly given the desktop-first nature of the project and its accessibility through modern web browsers.

The adoption of the MediaWiki ecosystem, particularly through the use of the Wikibase Suite, was driven by the project team's initial proposal to manage and expose structured semantic data in a flexible and collaborative environment. MediaWiki, widely known for powering platforms such as Wikipedia [49], offers a robust and extensible foundation for knowledge organization. Its semantic extension, Wikibase, allows entities (items and properties) to be defined with multilingual labels, rich metadata, and semantic relationships. This ecosystem not only aligns with the project's needs for collaborative data curation and semantic structuring but also provides a standardized interface (via SPARQL and MediaWiki APIs) that supports external integration.

React was selected as the core framework for building the user interface. Its component-based architecture, declarative rendering, and extensive ecosystem offer a robust foundation for managing complex UI states and interactions. The modularity of React is particularly beneficial for implementing independent components, such as narrative selectors, property filters, item lists, and timeline controls. Moreover, the choice of React as the frontend framework was also reinforced by its increasing use in MediaWiki-related interfaces and community tools, ensuring compatibility and potential for future extensibility within the same ecosystem.

For map rendering and handling spatial interaction, React-Leaflet proved to be the optimal choice. As a React wrapper for the established Leaflet library, React-Leaflet integrates map functionality seamlessly within the React ecosystem. It supports essential features such as user geolocation, dynamic marker clustering, map zoom handling, and responsive overlays. These features directly address key system requirements, including item grouping at low zoom levels, displaying item counts in clusters, and centering the map based on the user's location.

In parallel, D3 was chosen to support the rendering of connections between items and to enhance the expressiveness of the visualization. D3 allows for fine-grained control over SVG elements and offers the flexibility to implement custom behavior, such as highlighting only relevant connections during hover events or visually encoding the meaning of each connection.

These technologies, together, create a coherent and capable stack that supports the prototype's goals of interactive exploration, semantic efficiency, and user-friendly navigation across the knowledge base.

4.3.4 Coordinate Assignment and Spatial Layout

A critical aspect of the system's visualization architecture is the placement of elements on the map. Given the heterogeneous nature of the geospatial data in the Wikibase entities, where the majority do not have direct coordinate information, a multi-phase coordinate assignment approach was implemented to ensure that each item could be meaningfully displayed within the map.

4.3.4.1 Direct and Inherited Geolocation

The primary source of spatial data is the property (*coordinate location*), which is extracted directly from the dataset and assigned to the corresponding item when available. *Kodak* has specific geographic coordinates because it refers to a particular company with an identifiable location—its headquarters or manufacturing facility. In contrast, items such as *Kodak Cellulose Nitrate Film* or *Nitrate Film* do not have coordinates, as they represent materials or processes that might not be associated with a single location. These entities can be produced, used, or referenced by various items across different regions, making it inappropriate or impossible to assign a unique geolocation to them.

To address this disparity, a fallback mechanism was implemented using semantic inheritance. If an item references another entity through the property (*location of formation*), and the referenced entity includes a valid coordinate, then the item will inherit that coordinate.

4.3.4.2 Hirearchical Spatial Propagation

After identifying all items with explicit or inherited coordinates (root items), a recursive strategy is used to propagate positions to remaining items that lack direct geolocation. To achieve this, the system uses a breadth-first traversal, starting from the root items. Each child node that has not been positioned yet is assigned a spatial location calculated via a spiral layout algorithm, as shown in Listing 4.3. This algorithm distributes the child nodes radially around their parent, using increasing radius and angular offsets to prevent overlap.

```
const distributeItemsAroundParent = (parentCoords, numChildren) => {
    const baseRadius = 0.02;
    const spiralFactor = 0.004;
    const jitterFactor = 0.002;

    return Array.from({ length: numChildren }).map((_, i) => {
        const angle = i * (2 * Math.PI / 5);
        const radius = baseRadius + spiralFactor * i;
        const jitterX = (Math.random() - 0.5) * jitterFactor;
        const jitterY = (Math.random() - 0.5) * jitterFactor;

        return [
            parentCoords[1] + (radius * Math.cos(angle)) + jitterX,
            parentCoords[0] + (radius * Math.sin(angle)) + jitterY,
        ];
    });
};
```

Listing 4.3: distributeItemsAroundParent function makes spiral layout calculation

The recursive process is implemented in the `generateVisibleData` function, which repeatedly iterates over the visible items and their outgoing connections, assigning coordinates to target items that have not yet been positioned. This is repeated until no additional placements are possible.

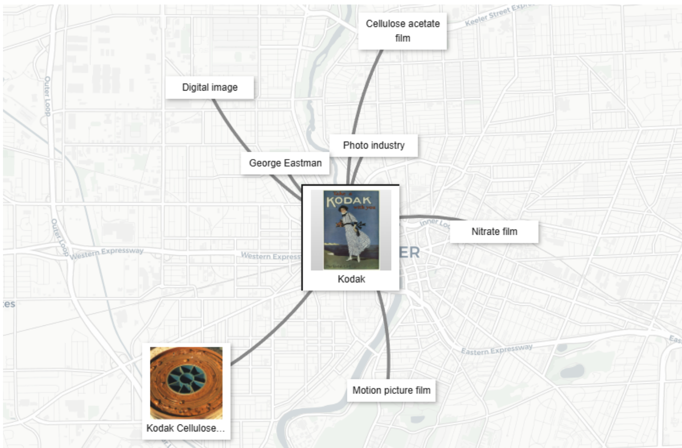
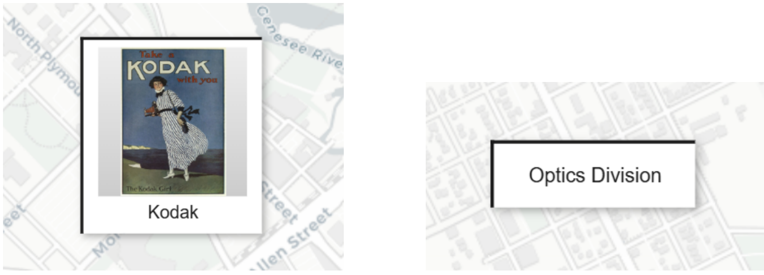


Figure 4.3: Spiral Distribution

4.3.5 Items Visual Representation

To enhance the interpretability and aesthetic quality of the map-based visualization, the system adapts the visual appearance of each item according to its metadata. Two main attributes influence the styling: the availability of geographical coordinates and the presence of an image associated with the item.

Root items. Items that contain spatial data through *coordinate location* are classified as root items. These items are displayed with distinct visual features to emphasize their anchoring role in the spatial layout. When an image is associated with such items, it is rendered inside a polaroid-style frame that includes the image and the item's label, as presented in Figure 4.4a. When an image is not present, the item is represented as a labeled box, as represented in Figure 4.4b. These icons are assigned a larger size and a ticker left and top border to distinguish them from non-root items.



(a) Root item with image (b) Root item without image

Figure 4.4: Visual representation of root items

Non-root items. Items that do not have direct coordinates are non-root items. When rendered on the map, if an image is present, the item is rendered in a polaroid format, as illustrated in Figure 4.5a. If no image is present, the items are represented as labeled boxes, as presented in Figure 4.5b.

(a) Non-root item with image (b) Non-root item without image

Figure 4.5: Visual representation of non-root items

Clustered Items. To manage dense areas of the map and maintain legibility, the system uses clustering. When multiple items are located near one another, they are aggregated into a cluster. These clusters are styled as compact polaroid-style frames, which visually mimic a photo label with a numerical count. Additionally, the cluster displays the number of grouped items while maintaining the visual consistency of individual item icons, as illustrated in Figure 4.6. Upon interaction, the cluster expands to reveal the individual items it contains.

Figure 4.6: Visual representation of clustered items

4.3.6 Connections

Semantic relationships between items on the map are connections and are visually represented on the map as curved arcs using D3. This section details the methods used for rendering the connections, drawing and style of arcs, the display of contextual information, and the interactive behaviors.

Arc Drawing and Styling. Connections are defined as directed links between two items, expressed via properties. Each connection is rendered as a curved SVG path overlaid on the Leaflet map canvas. Each arc is styled with a specific stroke color corresponding to the connection's property type. This color encoding aids users in quickly distinguishing between different types of relationships. When the property is not mapped explicitly, a default gray color is applied, as illustrated in Figure 4.7. In special cases, such as *instance of* property having the value *project*, *visual work*, or *creative work*, a predefined override color is used to highlight these links.

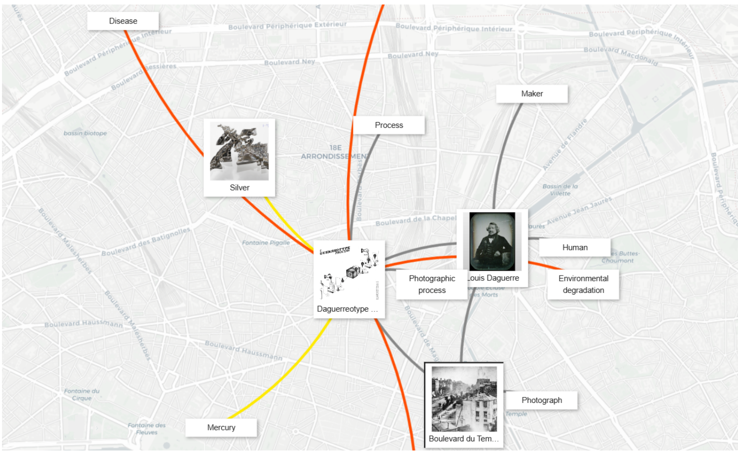


Figure 4.7: Visual representation of connections between items

Tooltips and Qualifiers. At first glance, connections do not reveal their information, such as label, target item, or additional metadata that provides context to the relationships (qualifiers). This data is displayed as part of an interactive information tooltip when the user hovers over a connection. At the top, the label of the connection, followed by the target item, and then, if present, the qualifiers, as shown in Figure 4.8. Additionally, each qualifier is styled using its own semantic color and label.

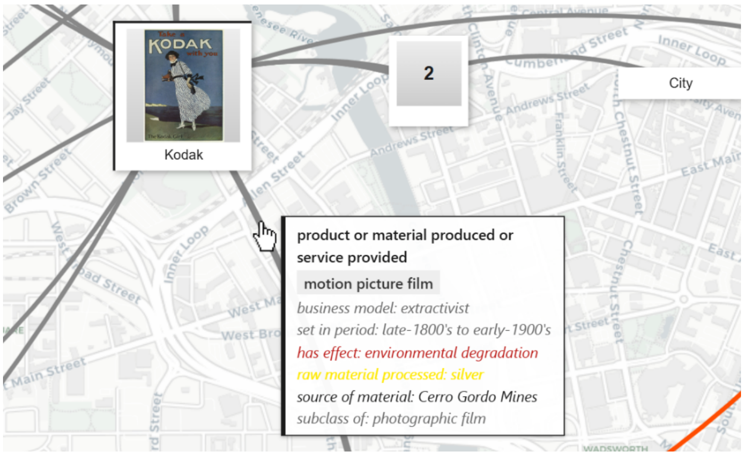


Figure 4.8: Connection tooltip

Interactivity. Connections are interactive and involve two main actions: hovering and clicking. When the user hovers over an arc, its stroke width increases, and the information tooltip appears. Clicking on a connection will highlight it and adjust the map view to center on either the source or target, depending on which one is further away. This is implemented using D3's event handling model, attached to each SVG path element.

4.3.7 Timeline Slider

The platform incorporates a timeline slider that enables users to view items and their relationships within a selected time range, addressing a core usability requirement.

The slider is present all the time in the interface and allows users to define a continuous range of years through a drag-and-drop interaction, as shown in Figure 4.9. As the selected range is adjusted, the map view updates in real time to reflect only the items and connections relevant to that interval. The system considers the available temporal properties, such as inception date, birth/death dates, and start/end periods, and compares them with the selected time range.

Figure 4.9: Timeline slider

4.3.8 Interactive Controls

The interactive controls of the platform are fundamental to achieving the platform's goals, where a series of elements capable of filtering the information are needed, in order to personalize the visual according to conceptual and contextual dimensions. These controls are divided into two main categories: filters and search.

Narrative, Axis, and Vocabulary filtering

The platform includes a filter panel, illustrated in Figure 4.10, that offers three curated dimensions that users can utilize to explore the dataset:

- **Narrative** — Based on the property *Storytelling*, represents a specific story that groups items, not just thematically related, but that collectively contribute to telling a coherent story. For instance, a narrative with value *Ecology of Images* might include materials, processes, institutions, and actors that together trace the lifecycle and the impact of the image process.
- **Axis** — This filter is based on the property *Axis* and refers to which axis the items belong to, such as *laboratorial* or *artistic*. It enables users to restrict the visualization to a specific viewpoint.
- **Vocabulary** — Based on the property *Vocabulary*, this filter groups items according to shared terminological values. Selecting a vocabulary term such as *Extractivism*, *Bioimages*, or *Wikidata* filters the visualization to include only the items explicitly linked to that term.

Each filter is presented as a list of toggleable buttons that can be turned on or off. Upon interaction, the map updates in real-time to show only the items and relationships that match the selected criteria. These filters are designed to work both independently and in combination. The options available for each filter are not predefined, as the system loads item data, it scans relevant properties and aggregates all distinct values.

Search

To address another important functional requirement, the platform includes a keyword-based search component that allows users to quickly locate specific entities or group various properties, as shown in Figure 4.11. The search interface supports two modes:

- **Property search** — This mode allows users to search for properties that describe relationships between items. Upon selecting one or more properties from the list, the map is updated to display only the items and relationships associated with those properties. Additionally, properties that have an associated color, as defined in the connection rendering logic, are visually represented with that color, aiding a visual correlation between properties and corresponding colors.

- **Item search** — This mode allows users to search for a specific item by name, limited to the items currently visible in the map. Once an item is selected, the user locates the item as the map view centers on its location, bringing the selected item into focus.

Both search modes present scrollable lists of options that are dynamically populated based on the currently visible data. When items or properties are highlighted, users receive immediate visual feedback in the map. Furthermore, the two search modes are mutually exclusive and can be switched using the tabs at the top of the search panel.

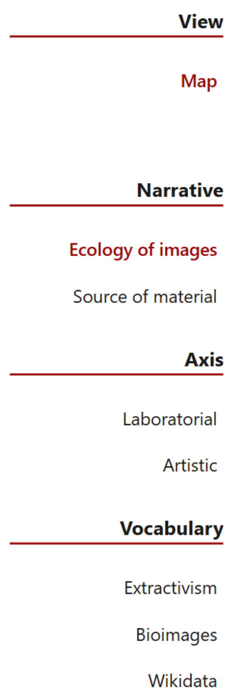


Figure 4.10: Filter Panel

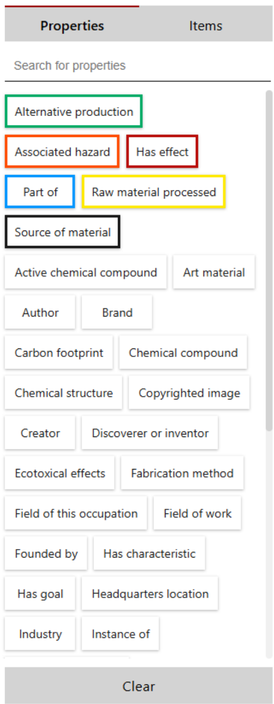


Figure 4.11: Search Interface

4.3.9 Interface Layout

The platform presents a structured interface composed of three main sections: the filter panel on the left, the central map visualization, and the search box on the right, as illustrated in Figure 4.12. Additionally, the timeline slider is positioned above the map, and below the map, an information box appears when a connection is clicked, showing a textual summary of the relationship.

The map visualization is the primary visualization area, occupying the majority of the horizontal space, ensuring greater readability. On the left side, the filter panel provides enough space to select the filter options, while a search box on the right gives room for dynamic lists and interactions without overwhelming the map. This layout was chosen to prioritize the map, while still offering sufficient space for interactive controls on both sides.

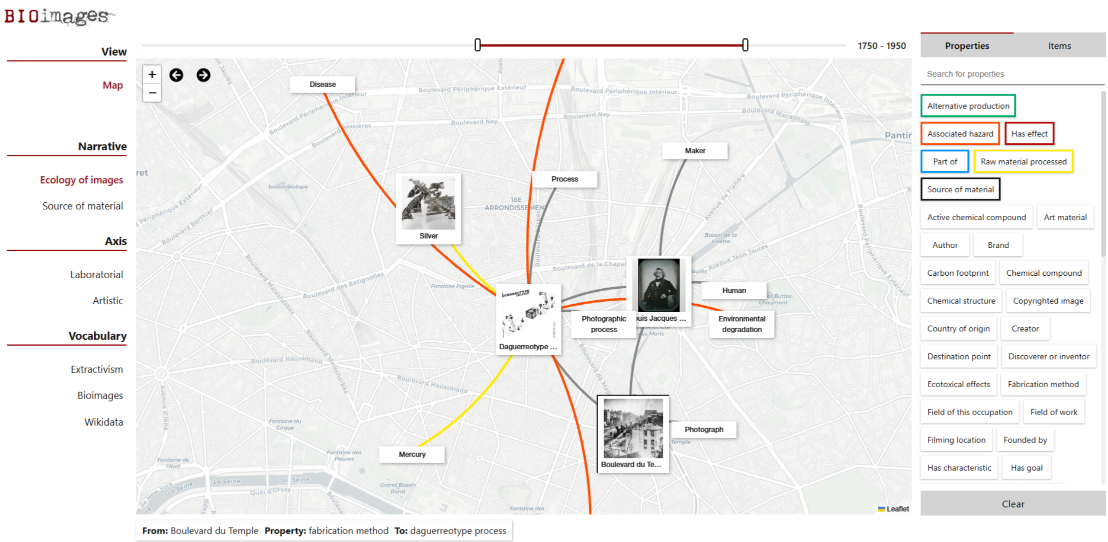


Figure 4.12: Interface layout of the platform

4.4 Summary

This chapter has presented the design and implementation of the proposed platform, focusing on its core components and functionalities. Section 4.1 detailed the collaborative approach with the research team to define precise visualization goals. In Sections 4.2 and 4.3 outlined the conceptual foundations and design of the solution, followed by a detailed explanation of its technical implementation.

The resulting system integrates semantic data retrieved from the Wikibase instance with interactive frontend technologies, allowing users to explore complex spatiotemporal relationships through a unified interface.

Chapter 5

Experimental Protocol

This chapter describes the experimental protocol developed to evaluate the platform. The chapter is structured as follows: Section 5.1 details the methodology, including the experimental setup and procedure. Section 5.2 describes the structure and content of the formative questionnaire used throughout the evaluation. Section 5.3 presents the pilot tests conducted to validate and refine the protocol and interface.

5.1 Test Methodology

The primary objective of the methodology is to evaluate the usability, navigability, and functional clarity of the system developed through a task-based user study. The methodology will be described below, and includes the general description of the experiment in Section 5.1.1, and a detailed experiment procedure in Section 5.1.2.

5.1.1 General Description

The experiments are designed to address questions such as:

- **Q1:** Does the platform support users in locating, filtering, and interpreting items and their relationships?
- **Q2:** Do users find the interface intuitive and enjoyable to interact with, particularly regarding the application of filters and search to explore complex data structures?

To address these questions, a task-based experimental design was adopted, where participants interact with the platform while performing guided tasks. Key aspects of the setup are outlined below:

- **Where, When, and Duration:** The prototype is available online and can be accessed from anywhere with an internet connection. The experimental phase occurred between April 12^{th} and May 31^{st}.

- **Equipment and Software:** Participants use their personal computers or laptops with internet access and a browser to access the platform.
- **Coordinator, observer, and facilitator:** The entire process is coordinated and monitored by the author of this thesis. All tests are conducted individually and remotely, without direct observation or supervision. This approach aligns with the nature of the platform, which is available online and designed for independent utilization by a wide variety of users. This method enables more participants to be involved without needing physical presence. Participants can access the platform at their convenience and engage with it naturally, which may lead to more authentic behavior and reduce potential biases caused by the presence of an observer.
- **Participants:** The experiment will be restricted to people with a background in Art & Design, specifically in education and research in this area.
- **Test Methods:** The prototype evaluation is conducted using a guide that includes questionnaires. This questionnaires are used to collect both pre-task, in-task, and post-task data from participants.
- **Help Resources:** At the beginning of the test, participants will be provided with a brief introductory text explaining the domain and purpose of the platform. Furthermore, some platforms' features are explained throughout the guide.

5.1.2 Experiment Procedure

Participants follow a standardized procedure designed to ensure consistency and comparability between sessions. Participants access the guide, and the procedure begins with the presentation of an informed consent form, which details the study's purpose, data usage, and the voluntary nature of participation. After giving consent, participants are asked to provide demographic data and their experience with interactive systems.

Following the questionnaire, participants access the platform through a provided link. The system

5.1.2.1 Initial System State

The platform is configured in a predefined state to ensure a common start point across participants. Specifically, the *Ecology of Images* narrative is preselected and visibly highlighted in the platform's interface, restricting the visualized data to a coherent thematic subset. Additionally, the timeline slider is predefined with the range *1750* to *1950*, and the filters for both *Axis* and *Vocabulary* in the left panel have no options selected, which means they do not restrict any items. Regarding the interactive map, if the user accepts the location request, it initializes with user's geographical center; if not, it initializes with a predefined geographical center.

5.1.2.2 Completion Criteria

The completion of an experiment requires the participant to fulfill specific critical requirements. Initially, the participant must consent to the terms in the Informed Consent Form at the start of the experiment. Next, they must complete all the mandatory questions in the pre-test, in-test, and post-test questionnaires. These conditions are necessary to ensure comprehensive data collection and confirm full participant engagement with the experiment.

5.1.2.3 Success Criteria

The experiment's success will be determined by the assertiveness of participants' responses to the task-specific questions. Each task presents multiple options. In the majority of tasks, there is only one correct answer, but there are tasks for which two options are correct. Success will be measured based on the number of correct responses. Correct answers are scored with one point, and incorrect answers are scored with zero points, ensuring that the evaluation is focused only on the accuracy of task completion. However, for tasks with two correct options, the score is the following: one point if both correct options are selected, half a point if only one of the correct options is selected, and zero points if no correct options are selected.

5.2 Formative Questionnaire

The evaluation employed a structured questionnaire developed using Google Forms [22], chosen for its accessibility, real-time data collection capabilities, and integration with quantitative and qualitative response formats.

The questionnaire (see Annex B) begins with an Informed Consent Form, introducing the study's purpose, participation requirements, and ethical safeguards (Section 5.2.1). Following the informed consent agreement, participants proceed to the Pre-Test Questionnaire, establishing participant demographics and baseline competencies(Section 5.2.2). Before task execution, guidance was provided about platform capabilities and evaluation expectations, ensuring uniform understanding of the interface's interactive features while maintaining methodological consistency by forbidding later answer changes. Then, the task-specific questions are presented to evaluate the user's interaction and comprehension (Section 5.2.3). Finally, the post-test evaluation combined the validated System Usability Scale (SUS) with open-ended questions (Section 5.2.4). The following sections provide detailed descriptions of each questionnaire component.

5.2.1 Informed Consent Form

Before participating, all users were required to review and accept an informed consent form. This form outlined the scope and purpose of the study, highlighting that participation involved engaging with the platform and answering the subsequent questionnaire. It communicated that:

- All collected data would be used anonymously and exclusively for academic research.

- No personally identifiable information would be published or shared beyond the study.
- Participation was entirely voluntary, with the option to withdraw at any time without justification.

Participants were asked to confirm that they had read and understood the information to ensure ethical compliance. Consent was recorded explicitly through a checkbox labeled *"I agree to the terms"*.

5.2.2 Pre-Test Questionnaire

In this part of the guide, participants were asked to complete a pre-test questionnaire designed to collect demographic and contextual information relevant to interpreting the results.

Demographic Information. Participants indicate their age group, selecting one of the options: *18-24*, *25-34*, *35-44*, *45-54*, *55+*. They also identified their gender, choosing from *Male*, *Female*, *Non-Binary*, *Prefer not to say*, or *Other*. Additionally, participants indicated their field of study or professional background through an open-ended question.

Digital Experience and Proficiency. Participants self-assess their digital proficiency using a 5-point Likert scale, where *1* indicated *not comfortable* and *5* indicated *very comfortable*—aimed to capture their confidence in using web-based applications and digital tools. In addition, participants are asked whether they had previous experience using interactive maps or data visualization interfaces, selecting from the options *Yes*, *No*, or *I'm not sure*.

5.2.3 Task-specific Questionnaire

In this stage, participants were guided through a series of sequential tasks designed to evaluate core functionalities of the platform and users' ability to navigate, interpret, and manipulate structured data in the platform. Tasks were interleaved with contextual feature descriptions, allowing participants to discover the core tools. This ensured that responses reflected usability and comprehension rather than trial-and-error exploration.

Task 1: Locate the item Kodak on the map. Once you find it, examine its connections. Which of the following items is produced by Kodak? (Expected answer: *Kodak Cellulose Nitrate Film*) - Tests the visualization's ability to represent an item's direct connections.

Task 2: What is the source of material of Kodak Cellulose Nitrate Film? Use the search feature to find and filter the desired property. (Expected answer: *Cerro Gordo Mines*) - Tests the effectiveness of the search and property filtering interface in narrowing down an item's relationships.

Task 3: In which year did operations begin at Cerro Gordo Mines? (Expected answer: *1865*) - Tests the visualization's ability to represent an item's metadata.

Task 4: What product or material is produced at this location? (Expected answer: *Silver*) - Tests the visualization's ability to represent the semantic meaning of a connection.

Task 5: What is the associated effect of producing that material? (Expected answer: *Environmental Degradation*) - Tests the visualization's ability to represent and make accessible the metadata associated with a connection.

Task 6: Over time, Kodak has produced several photographic developers. Identify it. Use the time slider to extend the time range. (Expected answer: *Kodak HC-110 developer*) - Tests the visualization's ability to represent temporal exploration by dynamically revealing time-dependent data using the time slider.

Task 7: What alternative production methods exist today for this developer (Kodak HC-110 developer) produced by Kodak? (Expected answers: *Caffenol, Thymintanol*) - Tests the visualization's ability to distinguish visually the different types of connections for an item.

Task 8: Which item uses Caffenol as a production method? (Expected answer: *Caffenol-C photography made with ecobject pinhole*) - Tests the visualization's ability to navigate through distant items via a connection.

Participants were explicitly instructed in some tasks to use specific platform features, such as the search tool or the time slider. This approach not only supported task completion but also enabled the collection of focused feedback on the usability of individual features.

5.2.4 Post-Test Questionnaire

The post-test questionnaire consists of a System Usability Scale (SUS) and a segment for participants to share open-ended feedback regarding the visualization. This setup is designed to obtain insights into the user's experience regarding ease, understanding, and engagement. The SUS provides a standardized measure of perceived usability, where participants rated each item on a five-point Likert scale ranging from "Strongly Disagree" to "Strongly Agree". It comprises the following ten statements:

1. I think that I would like to use this system frequently.
2. I found the system unnecessarily complex.
3. I thought the system was easy to use.
4. I think that I would need the support of a technical person to be able to use this system.
5. I found the various functions in this system were well integrated.
6. I thought there was too much inconsistency in this system.

7. I would imagine that most people would learn to use this system very quickly.
8. I found the system very cumbersome to use.
9. I felt very confident using the system.
10. I needed to learn a lot of things before I could get going with this system.

In addition to the structured SUS items, three qualitative questions were included to gather more feedback, aiming to capture users' impressions, difficulties, and improvement suggestions in their own words:

- If you could change one thing about the system, what would it be?
- Please use the space below to share any comments, suggestions, or criticisms that could help improve the usability and functionality of the platform.
- Did you find something out of the range of the guide?

5.3 Pilot Tests

Two pilot tests were conducted before the beginning of the evaluation period. The first pilot test was conducted on April 9$^{\text{th}}$, and the second on May 4$^{\text{th}}$. These sessions were instrumental in validating the platform's functionality, testing the structure and flow of the tasks and questionnaires, and identifying potential sources of confusion in the user interface. The pilots involved a small group of participants representative of the intended audience.

In both pilot tests, participants were presented with the guide, which included the informed consent form, pre-test questionnaire, task-specific questionnaire, and post-test questionnaire. The moderator was present and observed the participants to identify issues and common struggles in the process, without assisting.

As a result of the pilot tests, based on the insights gathered from participant behavior and feedback, the system and the questionnaire were refined, and the following improvements were implemented:

- **Properties and Items search:** Participants had difficulties in understanding the behavior of the search for properties and items, because the selection to search for a property or item was on the left side of the map, and the input to search was on the right side. Additionally, the search list contained properties and item labels, which confused the participants because they had difficulty distinguishing the entities. To solve this, firstly, the selection was moved to the top of the search box, and secondly, the list was separated into two: one for properties and another for items.
- **Item search:** When searching for an item, upon clicking on the item requested, the system was filtering the visible items on the map. Participants found this feature useless, since they

continued to have difficulty finding the item they were looking for due to the current map zoom or the complexity of items displayed. To address this, the functionality changed to locate the item on the map. Thus, upon clicking on the requested item, the map goes to the item's location.

- **Properties color:** When displaying the connections, participants found it difficult to intuitively associate the color of the connection to the property that it represents. To fix this problem, the color was included in the list of properties; thus, when looking for the list, the user can immediately associate the property with the color.
- **Connections lines thickness:** Participants had difficulties hovering over the connections in the map. This happened due to the thickness of the lines, which was too narrow. To address this, the width of the line has been increased, as well as the space for hovering.
- **Connections' tooltip information:** When there was a big complexity of items and connections displayed, participants had difficulties identifying the target of a connection. To address this, the target of the specified connection was included in the tooltip of that connection.
- **Refactor of Form Questions:** In some tasks, the question was poorly formulated from a technical point of view, leading to a misunderstanding among participants.
- **Feature presentation in the Form:** Participants had difficulty understanding the platform' features present in the questionnaire. This happened due to how this information was being displayed, since there was a lot of text and a lot of information being transmitted. To address this, images illustrating the features were included, and the information was more distributed along the guide.

5.4 Summary

The experimental protocol described in this chapter enabled a comprehensive evaluation of the platform's usability through structured user testing. The methodology maintained consistency across participants while facilitating genuine and independent interactions with the system. A formative questionnaire collected both quantitative and qualitative feedback, providing valuable insights into users' experiences and their understanding of the interface. The pilot tests were essential in identifying usability issues, resulting in significant enhancements such as improved search functionality, better visualization cues, and clearer questionnaire formulation. Overall, this experimental setup provided a strong foundation for assessing how effectively the platform achieves its intended goals.

Chapter 6

Results

This chapter presents the results of the empirical evaluation conducted to assess the usability, effectiveness, and overall experience of the prototype developed. The evaluation followed a formative approach detailed in Chapter 5. The results include information from the formative questionnaire (Section 6.1), such as demographic and digital background information, task performance statistics, the System Usability Scale evaluation, as well as participant feedback and suggestions. The interpretation of these findings and the discussion are addressed in Section 6.2.

6.1 Formative Questionnaire

The formative questionnaire was designed to contextualize participants' interaction with the system, gather essential background data about them, make them perform tasks using the prototype, and measure the overall satisfaction with the system. Their responses were recorded to analyze task accuracy and identify potential difficulties in information retrieval or navigation. The final part of the questionnaire included the System Usability Scale (SUS) and open-ended questions, which provided both numerical scores and qualitative insights regarding the user experience.

6.1.1 Demographic Statistics

Among the 31 submissions, 21 participants were aged between 45 and 54 years old (67,71%), followed by 6 participants in the 25-34 age range (19,35%), 3 participants in the 35-44 age range (9,68%), and only one participant was aged 55 or older (3,23%). In terms of gender, 17 participants identified as male (54,84%), 13 as female (41,94%), and 1 as non-binary (3,23%).

The participants' fields of study or profession were categorized into five main groups based on thematic similarities. The two most represented categories were *Art & Design Education* and *Academic Research & Teaching*, each with 10 participants (32,26%). These categories include individuals involved in teaching, research, and doctoral studies, particularly in artistic or educational contexts. Additionally, 5 participants have a background in *Art & Visual Arts* (16,13%), including artists and professionals involved in creative production. The *Design & Digital Media* category comprised 4 participants (12,90%), representing areas such as product design, interaction design, and digital technologies. Finally, 2 participants reported backgrounds in *Engineering or Computer Science* (6,45%).

Regarding digital proficiency, Table 6.1 displays the distribution of digital proficiency among the participants. Furthermore, when asked about prior experience with interactive maps, 24 participants reported having used them before (77,42%), while 4 participants were unsure (12,90%) and 3 participants had not used interactive maps before (9,68%).

Table 6.1: Distribution of digital proficiency among participants

	Minimum	1st Quartile	Median	3rd Quartile	Maximum	Std. Dev.
Digital Proficiency	3,00	4,00	4,00	5,00	5,00	0,599

The distribution of professional backgrounds was expected, since the questionnaire was primarily disseminated among individuals connected to artistic, educational, and research fields. Therefore, the representation of participants from art and design education, academic research, and visual arts aligns with the intended target audience. Moreover, the high levels of digital proficiency and the previous use of interactive maps further indicate that the sample is suitable for evaluating the platform based on visual and interactive digital tools.

6.1.2 Task Statistics

In order to evaluate task performance and analyze how effective the visualization is, success is defined as a participant's answer matching the correct answer provided by the experiment organizer, as explained in Section 5.1.2.3. Correct answers are scored with 1 point, and incorrect answers are scored with 0 points. For Task 7, 0.5 points are attributed if only one correct option is selected, with accuracy reflecting the average score across participants. Table 6.2 presents the task accuracy per question for the 31 submissions.

Table 6.2: Task accuracy per question

	Correct Answers	Task Accuracy
Task 1	29 / 31	93,5%
Task 2	21 / 31	67,7%
Task 3	29 / 31	93,5%
Task 4	30 / 31	96,8%
Task 5	23 / 31	74,2%
Task 6	26 / 31	83,9%
Task 7	18,5 / 31	59,7%
Task 8	12 / 31	38,7%

From the table above, it is clear that Tasks 1, 3, and 4 achieved the highest accuracy rate, with more than 28 participants answering correctly. In contrast, Task 8 had the lowest performance, with only 12 participants answering correctly (38.7%). Overall, the results indicate varying levels of task difficulty and participant understanding, which are analyzed individually in the paragraphs below.

Question Task 1. Out of 31 participants, 29 correctly identified *Kodak Cellulose Nitrate Film*. Only 2 participants chose *George Eastman*. The option *Rochester* and option *Photo industry* were not selected by any participant. Refer to the bar chart in Annex C (Figure C.5) for a graphical overview of the response distribution.

Question Task 2. Out of 31 participants, 21 correctly identified *Cerro Gordo Mines*. The next most common response was *Silver*, selected by 8 participants. Options *Kodak* and *Optics Division* were selected by only 1 participant each. In total, 4 distinct values were chosen out of the available options (the source of material of Kodak Cellulose Nitrate Film). Refer to the bar chart in Annex C (Figure C.6) for a graphical overview of the response distribution.

Question Task 3. Out of 31 participants, 29 correctly identified *1865*. Options *1755* and *1950* were selected by only 1 participant each. The option *1800* was not selected by any participant. Refer to the bar chart in Annex C (Figure C.7) for a graphical overview of the response distribution.

Question Task 4. Out of 31 participants, 30 correctly identified *Silver*. Only one participant chose *Kodak Cellulose Nitrate Film*. Options *Optics Division* and *Thymol* were not selected by any participant. Refer to the bar chart in Annex C (Figure C.8) for a graphical overview of the response distribution.

Question Task 5. Out of 31 participants, 23 correctly identified *Environmental Degradation*. The next most common response was *Extractivism*, selected by 7 participants. Only 1 participant chose *Film Degradation*. The option *Mistreatment of animal* was not selected by any participant. Refer to the bar chart in Annex C (Figure C.9) for a graphical overview of the response distribution.

Question Task 6. Out of 31 participants, 26 correctly identified *Kodak HC-110 developer*. 5 participants selected *Nitrate film*. The options *business* and *Silver* were not selected by any participant. Refer to the bar chart in Annex C (Figure C.10) for a graphical overview of the response distribution.

Question Task 7. Out of 31 participants, 14 correctly identified both *Thymintanol* and *Caffenol*. Earning partial credit, 9 participants selected only one of the two correct options. The remaining 8 participants chose only incorrect options or a combination that included incorrect options, such as *Cellulose* or *Thymol*. Notably, *Caffenol* was the most frequently selected option, appearing in 24 out of 31 responses, while Thymintanol appeared in 17 responses. Incorrect options were less popular: *Cellulose* was chosen 6 times, and *Thymol* was chosen 4 times. Refer to the bar chart in Annex C (Figure C.11) for a graphical overview of the response distribution.

Question Task 8. Out of 31 participants, 12 correctly identified *Caffenol-C photography made with ecobject pinhole*. The other responses were distributed as follows: 9 participants chose *Coffee*, 6 participants selected *Caffeic acid*, and 4 participants picked *Photography*. In total, 4 distinct values were chosen out of the available options (the item using Caffenol as a production method). Refer to the bar chart in Annex C (Figure C.12) for a graphical overview of the response distribution.

6.1.2.1 Task Performance per Participant

Examining participants' performance across all tasks, the bar chart in Figure 6.1 shows the distribution of the number of errors made by participants in the task-specific section of the questionnaire. Notably, approximately 58% of participants (18 out of 31) made between 0 and 2 errors. Specifically, 5 participants answered all questions correctly (16,13%), 6 participants made only 1 error (19,4%), and 2 participants made 1,5 errors (6,45%). Additionally, 5 participants made 2 errors, while 6 participants accumulated 2.5 errors (19,35%), the highest frequency observed. Furthermore, 4 participants made 3 errors (12,90%), 2 participants made 4 errors (6,45%), and only 1 participant made 5.5 errors (3,23%). The presence of fractional values stems from Task 7, where partial correctness was allowed.

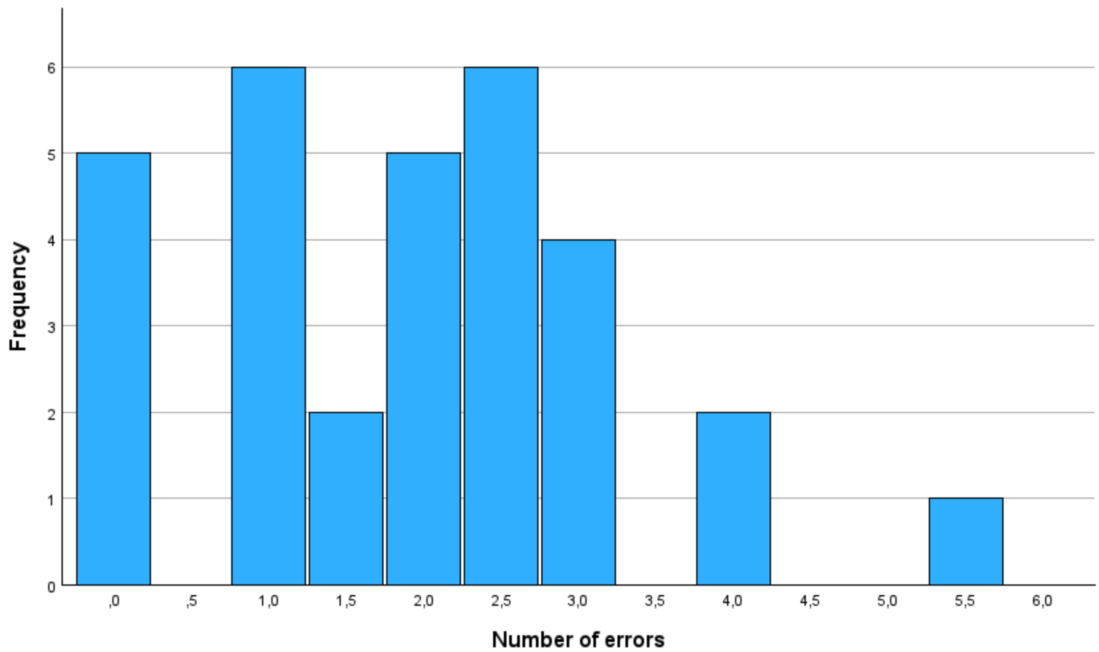


Figure 6.1: Bar chart of distribution of task errors among participants.

Field of Study or Profession

A one-way ANOVA was performed to analyze the correlation between task errors and participants' field of study or profession. As shown in Table 6.3, there was no statistically significant difference in errors between groups, $F(4,26) = 1.077$, $p = .388$. Additionally, a Tukey Honestly Significant Difference (HSD) post-hoc test was performed to explore pairwise differences between fields of study, with no statistically significant differences found between any groups ($p > 0.05$). This confirms the ANOVA result, indicating that the mean number of task errors does not differ significantly between participants from different fields. Table 6.4 displays the mean errors, that ranged from $M = 0.50$ in *Engineering & Computer Science* to $M = 2.20$ in *Art & Design Education* and *Academic Research & Teaching*.

Table 6.3: One-Way ANOVA Summary for Task Errors across Fields of Study or Profession

Source	SS	df	MS	F (p-value)
Between Groups	7.398	4	1.850	1.077 ($p = 0.388$)
Within Groups	44.650	26	1.717	
Total	52.048	30		

Table 6.4: Mean Number of Errors by Field of Study or Profession (Tukey HSD Post-hoc Test)

Field of Study or Profession	Mean Errors
Engineering & Computer Science	0.50
Design & Digital Media	1.25
Art & Visual Arts	1.90
Art & Design Education	2.20
Academic Research & Teaching	2.20

Digital Proficiency

To investigate the relationship between digital proficiency and the number of task errors, a Spearman correlation analysis was conducted. The results revealed a weak and non-significant negative correlation, indicating that there is no statistically significant monotonic association between these two variables, $\rho(31) = -0.103$, $p = 0.581$ (see Table 6.5).

Table 6.5

	Correlation Coefficient	(p-value)
Digital Proficiency	-0.103	0.581

This finding is consistent with the box plot (see Figure 6.2), which visually compares the distribution of errors across levels of digital proficiency. Participants with higher proficiency levels (4 and 5) do not show notably lower error rates compared to those with moderate proficiency level (3). Median error counts remain similar across groups, and considerable overlap in interquartile ranges further supports the lack of a clear trend. A single outlier at level 4 also suggests that error counts are not highly clustered, even within proficiency levels.

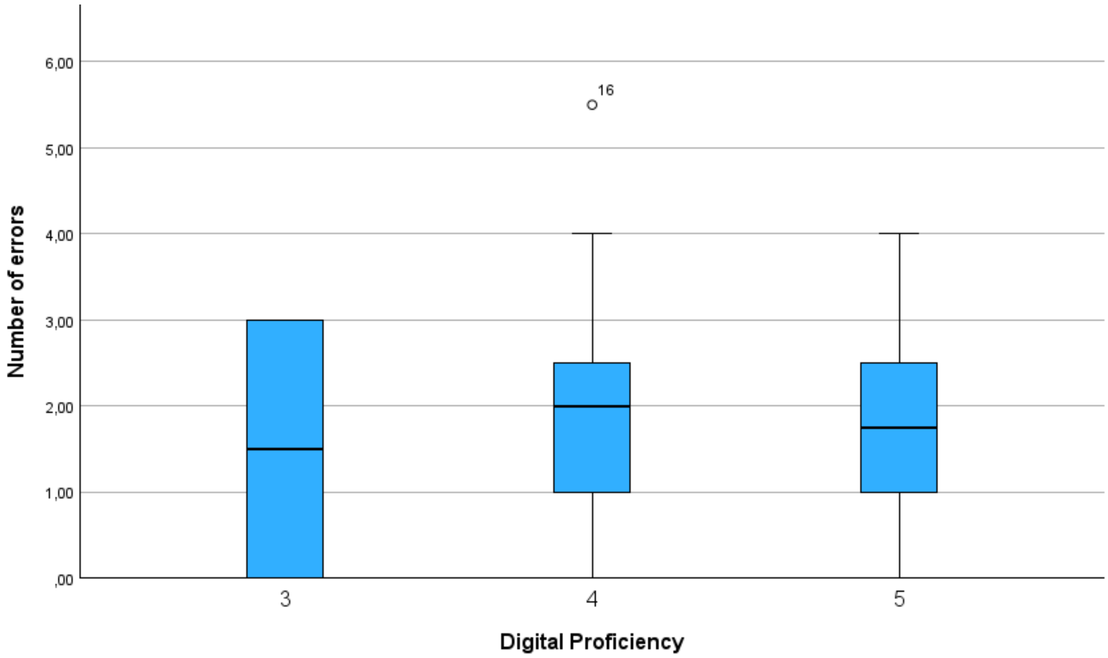


Figure 6.2: Box-plot showing number of errors across self-reported digital proficiency levels

Use of Interactive Maps Before

To explore whether previous experience with interactive maps was associated with the number of task errors, a Spearman correlation was computed. The result indicated a weak negative correlation, $\rho(31) = -0.178$, $p = 0.389$ (see Table 6.6), which was not statistically significant. This suggests that participants who had previously used interactive maps did not perform significantly better than those who had not. The box-plot visualization, present in Figure 6.3, supports this conclusion. While the group that answered *Yes* shows a slightly lower median number of errors, there is considerable variability across all three groups, with overlapping interquartile ranges. The *Yes* group includes an outlier, and the “No” group shows a narrow but higher error range. These visual patterns further confirm that prior use of interactive maps does not strongly predict task accuracy in this context.

Table 6.6: Correlation between previous use of interactive maps and number of task errors

	Correlation Coefficient	(p-value)
Have used interactive maps before	-0.178	0.389

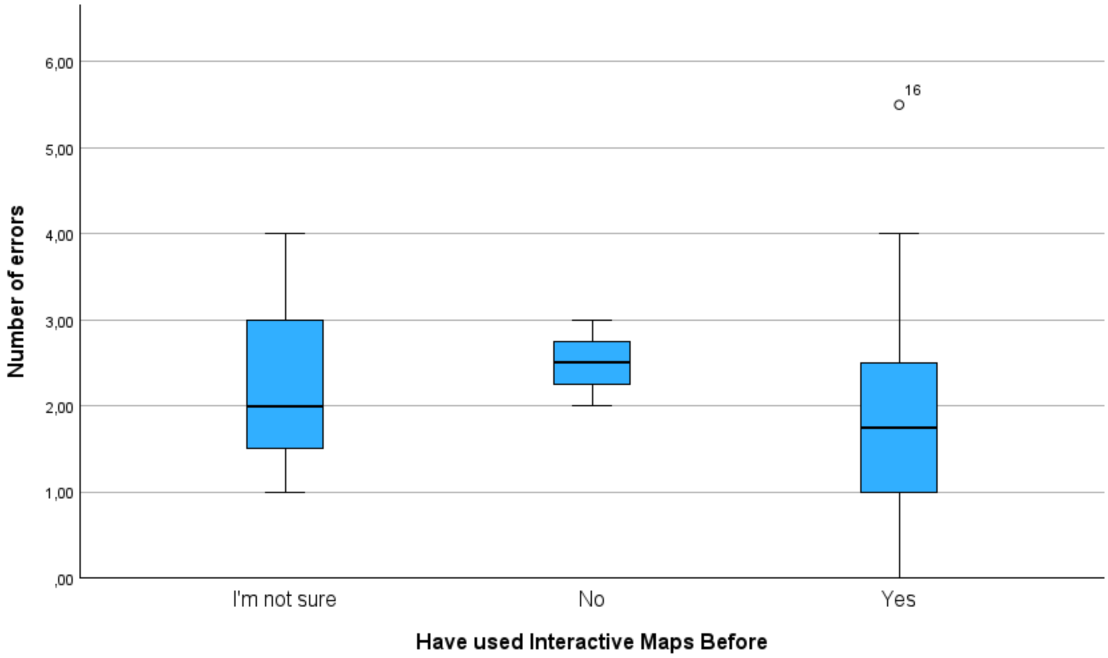


Figure 6.3: Box-plot of errors based on self-reported experience with interactive maps

6.1.3 System Usability Evaluation

At the end of their interaction with the system, participants quantitatively assess the usability of the platform using the System Usability Scale (SUS). Additionally, they are requested to provide qualitative feedback through open-ended questions, allowing them to comment freely on their experience and suggest potential improvements.

6.1.3.1 System Usability Scale

Participants rated the ten-item SUS using a 5-point Likert scale. These responses offer quantitative insights into the platform's usability, effectiveness, and user satisfaction. Table 6.7 and Figure 6.4 display the calculated minimum, 1st quartile, median, 3rd quartile, maximum, and standard deviation (Std. Dev.) for each SUS question.

SUS makes an alternating phrasing where odd-numbered questions are positive (higher scores imply superior usability) and even-numbered questions are negative (lower scores are preferable). The results suggest that participants generally perceived the platform favorably, though with exceptions.

Firstly, odd-numbered questions (SUS1, SUS3, SUS5, SUS7, SUS9) consistently achieved medians of 3.00 and 4.00. Notably, **SUS1** ("I would like to use this system frequently") and **SUS5** ("Functions were well integrated") had the highest scores, both with a median of 4.00 and 1st quartile greater than or equal to 3.00. These questions also showed moderate variability, with standard deviations ranging from approximately 1.01 to 1.15, indicating agreement among participants.

Table 6.7: Distribution of ratings per SUS question among participants

	Minimum	1st Quartile	Median	3rd Quartile	Maximum	Std. Dev.
SUS 1	1,00	3,00	4,00	4,00	5,00	1,151
SUS 2	1,00	2,00	3,00	4,00	5,00	1,203
SUS 3	1,00	2,00	3,00	4,00	5,00	1,014
SUS 4	1,00	1,00	2,00	4,00	5,00	1,358
SUS 5	1,00	3,00	4,00	4,00	5,00	1,013
SUS 6	1,00	1,00	2,00	2,00	3,00	0,682
SUS 7	1,00	3,00	3,00	4,00	5,00	1,166
SUS 8	1,00	1,00	2,00	4,00	5,00	1,288
SUS 9	1,00	2,00	3,00	4,00	5,00	1,138
SUS 10	1,00	2,00	2,00	3,00	5,00	1,014

Secondly, even-numbered questions (SUS2, SUS4, SUS6, SUS8, SUS10) revealed trouble points, particularly for **SUS4** ("I would need technical support") and **SUS8** ("System was cumbersome"). Both of these questions had the lowest median scores of 2.00 and the highest variability, with standard deviations around 1.29 to 1.36. Furthermore, **SUS6** ("System inconsistency") had the poorest score among the negative responses, with a median of 2.00 and a maximum of 3.00, suggesting that there was unanimous recognition of this issue among the participants.

The overall SUS score was computed according to the standard methodology of John Brooke [26], using the Equation 6.1. For each participant, each question's score contribution will range from 0 to 4. For odd-numbered questions, the score contribution is the scale position minus 1. For even-numbered questions, the contribution is 5 minus the scale position. The overall SUS score is the sum of the scores multiplied by 2.5, having a range of 0 to 100.

The average SUS score obtained was 63,15, while the median was 62,5. According to established benchmarks [4], these values fall within the "OK" to "Good" range, suggesting moderate usability of the platform.

$$\text{SUS} = \left(\sum_{i=1,3,5,7,9} (Q_i - 1) + \sum_{j=2,4,6,8,10} (5 - Q_j) \right) \times 2.5 \tag{6.1}$$

6.1.3.2 User Feedback and Comments

Participants were asked:

- "If you could change one thing about the system, what would it be?"
- "Please use the space below to share any comments, suggestions, or criticisms that could help improve the usability and functionality of the platform"
- "Did you find something out of the range of the guide?"

The responses varied widely and were grouped into thematic categories. A summary of representative comments is presented below:

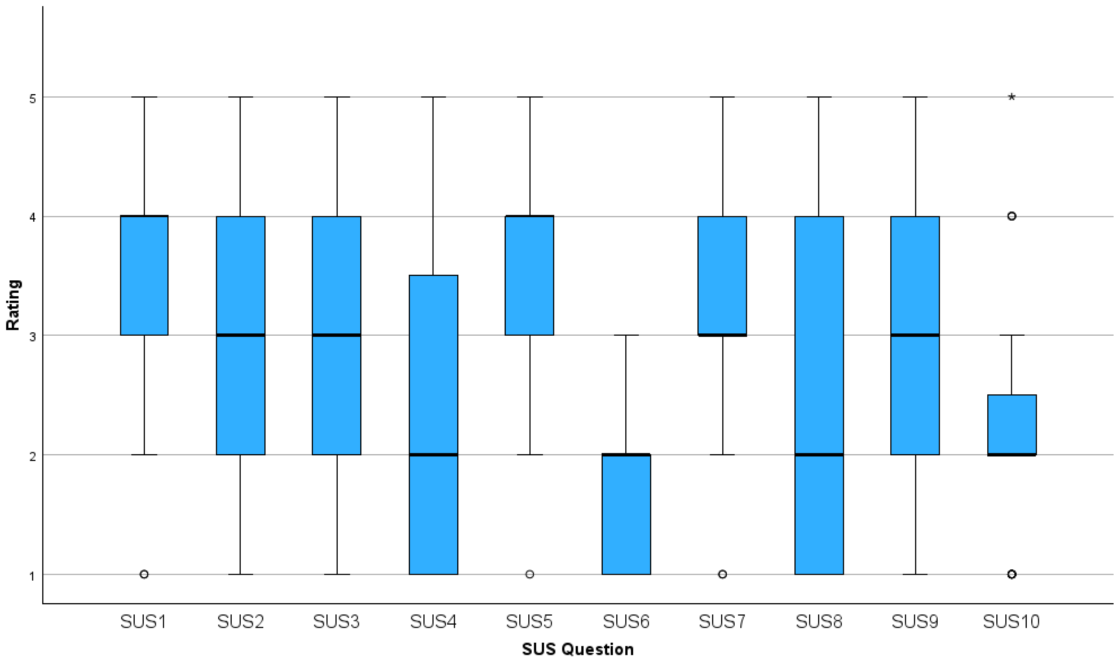


Figure 6.4: Box-plot of ratings per SUS question among participants

Visual Design and Interface Clarity. Participants highlighted the need for clearer layout, better scaling, and refined visual elements: One participant stated that sometimes there is an overload of information; One participant suggested making the item's icon a little smaller; Two participants had difficulties seeing all the information on the screen, suggesting the possibility to adjust maps' window size.

Navigation and Zooming Behavior. Participants mentioned difficulty interacting with the zoom system: One participant mentioned that when zooming, the timeline was no longer visible; One participant suggested automating zoom in and zoom out; One participant suggested zooming more upon clicking on the overlapping items.

Search and Filtering Filtering and search behavior were frequent pain points: One participant had difficulty locating an item when using the filters; One participant stated that the way of searching topics is not responsive. Two participants had difficulties clearing their options. Two participants mentioned that when searching for an item, keywords didn't appear.

Guidance and Documentation. Participants expressed a desire for better instructions: One participant suggested the inclusion of an "about page" with a few hints on how to use the system; One participant stated that the narrative filter was not clear for him; Two participants expressed the desire for more precise and clear instructions.

Interactivity and Features. Many participants' suggestions focused on making the platform more expressive or modular: One participant suggested the possibility of creating conceptual or relational maps; One participant suggested allowing the inclusion and articulation between entities of different types: texts, static images, videos, and audio; One participant suggested greater fluidity on turning on/off elements; One participant suggested the possibility of raising questions about each item which can be classified by specialty and/or by response competence ranking, making a debate method to be approved by administrators, where users can respond.

Personal Factors Influencing Experience. One participant reflected on how individual knowledge impacted the user's experience, mentioning that his knowledge about photography has facilitated the navigation and filling out the questionnaire.

Positive Feedback. Two participants stated that the platform is interesting; One participant wrote that the platform has an important use to it; One participant mentioned that he liked it and found it intuitive.

Exploration Beyond the Guide. Participants were asked whether they had discovered any functionality outside the scope of the provided guide. Most participants responded negatively, indicating that they had either followed the instructions as given or were not consciously aware of exploring beyond the guided path. However, one participant noted that they had explored additional features, specifically using the properties menu and item labels as filters. Another participant reported having difficulty with question 5. Some participants have also provided positive affirmations in their responses to this question, such as: "No, well done!" and "Congratulations on the work you've done! It's turning out amazing,"

6.2 Discussion

The evaluation results provide valuable insights into the platform's usability, task performance, and perceived user experience. This discussion synthesizes the quantitative and qualitative findings to assess how effectively the platform supported users in navigating and interpreting the available information.

6.2.1 Task Performance Interpretation

The analysis of task accuracy (see Table 6.2) revealed a mixed pattern of performance. Tasks 1, 3, and 4 achieved the highest success rates, indicating that the system effectively supported users in straightforward identification and relational tasks. Notably, Tasks 1 and 4 involved interpreting visual connections between items, which most participants found intuitive, as reflected in the high accuracy rates. Task 3 required users to click on an item to access detailed information, a direct interaction that participants also understood well.

In contrast, Task 8 had the lowest accuracy (38.7%), and Task 7, which involved selecting multiple correct options, had a moderate success rate of 59.7%. One possible explanation for the difficulties encountered during these tasks is the visual density of the map, which made it harder for participants to identify the relevant items. Although the platform offers filtering tools and a timeline slider to help narrow the visible information, effective use of these features requires some initiative and familiarity. Participants who did not adjust the filters or timeline appropriately may have found the task more challenging to complete.

Task-specific insights indicate that the frequency of errors did not significantly vary based on participants' field of study or profession, or their levels of digital proficiency. This suggests that the challenges faced during the tasks were likely inherent to the platform's design or interface clarity rather than due to user background. Furthermore, the lack of a correlation between task performance and previous experience with interactive maps demonstrates that even those who had used such tools before did not gain a significant advantage.

6.2.2 System Usability and Participant Feedback

The system SUS scores indicate that while the system is functional and generally meets user needs, there is significant potential for improvement. Participants rated the positively worded SUS items, such as statements relating to the system's usefulness and ease of integration with other functions, higher than the negatively worded items, which addressed issues of complexity and inconsistency. This pattern highlights a general acceptance of the system's usefulness and integration of features. However, the low median scores on questions related to complexity, inconsistency, and technical support highlight perceived difficulty in navigating the interface or understanding how to perform certain actions.

However, the low median scores on specific items concerning aspects like navigational complexity, the consistency of design elements, and the effectiveness of technical support reveal important areas of concern. Many users expressed difficulties in navigating the interface or understanding how to execute certain tasks efficiently. This suggests that while the foundational concept of the platform was well-received, there are critical gaps in its implementation that need to be addressed.

Several users reported uncertainty regarding how to begin exploring the platform or how to interpret specific features such as the narrative filter, property selection, and the meaning of visual connections. As suggested by participants, a help section or a short tutorial could help mitigate this initial learning barrier by clearly outlining the structure, the goals, and the functionalities of the system. Furthermore, this guidance would not only support recent users but also enhance the platform's discoverability and encourage deeper interaction with its features.

Based on the feedback received, a second iteration of the platform could be developed to address the most critical usability issues, such as improving navigation clarity, enhancing filter responsiveness, and providing guidance. This updated version should undergo another round of user testing, including a revised SUS assessment, to evaluate the impact of the design improvements and ensure that the platform meets user expectations for both usability and engagement.

6.3 Summary

This chapter presented the results of the empirical evaluation conducted to assess the usability and effectiveness of the developed platform. Through the analysis of 31 submissions to the formative questionnaire, valuable insights were obtained regarding user demographics, task performance, system usability, and qualitative feedback. The task performance results revealed high accuracy in tasks related to item direct relationships, while tasks requiring more navigation and interaction with filters and timeline showed lower success rates. System Usability Scale results indicate a moderate level of usability, with positive responses focused on the platform's integration and functionality. However, negative scores and open-ended feedback highlighted challenges in system consistency, visual clarity, and ease of navigation. Participant suggestions emphasized the need for clearer instructions, improved filtering behavior, and a more responsive interface.

Overall, the results support the platform's conceptual relevance and functional potential, while also identifying concrete areas for improvement.

Chapter 7

Conclusions and Future Work

7.1 Final Remarks

This dissertation presented the design, implementation, and evaluation of an interactive spatiotemporal visualization platform developed within the scope of the Bioimages project. The project's primary goal is to foster critical reflection on the ecological and social impacts of image production. The platform was conceived to support researchers in exploring complex datasets that document the historical, geographical, and material aspects of image production, ranging from early photographic processes to contemporary digital infrastructures. By visually exposing the relationships between materials, people, institutions, and environmental consequences, the proposed solution contributes to both objectives of the project: on the one hand, it supports the research goal; on the other, it addresses the pedagogical goal of promoting narratives oriented to sustainability and understanding the image lifecycle.

The systematic review indicated that, although spatiotemporal visualizations are widely applied in domains such as public health, cultural heritage, and urban planning, there is limited research on generalized frameworks suitable for various contexts. Moreover, the review highlighted gaps in the integration of real-time interactive data and considerations for sustainability and accessibility in visualization systems. The review confirmed the core role of HCI principles such as iterative design, user feedback loops, and systematic usability evaluation methods in guiding the design of effective visualization systems. These principles were therefore integrated into the methodological framework of this dissertation.

The State-of-the-Art confirmed the relevance of combining map-based interfaces with graph and timeline representations to handle complex spatiotemporal relationships. In particular, tools such as trajectory maps, spiral graphs, and arc diagrams were identified as effective techniques for visualizing dense or dynamic relationships between entities. It also reinforced the central role of HCI principles in the success of visualization platforms, with concepts such as interface visibility, interaction consistency, and user-centered feedback mechanisms emerging as critical for ensuring system usability and engagement.

The system design process was grounded in a thorough elicitation of requirements, based on both the project's pedagogical goals and the practical needs of its researchers. This user-centred and problem-driven approach ensured that the resulting platform addressed specific limitations in current semantic data tools. A key innovation of the solution is its integration with a MediaWiki-based semantic infrastructure. By utilizing Wikibase Suite as the backend, the platform allows structured knowledge, previously managed through tabular interfaces or SPARQL queries, to be visualized using an intuitive and interactive frontend. This approach bridges the gap between semantic data modelling and dynamic exploration, providing a new way of interacting with data stored in a wiki environment.

The implementation combined several web technologies to provide a robust and interactive experience. React was chosen for its modularity and responsiveness, while React-Leaflet enabled spatial rendering and map interaction, and D3 supported the dynamic generation of semantic connections through colored arc diagrams. The solution also included a timeline slider, filter panels, and semantic search, enabling the exploration of entities, relationships, and metadata over time and space. A particularly technical contribution is the implementation of a spiral layout algorithm to position items lacking geographic coordinates. This algorithm distributes non-root items radially around their parent nodes, ensuring clear visual separation and reducing overlap even in dense clusters.

An experimental methodology, composed of various phases, was designed to assess the platform's usability, navigability, and user comprehension. It began with the development of a formative questionnaire, combining quantitative and qualitative measures. Firstly, a pre-test phase to gather demographic and digital proficiency data to contextualize user profiles. Secondly, a task-based phase to evaluate user performance across a series of guided interactions on the platform, each targeting specific system functionalities such as search, filtering, and semantic interpretation. Finally, the post-test phase included a System Usability Scale (SUS) and open-ended questions to capture user feedback and suggestions. To ensure clarity and alignment with evaluation goals, the methodology was refined through two pilot tests, which helped identify and correct issues in form structure and interaction expectations.

The results revealed that tasks involving the identification of direct relationships between items and the retrieval of metadata were completed with high accuracy, indicating that the visual representation of connections and the accessibility of item information were both intuitive and effective. In contrast, tasks that required the combined use of filters, temporal navigation, or multi-step exploration showed lower success rates, pointing to usability limitations in more complex interactions. The average SUS score of 63.15 suggests moderate usability with clear potential for improvement. Additionally, the distribution of responses indicated that while users recognised the conceptual coherence of the platform, they faced difficulties related to search behaviour, interface consistency, and feature discoverability. However, this is not unexpected since, in a platform with a wide range of tools and features designed to support the exploration of dense and interconnected data, the initial learning curve can be steep. For many users, the interface may not seem fully intuitive at first sight, particularly without previous experience or contextual guidance. Nevertheless, the qualitative feedback and task performance both confirmed the platform's value and provided concrete directions for refining its usability and interaction design in future iterations.

Based on the work performed throughout this dissertation, the following responses address the initial research questions:

Q1: What are the primary project visualization goals? The visualization goals focused on enabling users to explore semantic relationships between actors, materials, and processes of image production across space and time. The project aims, through intuitive, meaningful, and user-centered visualizations, to promote understanding of the sustainability and ecological implications of image production.

Q2: How should multimedia spatiotemporal data be displayed in an efficient and effective way? A combined spatial and temporal interface proved to be the most effective approach. By integrating an interactive map, timeline slider, semantic filtering, and hover/click actions, users were able to manipulate complex datasets dynamically and intuitively.

Q3: What effective visualizations can be considered for the defined goals? The implementation validated the effectiveness of multiple visual strategies, including item representations, arc-based connections, and property-specific color encoding. These visuals allowed users to intuitively distinguish data types and relationships while supporting interactive exploration. In addition, graph-based representation proved to be especially effective in illustrating the complexity and interconnections within the data. This visualization minimized the visual noise, organized dense relationships, and directed the user's attention to significant patterns.

Q4: How can the proposed approach be validated? Validation was conducted through a structured experimental protocol involving 31 participants. High accuracy in simpler tasks demonstrated that users understood the core functionalities, while moderate SUS scores and detailed feedback identified usability issues. This confirms the platform's conceptual viability and establishes a foundation for iterative refinement and future evaluation.

7.2 Future Work

The platform will continue to be developed beyond this dissertation's scope, aiming to deliver a final, refined version to serve as the official visualization tool of the Bioimages project.

The evaluation phase revealed valuable insights into usability and interface design, highlighting clear opportunities for improvement. One aspect identified for enhancement is the expansion of the visible map area by allowing users to collapse or temporarily hide the side panels. This adjustment would significantly improve the readability of the visualization, especially when dealing with a dense network of items and connections. A larger map viewport would facilitate the identification of overlapping elements, reduce visual clutter, and make it easier for users to identify connections between entities. It would also support a clearer understanding of spatial distributions and semantic groupings, particularly in scenarios where multiple relationships intersect or cluster in close proximity.

Additionally, to address the initial learning curve identified by participants in open-ended questions, future iterations should also include a dedicated tutorial page or onboarding guide where users can quickly understand the platform's structure, features, and available interactions. This resource could consist of short explanations, visual examples, and guided walkthroughs to support new users and educational use.

Besides usability improvements, future iterations of the platform may expand the range of visual representations to provide more modes of exploration and interpretation. One such representation is the histogram-based view, where events are stacked by year or decade along a timeline. This view would allow users to perceive temporal density patterns, identify peaks in activity, and explore chronological trends. Another representation is a whiteboard-style view, in which items are displayed in a free-form layout, not constrained by geographic or chronological logic. In this mode, items are initially placed, but users would be able to manually reposition them to isolate key elements or build custom groupings based on thematic or conceptual associations. This approach allows a more conceptual and exploratory interaction.

Moreover, the platform's modular and semantically driven architecture creates promising opportunities for broader applicability beyond the specific context of image ecology. Although originally designed to support the Bioimages project, the system is not tightly coupled to any one domain and can be adapted to other fields that involve the visualization of entities and relationships distributed across space and time. Its integration with Wikibase enables the ingestion and representation of structured knowledge in a flexible, multilingual, and extensible format, which could be valuable in domains such as cultural heritage, environmental studies, urban history, or scientific research data. To support this potential for reuse, an abstraction version has already been deployed.

Finally, the platform can be a valuable didactic tool. Through structured narratives, users can explore the origins of various entities, understand their components and connections, and reflect on their consequences, such as the environmental impacts of specific image production processes. This pedagogical potential positions the platform not only as a research tool but also as an educational instrument that encourages critical engagement with sustainability issues. To support this application, the guide developed was adapted, serving both as a usability evaluation instrument and a pedagogical resource. The guide is publicly available at: `https://forms.gle/AXRVwFYgpzkXxopK7`.

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Appendix A

Prototype Code

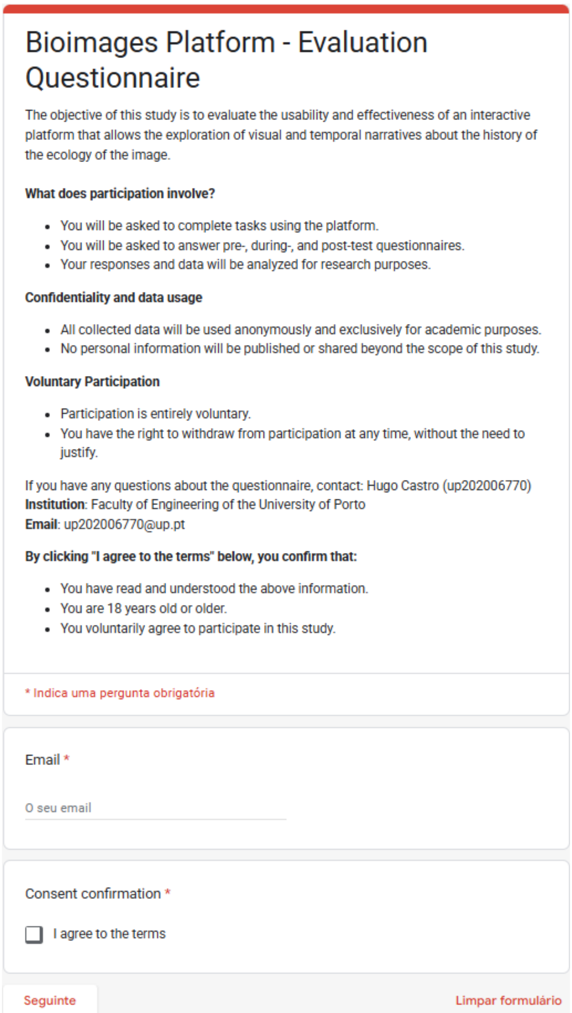
This Appendix contains the source code repository and access link to the online version of the platform.

- **Platform Source Code:** `https://github.com/hugocastro28/bioimages-platform`
- **Platform's online version:** `https://echoimages.labs.wikimedia.pt`

Appendix B

Formative Questionnaire

This Appendix presents the complete formative questionnaire used in the experimental procedure, as seen by participants during the study.



Bioimages Platform - Evaluation Questionnaire

The objective of this study is to evaluate the usability and effectiveness of an interactive platform that allows the exploration of visual and temporal narratives about the history of the ecology of the image.

What does participation involve?

- You will be asked to complete tasks using the platform.
- You will be asked to answer pre-, during-, and post-test questionnaires.
- Your responses and data will be analyzed for research purposes.

Confidentiality and data usage

- All collected data will be used anonymously and exclusively for academic purposes.
- No personal information will be published or shared beyond the scope of this study.

Voluntary Participation

- Participation is entirely voluntary.
- You have the right to withdraw from participation at any time, without the need to justify.

If you have any questions about the questionnaire, contact: Hugo Castro (up202006770)
Institution: Faculty of Engineering of the University of Porto
Email: up202006770@up.pt

By clicking "I agree to the terms" below, you confirm that:

- You have read and understood the above information.
- You are 18 years old or older.
- You voluntarily agree to participate in this study.

* Indica uma pergunta obrigatória

Email *

O seu email

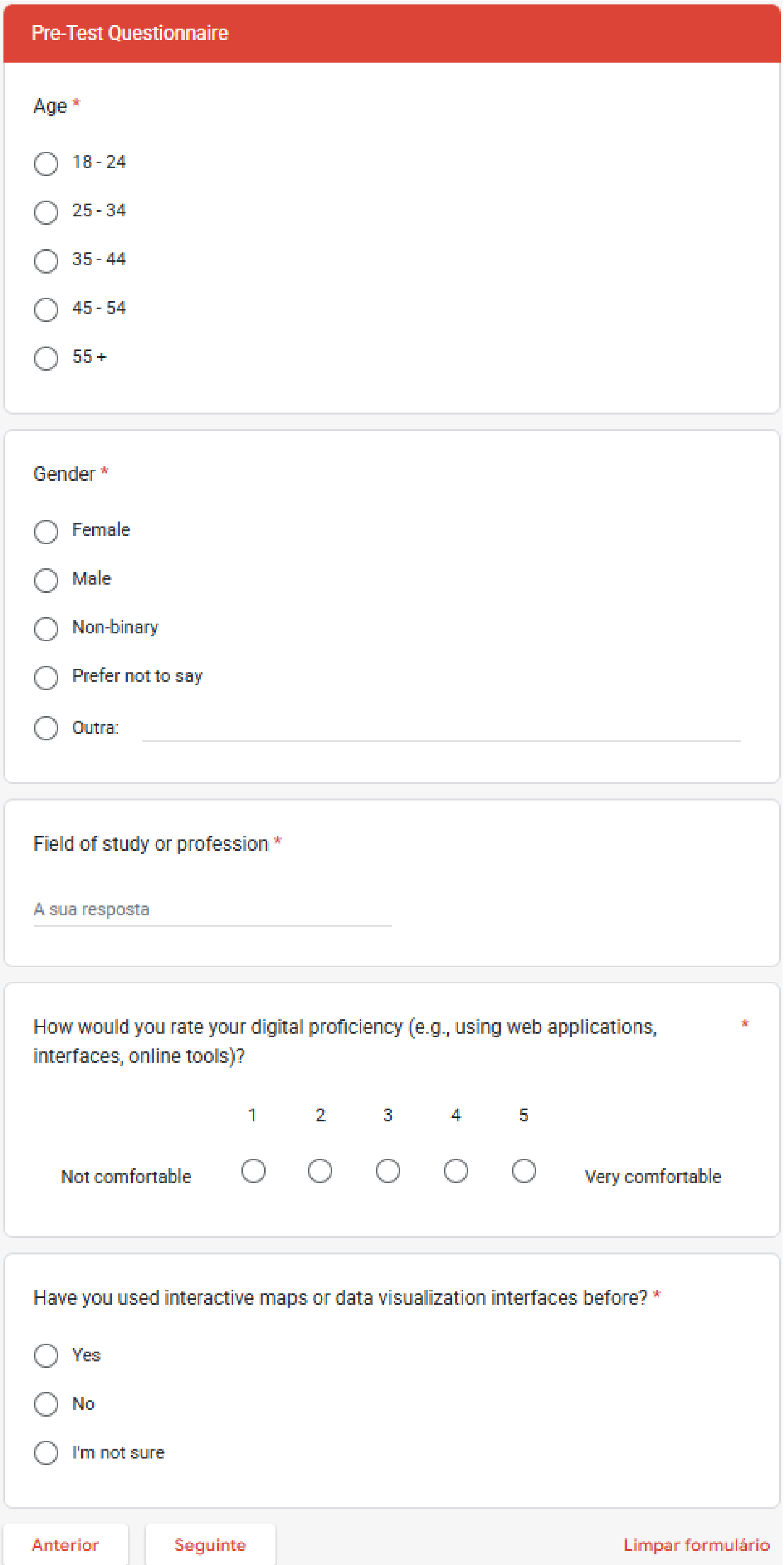
Consent confirmation *

☐ I agree to the terms

Seguinte

Limpar formulário

Figure B.1: Informed Consent Form



Pre-Test Questionnaire

Age *

- 18 - 24
- 25 - 34
- 35 - 44
- 45 - 54
- 55 +

Gender *

- Female
- Male
- Non-binary
- Prefer not to say
- Outra:

Field of study or profession *

A sua resposta

How would you rate your digital proficiency (e.g., using web applications, interfaces, online tools)? *

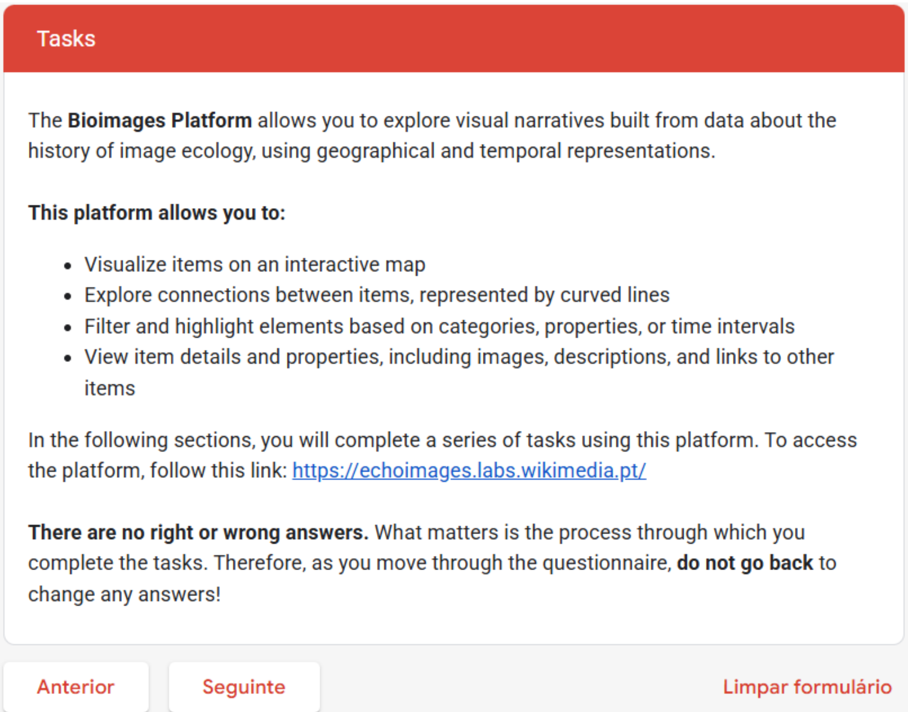
	1	2	3	4	5	
Not comfortable	○	○	○	○	○	Very comfortable

Have you used interactive maps or data visualization interfaces before? *

- Yes
- No
- I'm not sure

Anterior Seguinte Limpar formulário

Figure B.2: Pre-test questions



Tasks

The **Bioimages Platform** allows you to explore visual narratives built from data about the history of image ecology, using geographical and temporal representations.

This platform allows you to:

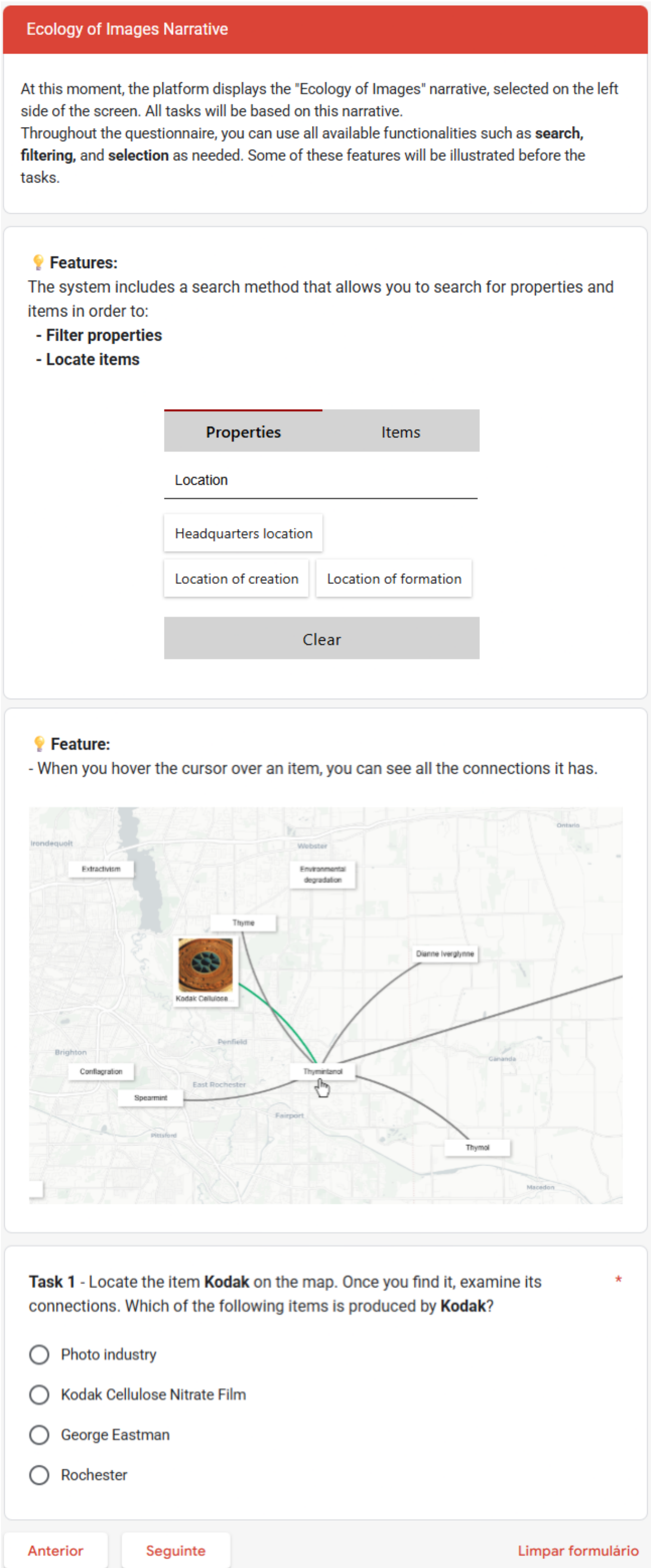
- Visualize items on an interactive map
- Explore connections between items, represented by curved lines
- Filter and highlight elements based on categories, properties, or time intervals
- View item details and properties, including images, descriptions, and links to other items

In the following sections, you will complete a series of tasks using this platform. To access the platform, follow this link: https://echoimages.labs.wikimedia.pt/

There are no right or wrong answers. What matters is the process through which you complete the tasks. Therefore, as you move through the questionnaire, **do not go back** to change any answers!

Anterior Seguinte Limpar formulário

Figure B.3: Information



Ecology of Images Narrative

At this moment, the platform displays the "Ecology of Images" narrative, selected on the left side of the screen. All tasks will be based on this narrative.
Throughout the questionnaire, you can use all available functionalities such as **search, filtering,** and **selection** as needed. Some of these features will be illustrated before the tasks.

💡 **Features:**
The system includes a search method that allows you to search for properties and items in order to:
- **Filter properties**
- **Locate items**

Properties Items

Location

Headquarters location

Location of creation

Location of formation

Clear

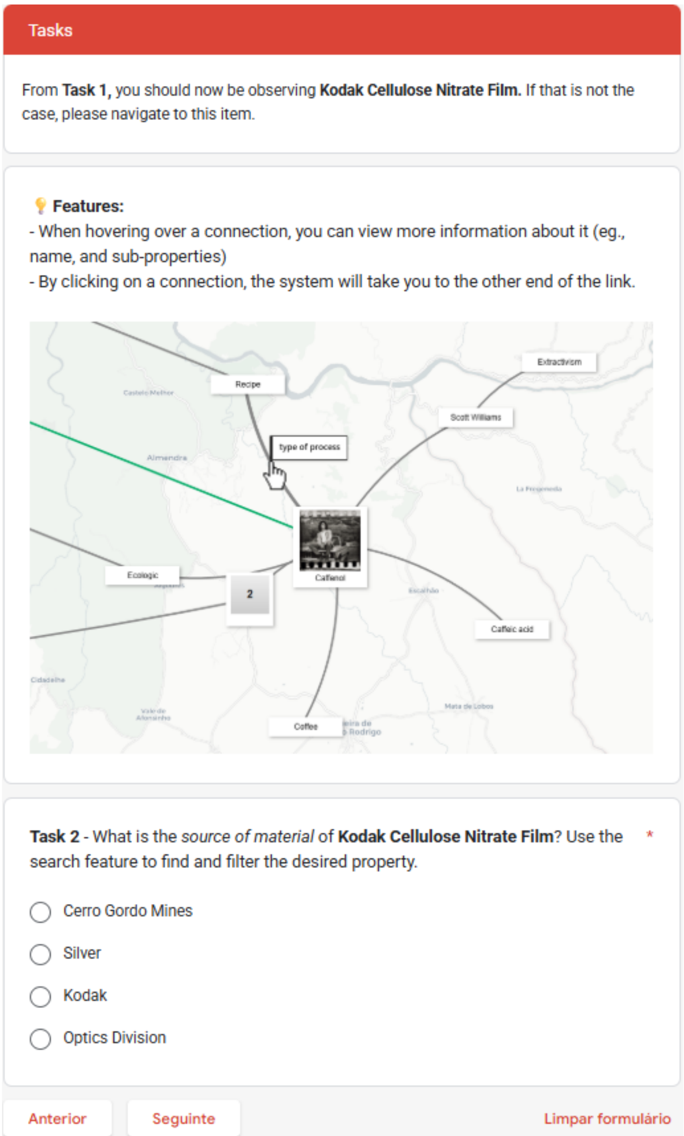
💡 **Feature:**
- When you hover the cursor over an item, you can see all the connections it has.

Task 1 - Locate the item **Kodak** on the map. Once you find it, examine its connections. Which of the following items is produced by **Kodak**? *

- Photo industry
- Kodak Cellulose Nitrate Film
- George Eastman
- Rochester

Anterior Seguinte Limpar formulário

Figure B.4: Task 1



Tasks

From **Task 1,** you should now be observing **Kodak Cellulose Nitrate Film.** If that is not the case, please navigate to this item.

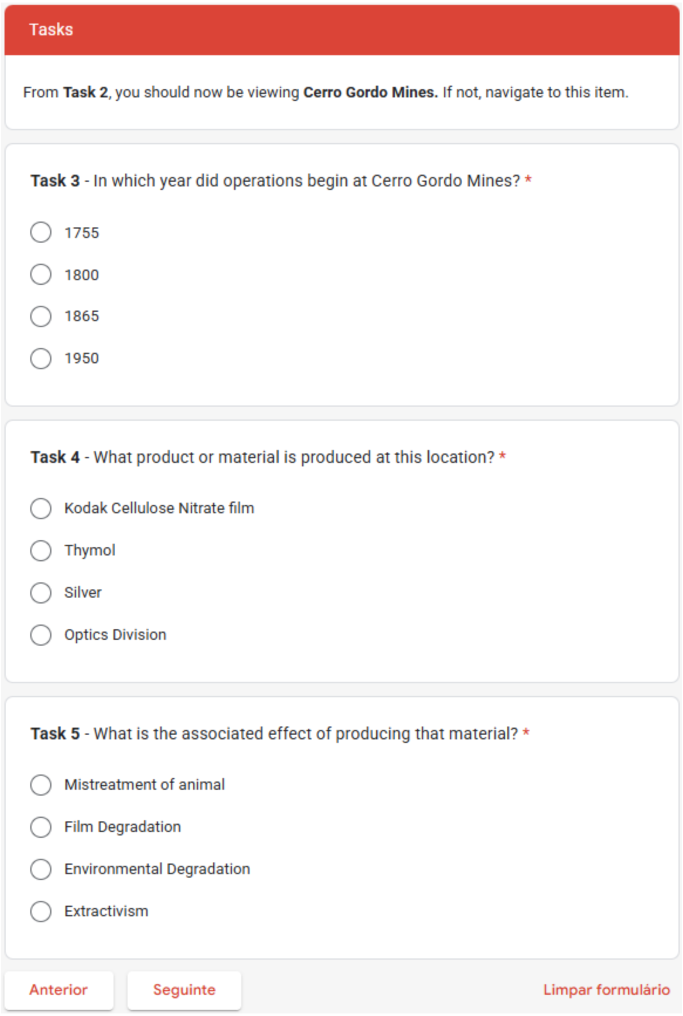
💡 **Features:**
- When hovering over a connection, you can view more information about it (eg., name, and sub-properties)
- By clicking on a connection, the system will take you to the other end of the link.

Task 2 - What is the *source of material* of **Kodak Cellulose Nitrate Film**? Use the search feature to find and filter the desired property. *

- Cerro Gordo Mines
- Silver
- Kodak
- Optics Division

Anterior Seguinte Limpar formulário

Figure B.5: Task 2



Tasks

From **Task 2**, you should now be viewing **Cerro Gordo Mines.** If not, navigate to this item.

Task 3 - In which year did operations begin at Cerro Gordo Mines? *

- 1755
- 1800
- 1865
- 1950

Task 4 - What product or material is produced at this location? *

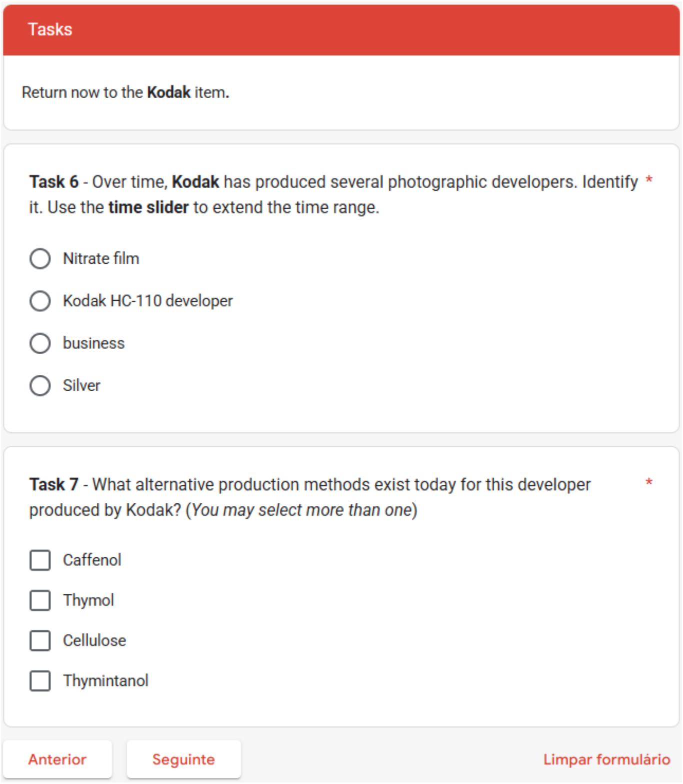
- Kodak Cellulose Nitrate film
- Thymol
- Silver
- Optics Division

Task 5 - What is the associated effect of producing that material? *

- Mistreatment of animal
- Film Degradation
- Environmental Degradation
- Extractivism

Anterior Seguinte Limpar formulário

Figure B.6: Tasks 3, 4, 5



Tasks

Return now to the **Kodak** item.

Task 6 - Over time, **Kodak** has produced several photographic developers. Identify it. Use the **time slider** to extend the time range. *

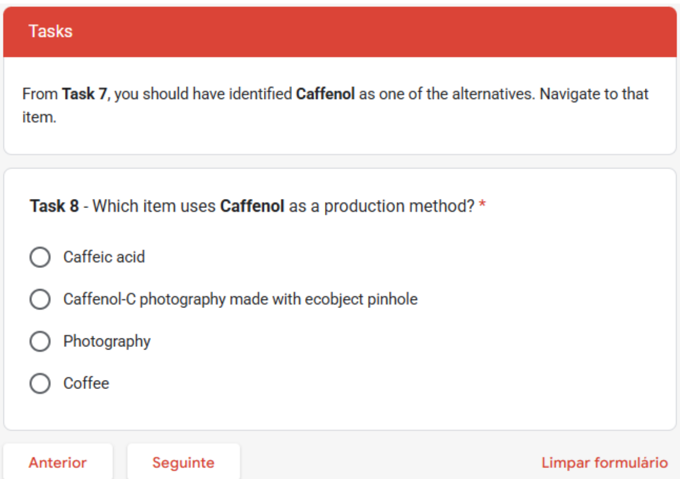
- Nitrate film
- Kodak HC-110 developer
- business
- Silver

Task 7 - What alternative production methods exist today for this developer produced by Kodak? (*You may select more than one*) *

- Caffenol
- Thymol
- Cellulose
- Thymintanol

Anterior | Seguinte | Limpar formulário

Figure B.7: Task 6, 7



Tasks

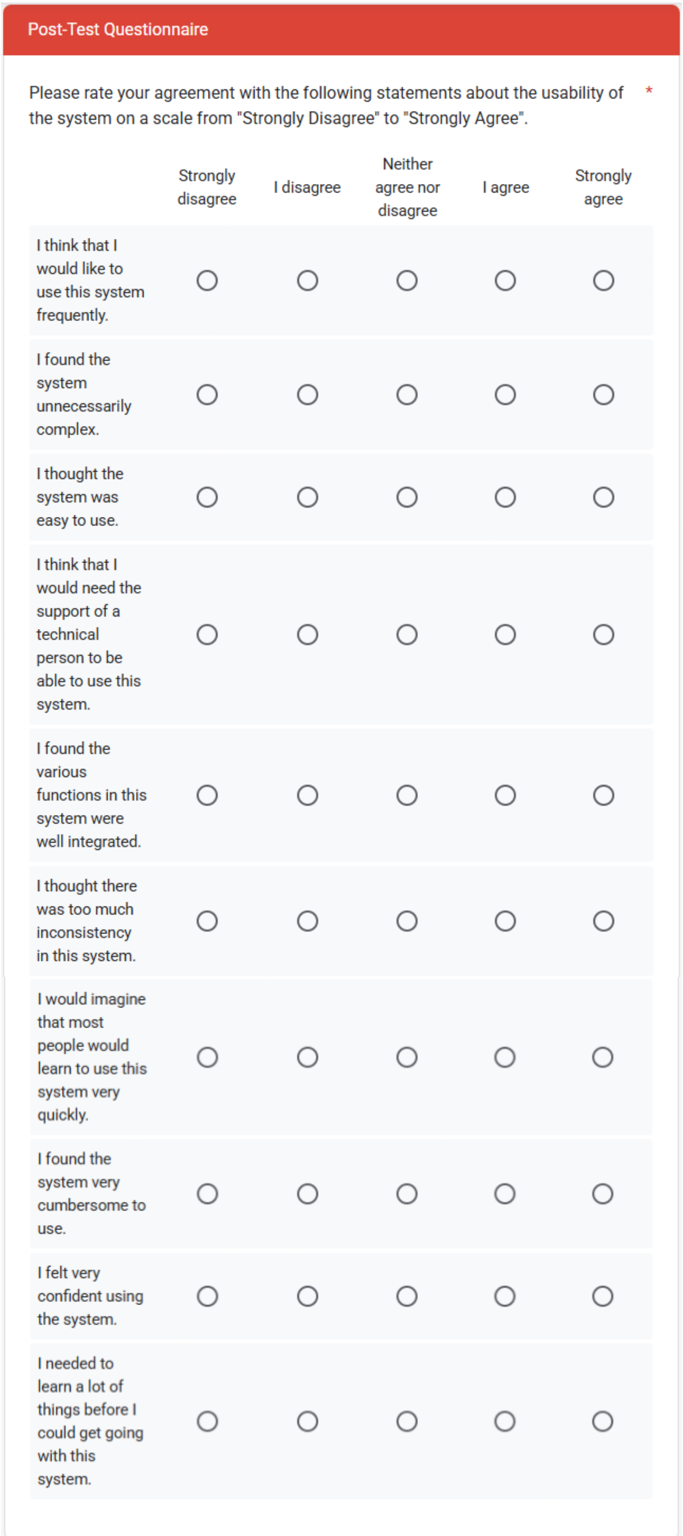
From **Task 7**, you should have identified **Caffenol** as one of the alternatives. Navigate to that item.

Task 8 - Which item uses **Caffenol** as a production method? *

- Caffeic acid
- Caffenol-C photography made with ecobject pinhole
- Photography
- Coffee

Anterior | Seguinte | Limpar formulário

Figure B.8: Task 8

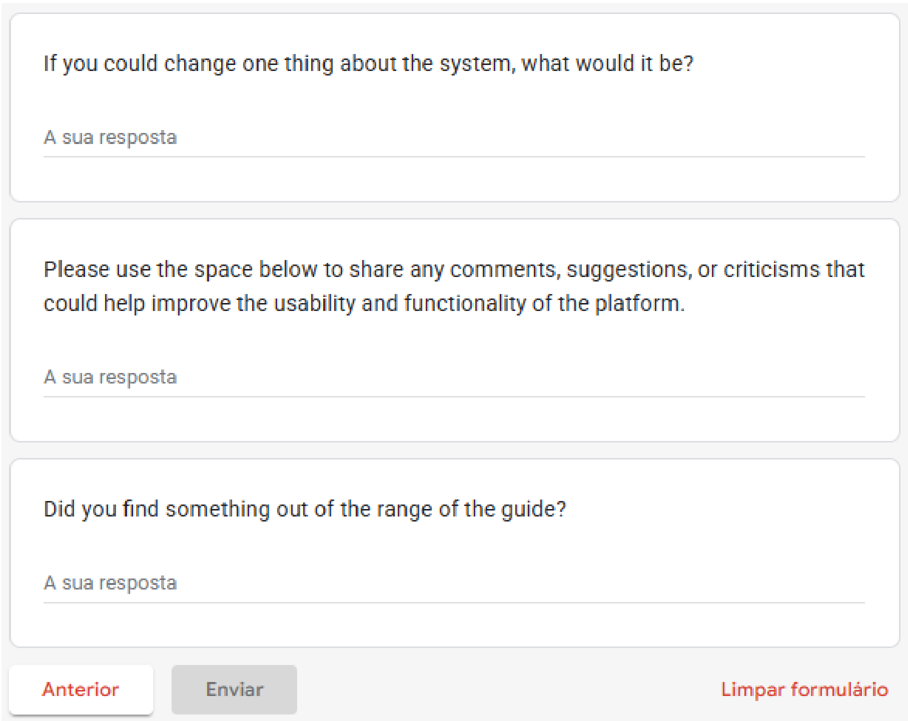


Post-Test Questionnaire

Please rate your agreement with the following statements about the usability of the system on a scale from "Strongly Disagree" to "Strongly Agree". *

	Strongly disagree	I disagree	Neither agree nor disagree	I agree	Strongly agree
I think that I would like to use this system frequently.	○	○	○	○	○
I found the system unnecessarily complex.	○	○	○	○	○
I thought the system was easy to use.	○	○	○	○	○
I think that I would need the support of a technical person to be able to use this system.	○	○	○	○	○
I found the various functions in this system were well integrated.	○	○	○	○	○
I thought there was too much inconsistency in this system.	○	○	○	○	○
I would imagine that most people would learn to use this system very quickly.	○	○	○	○	○
I found the system very cumbersome to use.	○	○	○	○	○
I felt very confident using the system.	○	○	○	○	○
I needed to learn a lot of things before I could get going with this system.	○	○	○	○	○

Figure B.9: System Usability Scale



If you could change one thing about the system, what would it be?

A sua resposta

Please use the space below to share any comments, suggestions, or criticisms that could help improve the usability and functionality of the platform.

A sua resposta

Did you find something out of the range of the guide?

A sua resposta

Anterior | Enviar | Limpar formulário

Figure B.10: Open-ended questions

Appendix C

Supplementary Results

This Appendix provides supplementary graphical results that support and elaborate on the findings presented in the Results chapter.

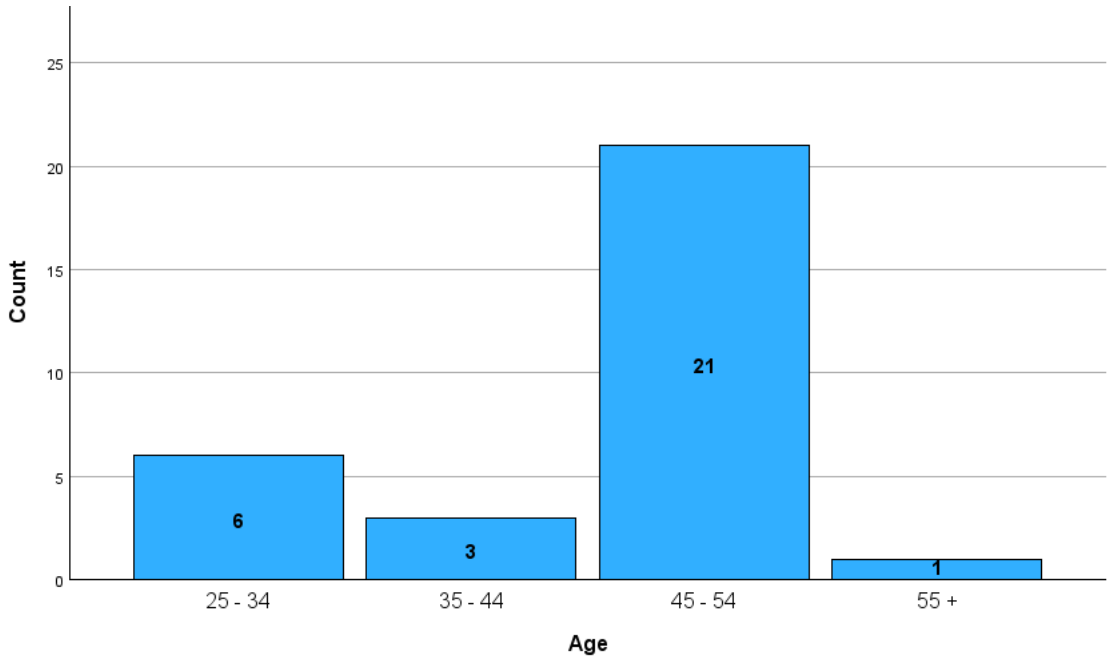


Figure C.1: Distribution of Participants by Age Group

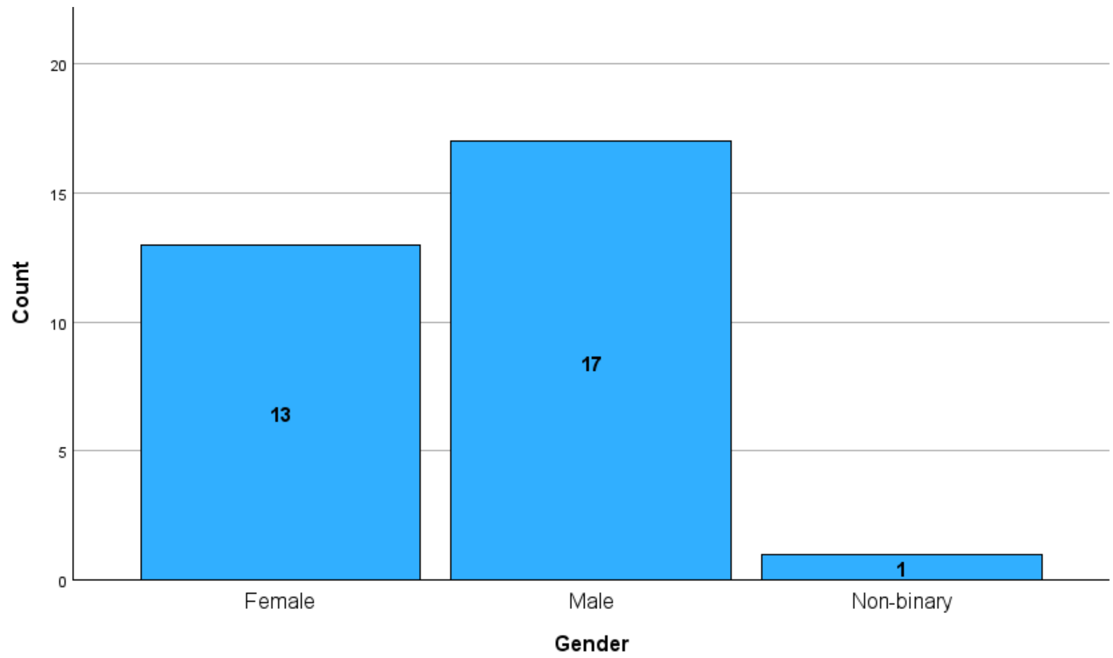


Figure C.2: Distribution of Participants by Gender

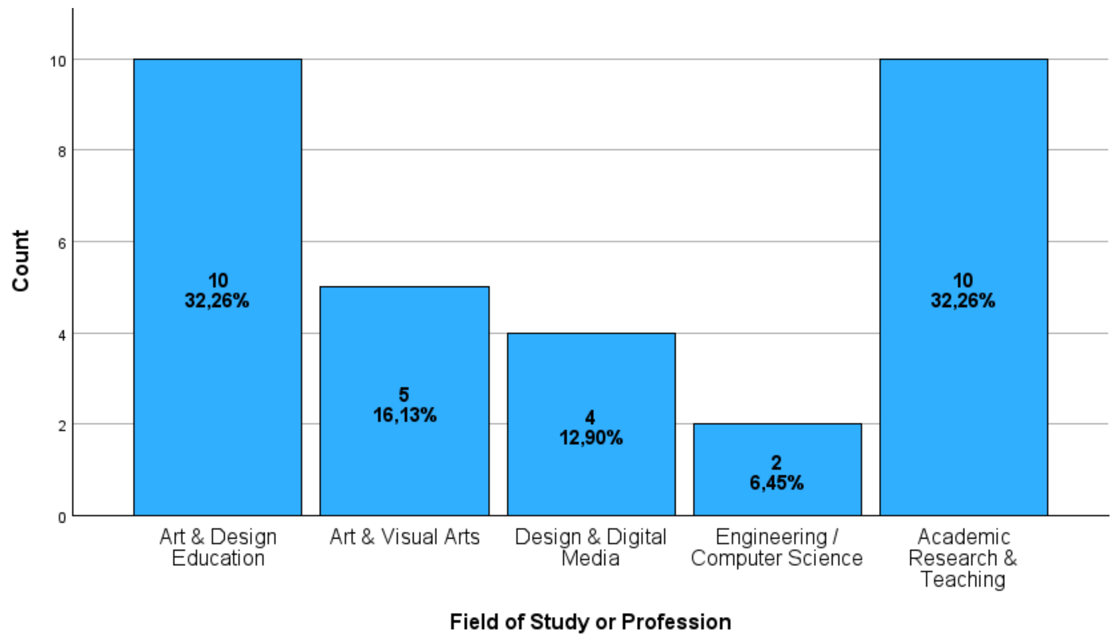


Figure C.3: Bar chart of field of study or profession distribution among participants

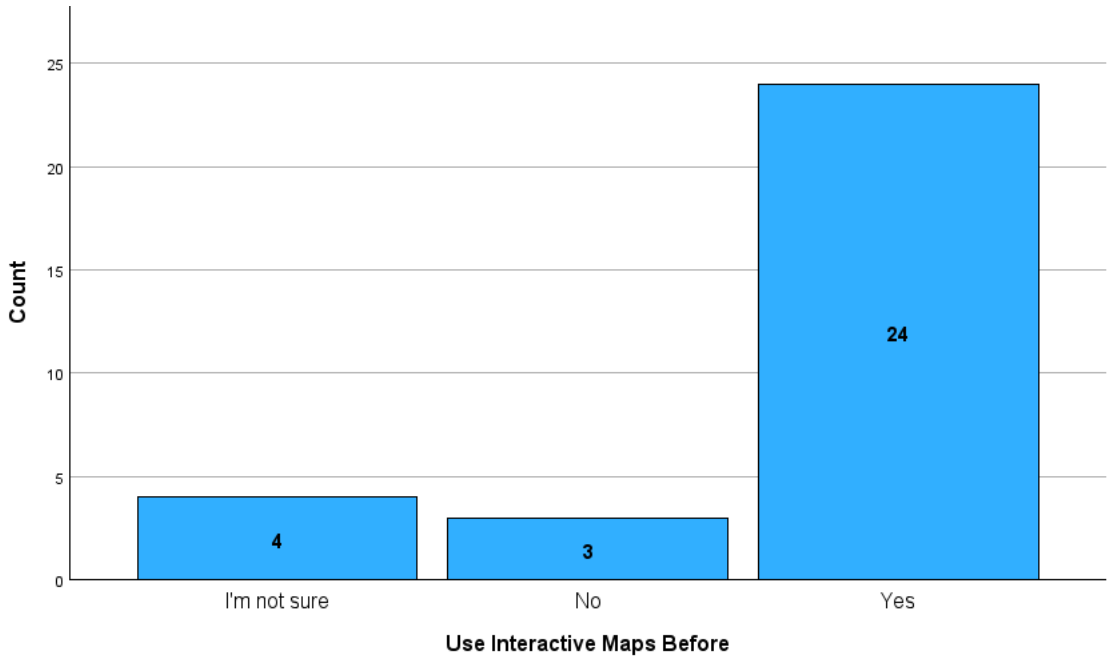


Figure C.4: Distribution of Participants by Previous Experience with Interactive Maps

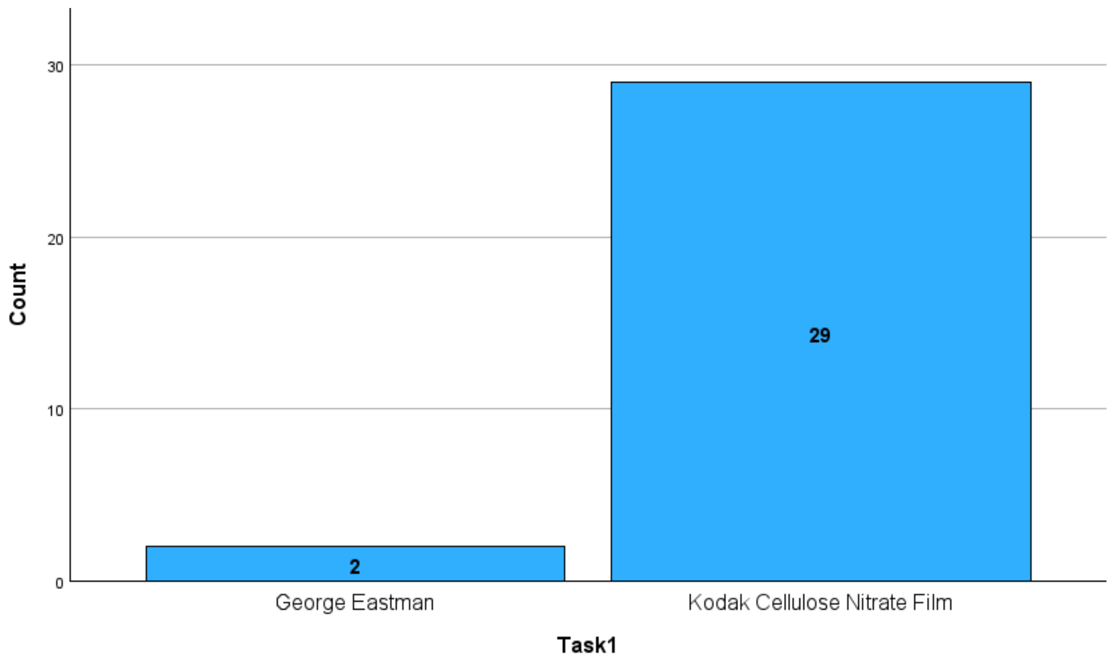


Figure C.5: Bar chart of the distribution of responses to question Task 1 among participants

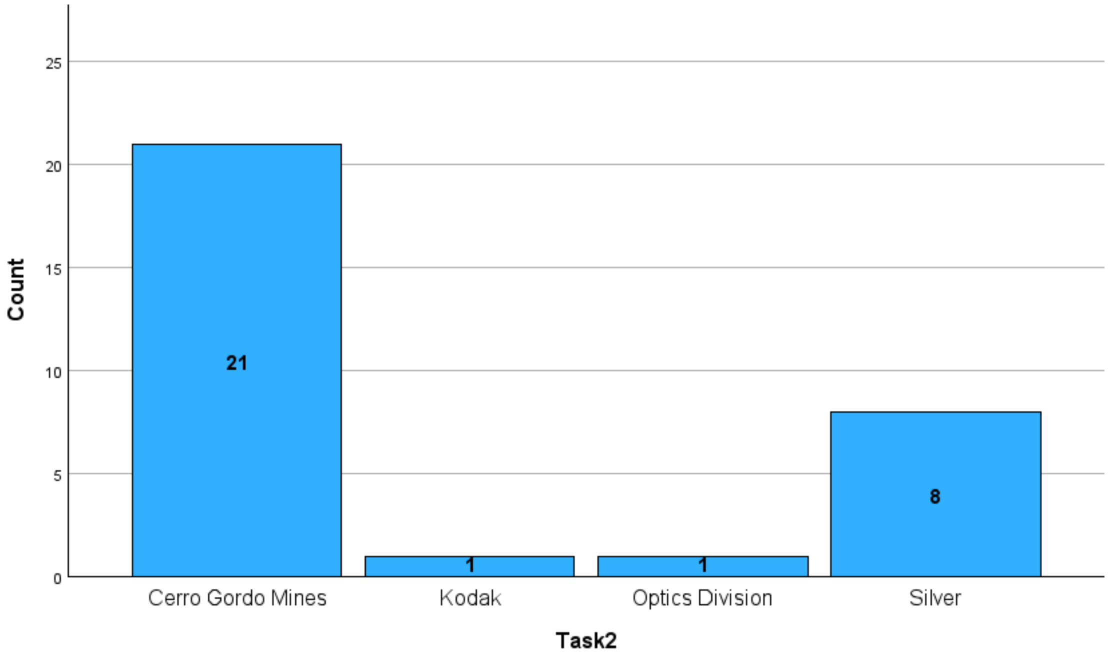


Figure C.6: Bar chart of the distribution of responses to question Task 2 among participants

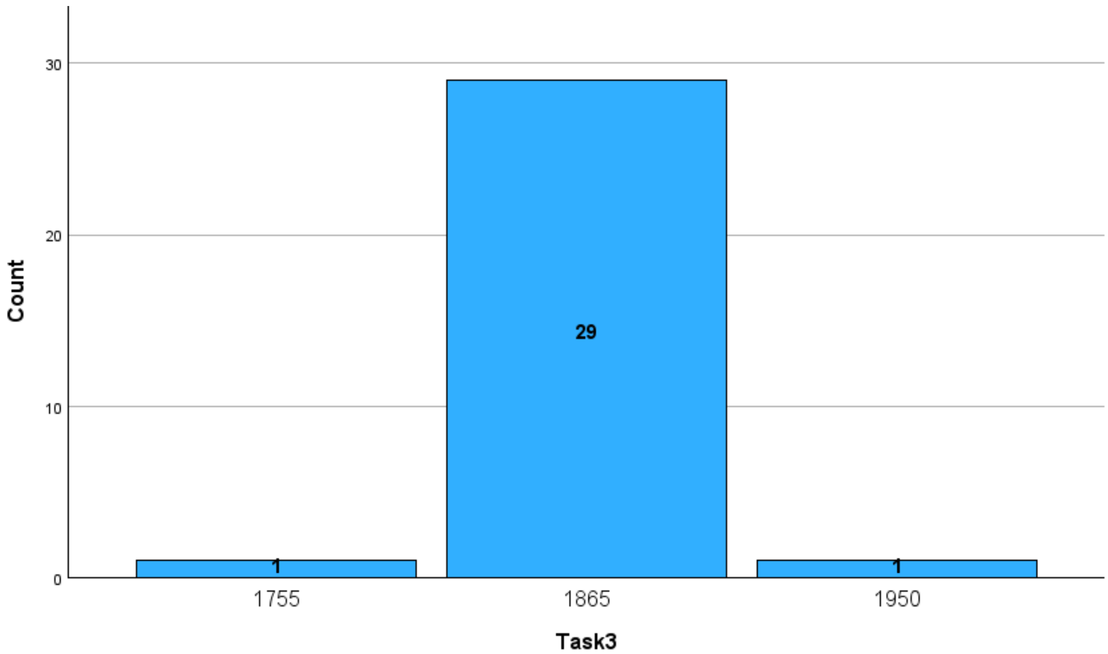


Figure C.7: Bar chart of the distribution of responses to question Task 3 among participants

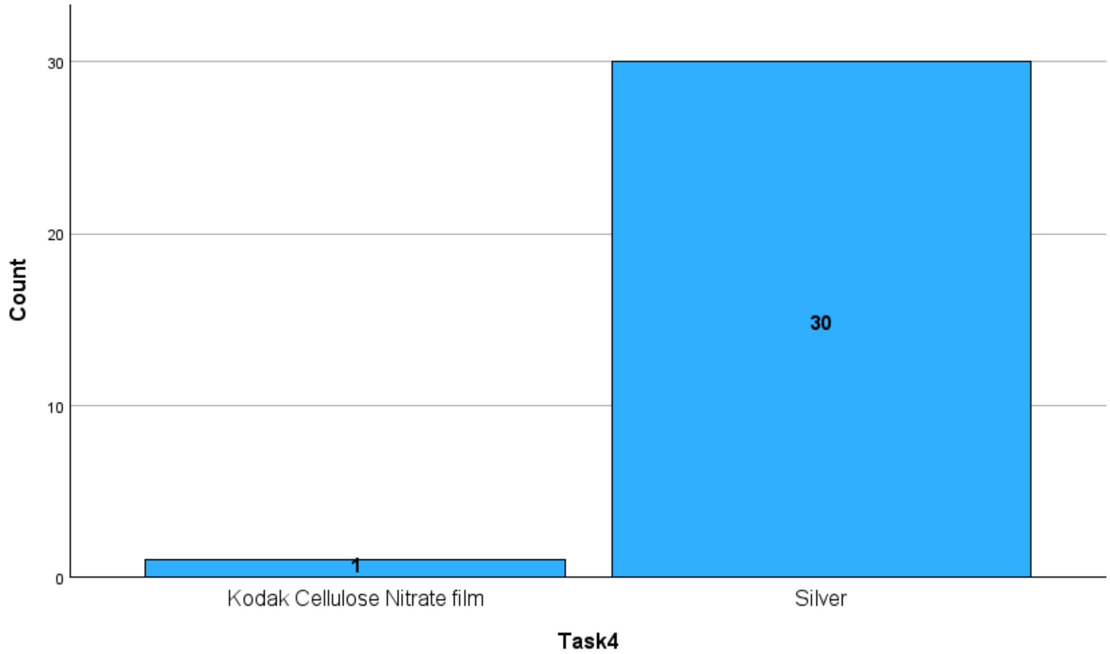


Figure C.8: Bar chart of the distribution of responses to question Task 4 among participants

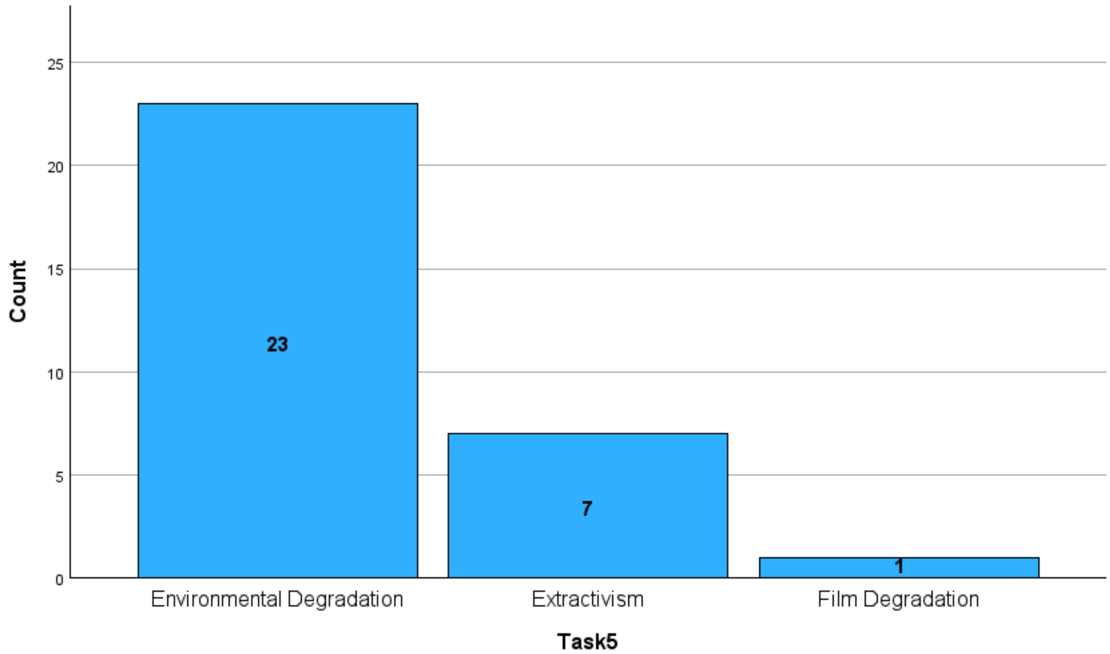


Figure C.9: Bar chart of the distribution of responses to question Task 5 among participants

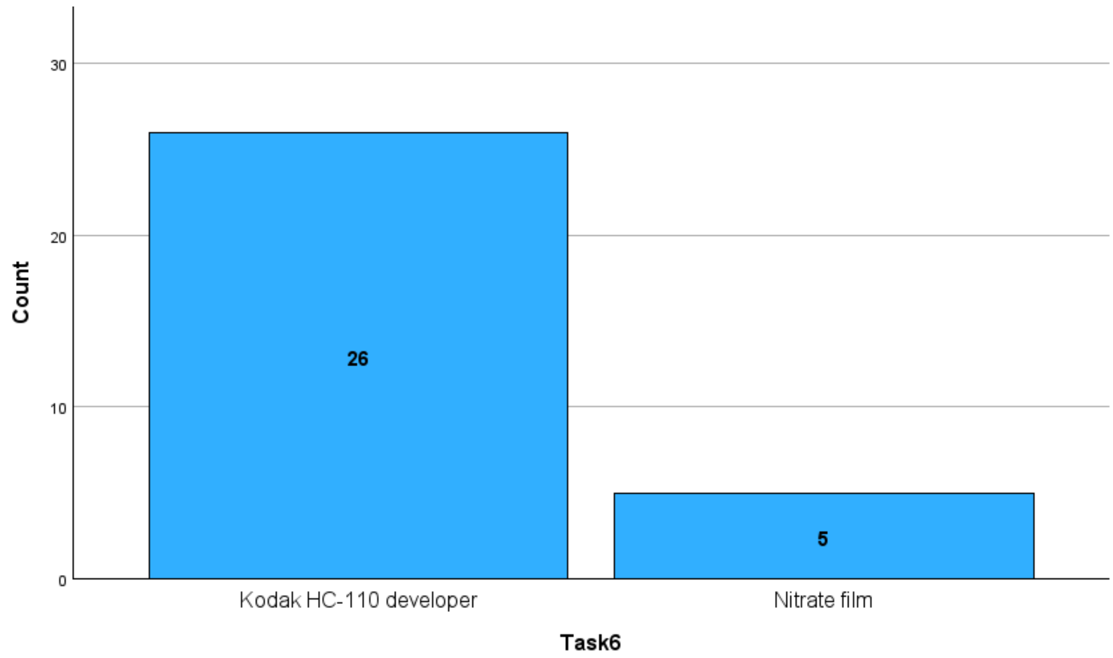


Figure C.10: Bar chart of the distribution of responses to question Task 6 among participants

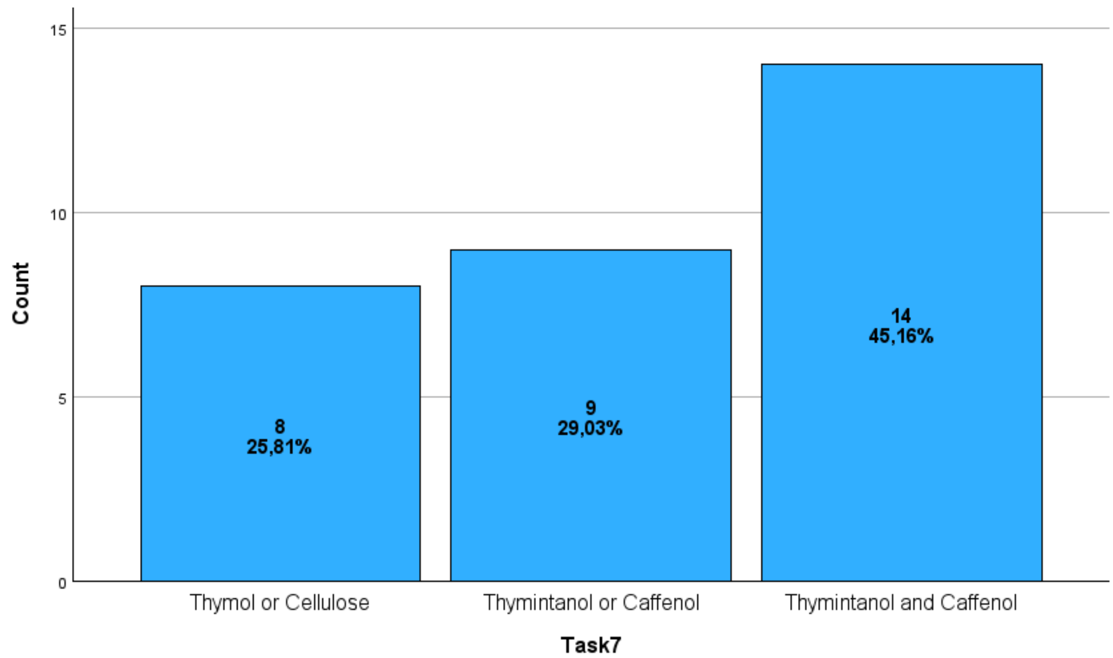


Figure C.11: Bar chart of the distribution of responses to question Task 7 among participants

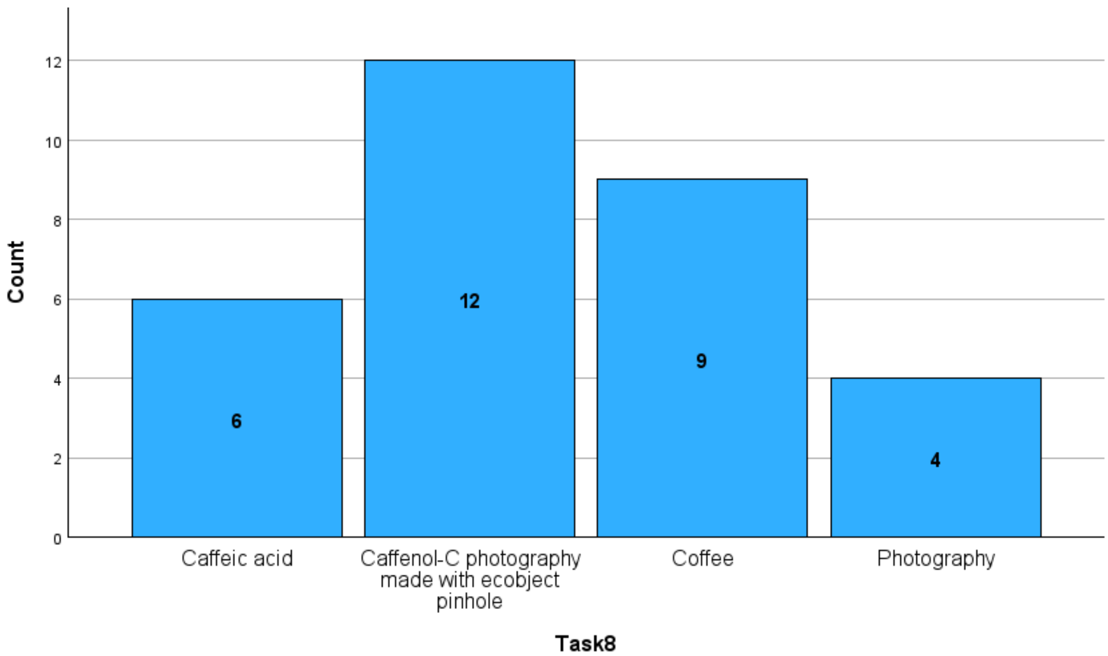


Figure C.12: Bar chart of the distribution of responses to question Task 8 among participants