Metadata Visualizations in Virtual Reality

A study of alternative ways of visualizing a search result's metadata in virtual reality.

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Abstract

This study explores ways of visualizing metadata in virtual reality through means other than text. Specifically, we focus on the metadata of a 3D object as a search result and how these visualizations can support understanding of the object. The study draws on research from the field of information science and is positioned in the domain of cultural heritage. There are few studies about human information interaction in virtual reality or metadata visualization in these environments. However, metadata can be a useful tool in the information seeking search process. Because its visualization should depend on purpose, ways of visualizing metadata other than through text are in need of exploration. This study answers the following question: How can descriptive metadata of a 3D search result object be visualized in VR to support users' understanding of the object? A research through design approach was employed. Data was collected through interviews about objects with visitors at a museum. These interview data were analyzed using a thematic analysis, and the results of that analysis were triangulated with the objects' metadata in a database. This triangulation resulted in sets of characteristics and techniques that, as expressed by interviewees, could help them gain an understanding of an object of historical and cultural significance. We then selected a smaller set of characteristics for implementation using a prioritization matrix, and an object to visualize metadata for. Brainstorming sessions generated ways of visualizing these characteristics using relevant techniques. The prototype is a virtual reality experience that allows the user to navigate three layers of information with visualizations of the 3D object's characteristics. The prototype was interactively demonstrated with four participants and their feedback was documented. The discussion is about the definition of metadata, unforeseen designs, the search process, the role of virtual reality in information seeking, how metadata visualizations can support understanding of an object and whether our do, our choice of using research through design as the approach and the study's ethical and societal implications and its limitations. We conclude that metadata of a search result as an object in VR can be visualized by segmenting the VR experience into different layers of information, specifying a sequence in which the layers are presented that builds a narrative and provides users with multisensory feedback. We encourage future evaluative and comparative studies.

Keywords: virtual reality, metadata, information seeking, understanding

Synopsis

Background

The study is positioned in the fields of information science and immersive technologies and the cultural heritage domain. The background includes previous research on the search process, human information interaction in VR, techniques used to document historical artifacts, metadata visualization, and definitions of virtual reality, immersion, objects, metadata and the concept of understanding.

Problem

The current trend to rely on text for visualizing metadata in VR is not responsive to the user's understanding of the object. For use cases where text-based metadata is not the most useful means of understanding an object, alternative ways to visualize the metadata are lacking in the current body of research in the information seeking field and the small field of metadata visualization. That is the problem this study addresses.

Research Question

How can descriptive metadata of a 3D search result object be visualized in VR to support users' understanding of the object?

Method

The research strategy was research through design. Data was collected through semi-structured interviews with visitors at a museum about objects in their close proximity. A thematic analysis of the data generated characteristics of an object that can support users' understanding of it, and techniques for visualizing them. The characteristics were triangulated with the objects' metadata from a database. The selection of characteristics to visualize in the subsequently developed prototype was based on a prioritization matrix. For ideating characteristic visualizations we conducted brainstorming sessions.

Result

Sets of characteristics and techniques that the interviewees expressed could help them gain understanding of the object and the level of informativeness from certain types of metadata. The selected characteristics were: Setting, Layers of the Object and How the Object is a Component. The brainstorming session resulted in an updated list of the characteristics selected for implementation: Setting, Manufacturing, Usage, How the Object is a Component, Angles of the Object and Size and ways of visualizing these characteristics. We developed a VR experience and implemented these visualizations. The prototype was interactively demonstrated with participants.

Discussion

We discuss the answer to the research question, unforeseen designs, the search process, the role of VR in information seeking, how metadata visualizations can support understanding of an object and whether ours do, our choice of using research through design as the approach and the study's limitations. We conclude that metadata of a search result as an object in VR can be visualized by segmenting the VR experience into different layers of information, specifying a sequence in which the layers are presented that builds a narrative and provides users with multisensory feedback.

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List of Abbreviations

IR	Information Retrieval
IS	Information Seeking
VR	Virtual Reality
2D	Two-dimensional
3D	Three-dimensional
SERP	Search Engine Result Page
ASK	Anomalous State of Knowledge
ISP	Information Search Process
AR	Augmented Reality
MR	Mixed Reality
HMD	Head-mounted Display
RtD	Research through Design
DSV	Stockholm University's Department of Computer and Systems Sciences
ALLEA	All European Academies
ICR	Intercoder Reliability
PDF	Portable Document Format
XLSX	Microsoft Excel Open XML (extensible markup language) Spreadsheet

1 Introduction

1.1 Background

Information science branches out into two fields, namely information retrieval (IR) and information seeking (IS). In IR, mathematical models are used to generate search results (Hiemstra 2009) relevant to the query. In IS, the behaviors of humans during search are studied (Ingwersen & Järvelin 2005). These behaviors are individual and the information needs in different stages of search can vary (Liu et al. 2021). There are few published studies in human information interaction, all of which have been conducted with IR perspectives (Schleussinger 2022). As a complement to these, Schleussinger (2022) suggests future studies with applied IS perspectives, one example being on result representation and browsing in VR. Ward and Capra (2020) conducted a study on this and represented results in two-dimensional (2D) panels in VR. Their study was conducted in the field of IR (Ward and Capra 2020).

VR is gaining interest in the domain of cultural heritage (Cecotti 2022; Wang 2022). For decades museums and other cultural institutions have digitized their collections. A conventional technique for documentation and digitization of collections is photography (Barratt 2021). However, in documentation of physical artifacts, these photographs cannot document their spatial dimension. More sophisticated techniques for documenting this were developed and resulted in three-dimensional (3D) virtual objects (Barratt 2021). However, when these objects are accessed by users they lack context. In VR, an artifact can be digitally copied as a 3D virtual object and contextualized visually and interactively, helping visitors understand and connect with them in an immersive way (Cecotti 2022; Wang 2022). Vital in understanding this object is metadata.

Metadata plays an important role in users' understanding and knowledge of data (Gartner 2016). It can be visualized in different ways depending on the use case (Gartner 2016). Despite this, it is often visualized with text in immersive environments - regardless of the use case. In this study, the 3D virtual object is a search result and the possibilities for visualizing its metadata are explored.

1.2 Problem

In immersive environments, objects' metadata are often visualized as text (see figure 2 and section *2.5.2 Metadata Visualization* for reference). This reiterates the trend to rely on 2D elements in 3D environments (Schleussinger 2022). Although there is a time and place for using text to visualize metadata in immersive environments, research shows it is most likely not appropriate for all use cases (Gartner 2016). The problem with only using text to visualize metadata in VR is that it is limiting to the user. For certain use cases text-based metadata may be most useful, however, likely not in all. The current trend to rely on text for visualizing metadata in VR is not responsive to the user's understanding of the object. For use cases, where text-based metadata is not most useful for understanding the object, alternative ways to visualize the metadata are lacking in the current body of research in the information seeking field and the small field of metadata visualization. That is the problem that this study addresses. There is a need to explore alternative metadata visualizations in VR. Alternative metadata visualizations could support interpretations of search results and contextualize the object of search.

1.3 Research Question

In response to the problem statement, we pose the following research question:

How can descriptive metadata of a 3D search result object be visualized in VR to support users' understanding of the object?

1.4 Delimitations

The research question includes the term *object* rather than *artifact*. The difference between an artifact and an object has been extensively discussed in the literature. The distinction is still not clear and in *2.4 The Definition of an Object* the problem is explained in more depth. To summarize, an artifact is defined as a man-made object to serve a specific purpose (Johannesson & Perjons 2014). This description is not useful to us because it would mean that any object in VR is an artifact because it is man-made. Instead, we use the term object because, in our study, it describes a search result. This is in line with Kallinikos, Aaltonen and Marton's (2013) definition of a target page in a search engine result page (SERP) as an object.

The question also includes the term metadata of which there are many types. This study undertakes the type descriptive. Descriptive metadata helps users understand and discover data (Riley 2017). In the context of a museum, an example of descriptive metadata can be the location where an object on display was discovered.

2 Extended Background

2.1 Searching in VR

This study positions itself in the field of computer and systems sciences with a focus on immersive technologies and information science. Information seeking (IS) is a branch of information science that takes a user-centric perspective on the search process (Ingwersen & Järvelin 2005). In IS, the process of how people search for or seek information through various sources and the associated behaviors are studied. IS involves a range of activities, such as browsing, scanning and reading, and they can be influenced by factors such as the user's knowledge, motivation and experience (Ingwersen & Järvelin 2005). This is in contrast to information retrieval (IR) which instead takes an algorithmic perspective by applying mathematical models to generate search results (Hiemstra 2009). IR focuses on the technical aspects of the search process, such as the use of Boolean operators, the selection of search terms and the ranking of search results (Ingwersen & Järvelin 2005). The focus in IR lies in generating relevant information in response to a search request or query. Among other tools, it involves the use of search engines and databases to locate and retrieve information that matches the user's query (Ingwersen & Järvelin 2005).

Studies on interactions between humans and information in VR are few, and those conducted have primarily been studied in the field of IR, rather than IS (Schleussinger 2022). These studies have primarily developed and evaluated various input methods for querying. Fashimpaur, Kin and Longest (2020) developed PinchType which allows users to interact with a virtual keyboard using a pinching hand gesture. Participants in their study found the input method comfortable but performance could be improved (Fashimpaur, Kin & Longest 2020). Henriques (2014) proposed a search interface with speech as an input method. In that study, participants could describe 3D objects in order to locate them. Regarding an object's description Henriques (2014) explains that its intrinsic information, such as file names, are insufficient for describing them, and they need new metadata as a complement. The results of Henriques' (2014) study were positive in terms of participants' perceptions of the objects and performance. Giunchi, James and Steed (2018) conducted a study that proposed 3D sketching as an input method for querying in VR. In their study, participants could query a collection of 3D objects by freely sketching their desired characteristics on a model. For locating the objects, the sketch was interpreted through machine learning. Each of these studies focus on technical implementations of innovative input methods in VR search. Ward et al. (2021) pays less attention to input methods in VR and instead directs attention to different information layouts in VR and how users interact with information in these environments. In one study, Ward and Capra (2020) investigated three different ways of representing results in VR. They found that participants completed tasks most efficiently when the results were presented in an arc shape, but preferred the other spatial layouts where results were presented in a grid or list.

In the IS domain, there is considerable research on how humans behave when they seek information. Liu et al. (2021) write useful summaries of the most influential models in the domain and some examples are as follows. Belkin (1980) proposed the anomalous state of knowledge (ASK) Model in which the user is assumed to recognize their own anomaly and resolve it. Notably, Belkin claimed that the search process does not necessarily begin when people can express and articulate their information needs. Bates' (1989) emphasized the dynamic nature of search in her Berry-Picking Model. She described the search process as iterative and paid particular attention to browsing. In Pirolli and Card's

(1999) Information Foraging Model, they describe human behaviors in the search process as responses to dynamic environments. The model stems from the information foraging theory which posits that people tend to “maximize information gain by minimizing the cost of information seeking” (Liu et al. 2021, p. 21). Ellis (1989) defined in the Information Seeking Behavior Model a set of characteristics of human behaviors in search. These were: “starting, chaining, browsing, differentiating, monitoring, extracting, verifying, and ending” (Liu et al. 2021, p. 22). These stages could then be designed for in systems to improve their usability. Kuhlthau (1991) also defined stages of the search process in the Information Search Process (ISP) Model. These were: “initiation, selection, exploration, formulation, collection, and presentation” (Liu et al. 2021, p. 24). The exploration stage was according to Kuhlthau the most challenging as it involved confusion and uncertainty. In Marchionini’s (1995) Information Seeking Process Model the search process is also described as iterative. According to this model, in general terms users select a search system, query, examine and extract relevant information and then reflect or stop searching. The model also conveys the probability of transitioning from one step to another (Liu et al. 2021). Based on these models, a general description of the search process is as follows: “(a) Identification of an information need (b) Selection of information sources (c) Query formulation (d) Sending the query to the system (e) Getting results in the form of information items (f) Examining, interpreting, and evaluating the results (g) Reformulating the query or stopping the searching” (Karwowski, Rizzo & Rodrick 2003, p. 187).

As previously stated, studies on human-information interaction in VR have primarily been studied in the context of IR. There are no studies that apply an IS perspective on search in VR (Schleussinger 2022). Case (2016) writes that in IR information is objectively defined as either relevant or not to the search request. He criticizes this and explains that “[t]he main problem facing an objective operationalization of relevance is the contextual nature of human judgment” (p. 112). For example, what information users find relevant during search can shift depending on the order in which results are represented, and the point at which a result becomes relevant varies greatly between users (Case 2016). Jansen and Rieh (2010) provide an additional view on the matter, and write that a problematic stance in IR is the assumption that the more information the user gets the better. For their counter arguments they draw on research from information searching, which according to them is a subset field of IS. They present three counter arguments from previous information searching research: 1) there are situations in which people avoid information, 2) more information can hamper decision-making and 3) perhaps in conflict with the assumption in IR that more information is better, users can be irrational in concluding the benefits of information (Jansen and Rieh 2010). Furthermore, Jansen and Rieh (2010) posit that information searching has directed its focus toward the cognitive and emotional aspects of information processing, such as knowledge acquisition and learning. In contrast, IR research has remained focused on refining algorithms that center around data and information. Additionally, information searching researchers have broadened their scope to investigate societal, cultural and organizational factors that influence or moderate the effectiveness of information use, while IR researchers have overlooked the social aspects of information usage.

Schleussinger (2022) wrote a recent article suggesting a number of possible future studies on search in VR. One was a study of result representation and browsing in VR with an applied IS perspective and focus on interactions with the results. Our study is based on this suggestion but with variations. We represent the search result as a 3D object and contextualize it with metadata to support users’ understanding of it. We return to the concept of understanding in 2.6 A Definition of Understanding and proceed here by providing the reader with a background of documentation techniques for historical artifacts and their limitations in terms of information gaps.

2.2 Digitization of Historical Archives

The five functions of digitizing cultural heritage are, according to Schilz and Rehbein (2022), to a) enable easy and ubiquitous access to it, b) aim to document it accurately in order to preserve it, which is of particular value when the original artifact is lost or damaged, c) use the digital version of the artifact when the original is fragile or especially valuable, for example in exhibitions, d) provide context of historical artifacts, which can be achieved virtually and e) use digitized materials for computer-aided analysis. For the first function, the internet has proved useful. Cultural institutions have their own websites which allow a vast number of users to visit it from different locations while accessing a multitude of information the institution has to offer (Guccio et al. 2016).

When visiting a museum's website a user can often view their online archive, including images of items in their collection (The British Museum n.d.; Smithsonian n.d.; Acropolis Museum 2023; Louvre n.d.). These images are often presented in a grid, see figure 1. Clough (2013) published a report through the Smithsonian Institution explaining that "... institutions must move beyond merely posting digital collections online to develop a context for understanding and applying the knowledge those collections contain. In the process, museums, archives, and libraries will become a resource that is infinitely more valuable than a passive set of digital images…". In other words, presenting images of a museum's collection in a grid format online is not engaging. Moreover, the grid design with photographs of the collections is a uniform design for a diverse set of items. Collections can, for example, include paintings, tools, texts and textiles. In part, Clough (2013) is saying that an artifact is more engaging if available in a 3D environment than in a 2D environment. One defining characteristic of documenting an artifact in three dimensions and making it available in a 3D environment is that the user gets a sense of the object's depth.

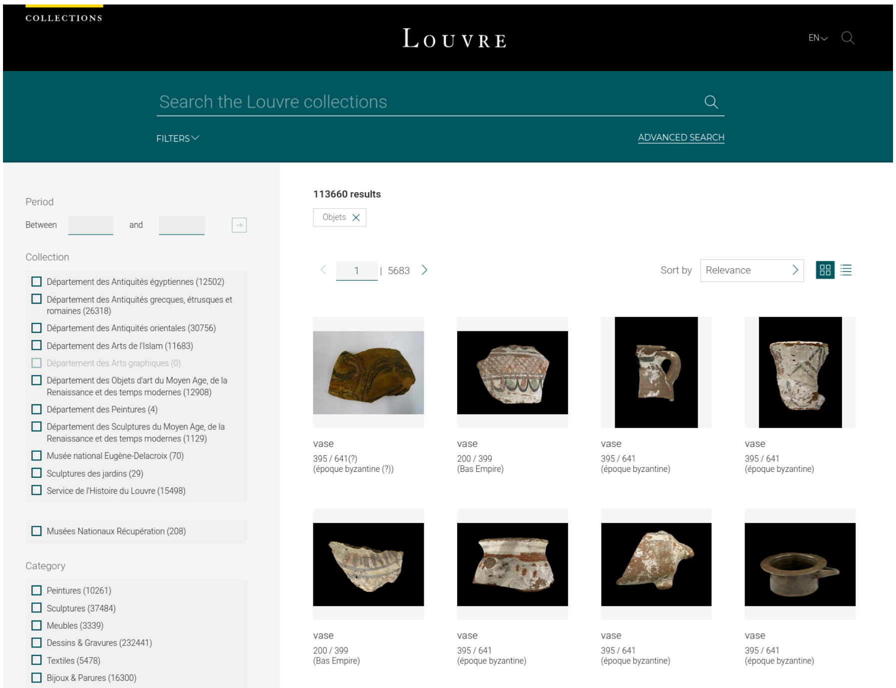

Figure 1: Screenshot of The Collections database on the Louvre's website. Selected category is objects (Louvre n.d.).

In the mid-1980's visualization techniques were developed between archaeologists and computer scientists as a result of advances in both computing and archaeological theory (Barratt 2021). These techniques were used to create archeological sites in 3D. The techniques are categorized as either reconstruction or survey-based. Using reconstruction-based techniques, users manually generate visualizations based on real and hypothetical data. These visualizations stem from established theories in archaeology. Examples of reconstruction-based techniques are software for 3D modeling such as SketchUp (n.d.) or Blender (n.d.). Using survey-based techniques, however, only real data is available and the visualizations are based on these. Examples of survey-based techniques include photogrammetry and laser scanning. Explained simply, photogrammetry is a technique that uses photographs to create 3D models through algorithms. Laser scanning is more expensive but often more accurate. Barratt writes that it "measures distances (ranging) by illuminating the target with laser light and measuring the reflection with a sensor" (Barratt 2021). These techniques offer a level of depth that regular photographs do not. The British Museum (n.d.) has a collection of 3D scanned artifacts. This is not the main website of the museum where a user can view the collection, as previously noted. Instead, it is for commercial use as the files are for sale. To summarize, The British Museum has an online archive of its collection of photographs for viewing. On its other website, the museum offers 3D scanned models of artifacts but these are explicitly for sale. Why the online archive does not include the already 3D scanned artifacts is not clear.

According to Clough (2013), cultural institutions need to develop contexts for understanding for their collections. Contextualizing cultural heritage is vital in understanding its importance, and it can be accomplished through digital worlds (Guccio et al. 2016). Schilz and Rehbein (2022, p. 1195) write that "digitized material can contribute to bringing together artifacts virtually in different, historically verifiable contexts". By using digitized material from cultural institutions in VR, users can experience the context of those materials. In VR, locations that are otherwise inaccessible can be simulated and visited by users (Cecotti 2022). Users can also experience places in different historical eras which would otherwise be currently impossible (Cecotti 2022). Furthermore, in a museum, historical artifacts are often placed in display cases (glass boxes) where they cannot be experienced interactively. In VR, however, interaction with the artifact is possible without risking damage to the original version. For example, a user can rotate a virtual copy of an artifact and look inside of it. The artifact can also interact with its virtual environment.

2.3 Virtual Reality and Immersion

Augmented reality (AR) and VR technologies provide consumers with immersive experiences (Skarbez, Smith & Whitton 2021). AR enhances the real world with virtual elements, as seen in applications such as Pokémon GO. VR offers computer-generated simulated environments through headsets such as Oculus Quest. Additionally, mixed reality (MR) combines the real and virtual worlds, enabling interaction between physical and digital elements (Skarbez, Smith & Whitton 2021).

VR can be described as a virtual environment that users can enter by donning a head-mounted-display (HMD) (Williamson, McGill & Outram 2019). Riva and Waterworth (2014) further explain that, in VR, users instinctively react in ways that suggest they are immersed in synthetic experiences. The concept of VR is not new, yet a renewed interest has been recently observed (Rostami and McMillan 2022). This interest has led to applications of VR in various domains, with a common goal of achieving immersion.

The concept of immersion has been approached from two perspectives: technological and psychological. According to Slater and Wilbur (1997), technological immersion can be objectively evaluated by considering environmental features such as inclusiveness, extensiveness, surroundedness, and vividness. In this context, immersion refers to the technology's ability to create an immersive and convincing environment for users to interact with (Daassi & Debbabi 2021).

According to Witmer and Singer (1998), psychological immersion is a state of mind where individuals perceive themselves to be enveloped and included in an environment that offers a continuous stream of experiences and stimuli. In this context, immersion refers to the emotional response of users towards the mediated environment (Daassi & Debbabi 2021). Unlike technological immersion, psychological immersion emphasizes the sense of being surrounded rather than being physically present (Fan, Jiang & Deng 2022). For instance, individuals may feel immersed in electronic music, but lack of spatial cues or fidelity factors may prevent them from feeling like they are physically present. These two dimensions of immersion are not mutually exclusive but rather complement each other. VR technology offers immersive functionality through embodiment equipment such as HMDs, providing users with the opportunity to physically engage in psychological immersion (Fan, Jiang & Deng 2022).

2.4 The Definition of an Object

The respective definitions of objects and artifacts and the differences between them have been thoroughly discussed in literature, often in the fields of social sciences and philosophy. In this study, we instead focus on how the two are defined in computer science, and specifically in virtual contexts.

In the context of design science, Johannesson & Perjons (2014, p. 3) define an artifact "an object made by humans with the intention that it be used to address a practical problem". They do not explicitly define what an object is (if it is not an artifact), but they do write that if an object is not man-made then it is not an artifact. We do note here that the authors write that there is no clear distinction between the two. An applied example of the definition is that an axe is an artifact because it was made by a human to address a problem, whilst a stone is not an artifact because it was not made by a human (Johannesson & Perjons 2014). This definition seems impractical for designing digital solutions, as all objects would be considered artifacts because they are man-made (designed or programmed, for example). Johannesson co-wrote a recent article in which the authors highlight the importance of defining an ontology of artifacts (Weigand, Johannesson & Andersson 2021). They write that "[t]here is a risk that the artifact concept loses its meaning if it includes any decision or any solution. To keep the connection with both common sense and the technical sciences and to able to give substance to the design aspect, an artifact must have something of 'an object made by humans'" (Weigand, Johannesson & Andersson 2021, p. 2).

Brey (2014) provides a definition that is more useful in the context of VR, and is therefore more useful to us. He writes that a virtual object is an artifact because it is designed by humans with a specific purpose (Brey 2014). He does not, however, refer to these objects as artifacts in the paper, he merely points it out. A virtual object is contrasted with a digital object. A digital object is, according to Brey (2014), a symbolic structure (symbols referring to machine code) made available and visible to users, such as an icon for a folder. "A virtual object is a digital object that is represented graphically as an object or region in a two- or three dimensional space and that can be interacted with or used through a computer interface" (Brey 2014, p. 44). Brey (2014) also writes that virtual objects appear as physical objects and are interacted with similarly.

One problem with defining an artifact as a man-made object is that everything in VR could be defined as an artifact because it is made by humans. That does not seem very useful. If there is a reason to develop an ontology of artifacts for physical reality, there must be a reason to develop it for virtual reality. The definition of what an artifact is in VR, and what a non-artifact object is in VR is not clear. Therefore, we rely on a definition that is most useful to us in the domain of information science. According to Kallinikos, Aaltonen and Marton (2013) a target page is an object. On a SERP search results are listed. These search results are pathways to target pages - the pages on other websites (Kallinikos, Aaltonen and Marton 2013). However, distinguishing between a search result and a target page seems bound to the conventional 2D interface of a search engine. In a library, for example, a book could be a search result and thus a search result could be an object. Therefore, we refer to the search result in our study as an object, and further define it as a virtual object, as it is graphically represented and can be interacted with.

2.5 Metadata

2.5.1 Definition of Metadata

Metadata, which refers to data about data (Gartner 2016), is a critical component of the software people use every day (Riley 2017). Platforms such as Spotify, Instagram and YouTube all use metadata to provide details about the content, such as the title, author, genre and other attributes (Riley 2017). Metadata is always subjectively constructed to communicate information for a specific purpose (Gartner 2016). It is subjective in the sense that a human has decided to include or omit certain data. Metadata can be represented in different ways, and they help users understand and gain knowledge about content (Gartner 2016).

The three primary types of metadata are administrative, structural, and descriptive (Gartner 2016). Administrative metadata is crucial for resource management and includes the subcategories *technical* metadata for decoding and rendering files, *preservation* metadata for long-term management and *rights* metadata for intellectual property rights (Riley 2017). Structural metadata links small segments of data that, in aggregate, form complex objects (Gartner 2016). An example is linking pages in a book as a chapter (Gartner 2016). The most recognizable type of metadata is descriptive metadata, which serves the purpose of helping users discover and understand data (Riley 2017). In a museum context, descriptive metadata provides visitors with information about objects on display, such as its historical significance (Riley 2017). It can also, for example, include information on where the objects on display were originally discovered and when. In this study we use descriptive metadata for the prototype and will in later chapters refer to this as simply metadata.

For a search result such as a web page there is a multitude of associated metadata. However, only a selection of these are accessible by the end user through the search engine. In our study we similarly only use a selection of descriptive metadata for the 3D search result object and make them available to the user, rather than include all of the object's associated metadata.

2.5.2 Metadata Visualization

Metadata can be visualized in vastly different ways. For example, Gartner (2016) describes how a globe can represent metadata of Earth. It can include names of countries and lines to represent borders between them, both of which are human-made constructs. To exemplify how metadata is constructed for specific purposes, Gartner (2016) compares how metadata is visualized in a Google Maps view of a city and a map of subway stations in a city. In the Google Maps view selected buildings and roads are represented, and the selection changes depending on how much it is zoomed in. In contrast, a map of a subway station might only include the name of stations, how they are connected and rough visualizations of their relative location from each other. As such, these two maps both visualize metadata to describe the city, but in completely different ways because they serve different purposes (Gartner 2016). These examples illustrate the ample opportunities for visualizing metadata in creative and useful ways. However, in 3D environments, descriptive metadata are typically represented more or less the same - with text. In a quite dated article, Patel et al. (2005) describe a study in which they developed a system for virtual exhibitions. They write that their prototype includes visualized metadata and this is represented as text. This way of visualizing descriptive metadata has persisted throughout technological advances in VR. The same can be observed in a more recent example, such as in the augmented reality (AR) feature of Google Arts & Culture (Google Arts and Culture, 2020). Figure 2 is a screenshot of an artwork in AR, with the associated metadata visualized as text. Notably, Gartner (2016) describes how metadata is visualized differently depending on the use case, yet in immersive environments descriptive metadata is often visualized in the same way (with text) - regardless of the use case.

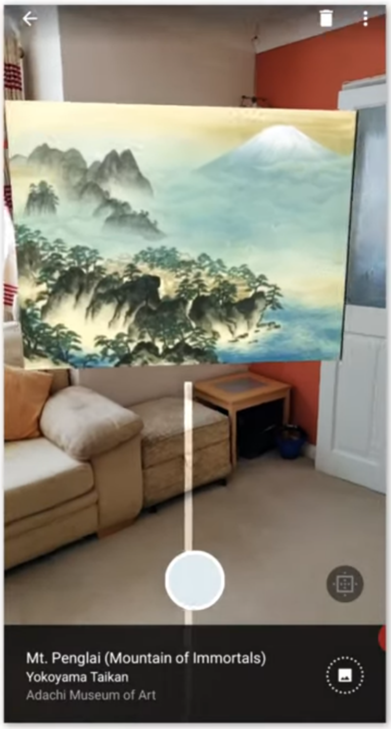

Figure 2: Screenshot of a video snippet showcasing Google Arts and Culture's AR feature where the artwork is 3D and the metadata is represented in text (lower dark panel) (Google Arts and Culture 2020).

Although research on visualizing metadata in 3D environments without relying solely on text is scarce, we found two examples. Lugmayr et al. (2011) demonstrated a VR experience in which a user could seek information with the help of metadata visualized without text. Figure 3 and 4 are two different scenarios in their study in which time and location are visualized. The objective of the paper was to create a proof of concept and therefore the prototype was not evaluated. Hendery and Burrell (2019) also proposed an alternative way of visualizing metadata in VR, though in their study the context was not in IS and instead archival data of endangered languages in the Pacific. Figure 5 depicts one way to visualize the geographical spread of and number of people speaking a language. The use case for the prototype was learning about endangered languages in the Pacific. Their data showed that users perceived an increased understanding of the data, and they found VR as a tool essential to the experience. The authors therefore suggested that immersiveness may play a key role in these increased understandings (Hendery and Burrell 2019).

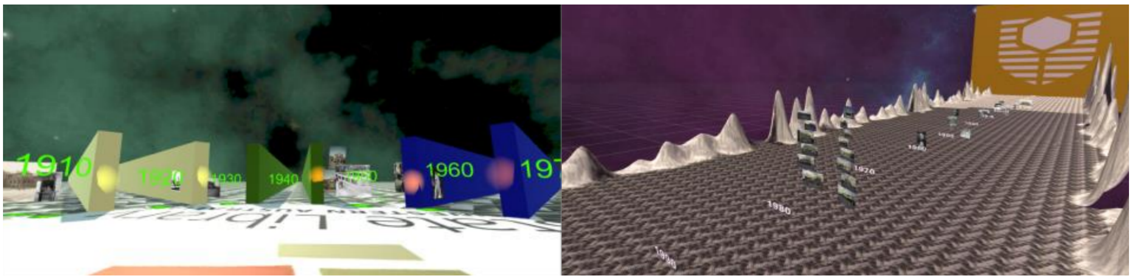

Figure 3: A scenario in which a user can seek information in VR with the help of temporal metadata visualizations (Lugmayr et al. 2011, p. 3).

Figure 4: A scenario in which a user can seek information in VR with the help of geographical metadata visualizations (Lugmayr et al. 2011, p. 4).

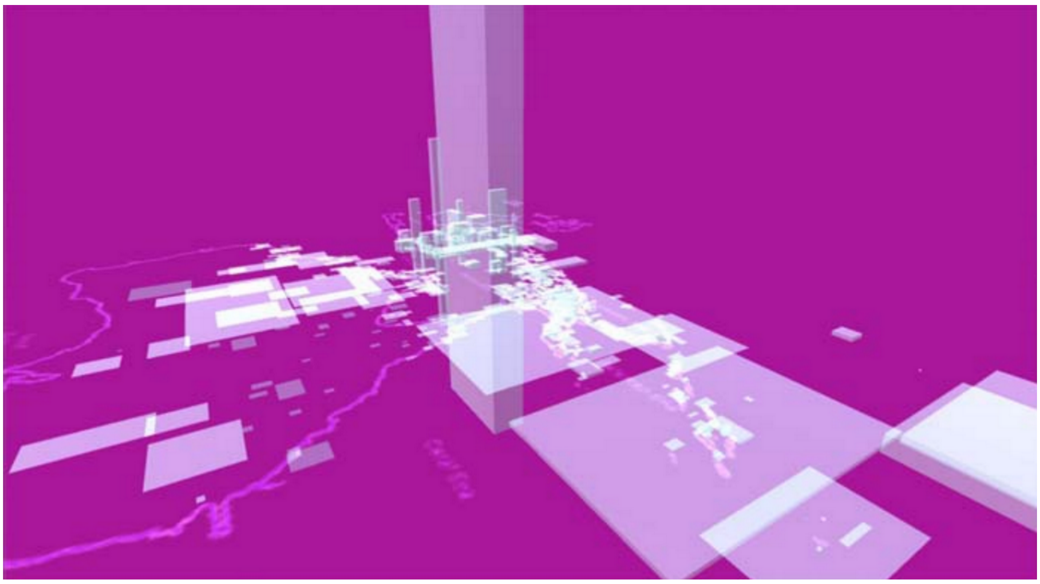

Figure 5: A visualization of the geographical spread of and the number of people speaking a language (Hendery & Burrell 2019, p. 493).

2.6 A Definition of Understanding

Ackoff's pyramid is a model that outlines the progression from data to information, knowledge, understanding and then wisdom (Gartner 2016). A single unit of data is at the bottom of this pyramid. By adding for example labels to the data, a person can extract information. Knowledge is defined as a connection of information to form meaningful patterns. Understanding involves analyzing patterns in knowledge to form new ones and drawing conclusions or making deductions from these. Wisdom is a higher level of insight and goes beyond understanding. It involves making decisions based on knowledge, understanding, values, ethics and what is best or morally right. Each level builds upon the previous. A different perspective is that the different levels address different types of questions. Data asks "What is the value?". Information asks "Who?", "What?", "When?" and "Where?". Knowledge asks "How?". Understanding asks "Why?". Wisdom asks "What is best?" and "What is the right thing?" (Gartner 2016). In the cultural heritage domain, understanding can be exemplified by recognizing historical significance. By examining historical objects we can gain a deeper understanding of why they hold significance and how they contribute to our understanding of the world (Wang 2022).

Mondada (2010) explains that the situated character of understanding is contextually and sequentially bound to the ongoing action. This can complement Gartner's (2016) perspective that understanding can be understood in terms of answering the question of why with the perspective that understanding is also affected by context. There are a multitude of definitions of what a context is (Bazire & Brézillon 2005). One definition that is useful in this study is that "[c]ontext is any information that can be used to characterize the situation of an entity, where the entity is a person, place, or object that is considered relevant to the interaction between a user and its application, including the user and the application themselves…" (Bazire & Brézillon 2005, p. 36). This definition can be used to explain that metadata can contextualize an object, and relating that to Mondada's (2010) reflection we can posit that this contextualization may support understanding of the object, assuming the information is relevant.

3 Methodology

This section presents the study's methodology. Figure 6 is a diagram of the chosen research methods and how they are related.

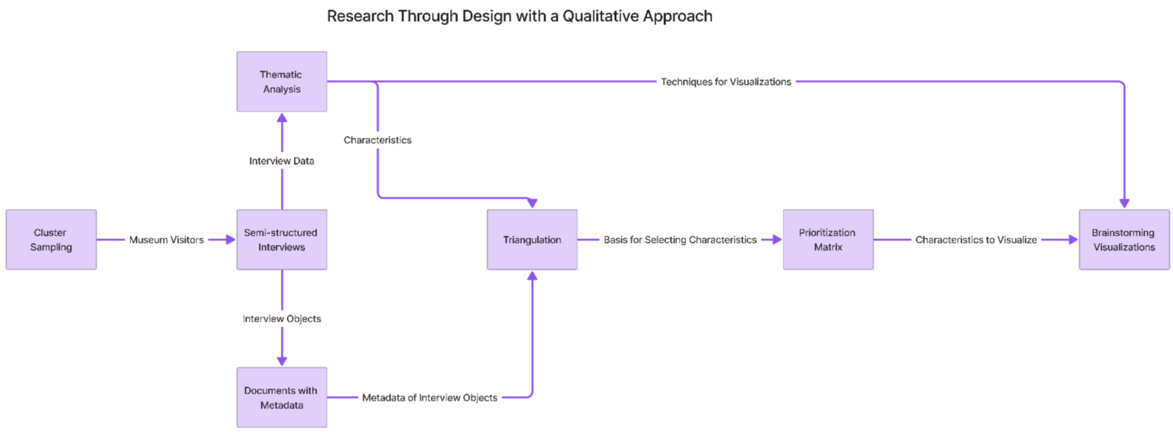

Figure 6: A diagram of the study's chosen research methods and how they are related.

3.1 Research Strategy

3.1.1 Research Through Design as Chosen Strategy

This study took a research through design (RtD) approach. When using this strategy, the goal of a project is to generate new knowledge and insights about a problem area (Zimmerman & Forlizzi 2014). RtD emphasizes the value of design practices, and how the reflective nature of the design process can highlight multiple perspectives on a problem to propose possible solutions (Zimmerman & Forlizzi 2014). Therefore, rigorous documentation of the design process and reasons for decisions are vital in an RtD project (Zimmerman, Forlizzi & Evenson 2007; Zimmerman & Forlizzi 2014). This strategy was suitable in our study because our research question suggested proposals on how to visualize metadata in an area of research where there are very few that exist. As implied, our study also took an exploratory approach. Exploratory studies generally use qualitative data (Zimmerman, Stolterman & Forlizzi 2010). There are few studies about alternative ways of visualizing metadata than through text, and in order to generate proposals we explored what metadata can help people gain understanding of an object and how these could be visualized in VR to support their understanding of it. This indicated a need for asking people open-ended questions. These types of questions are key in qualitative research.

3.1.2 Design Science as Alternative Strategy

As an alternative research strategy, we considered using a Design Science approach. Similar to RtD, this research in Design Science is concerned with creating an artifact (Johannesson & Perjons 2014). The general description of the design process in Design Science is as follows: explicate the problem, define the requirements, design and develop an artifact, demonstrate the artifact and evaluate the artifact. The process is iterative and not sequential as the description might suggest (Johannesson & Perjons 2014). The reason an RtD approach was deemed more useful in this study is because of the speculative direction it took. In RtD, researchers probe on "what the world could and should be" (Zimmerman & Forlizzi 2014, p. 168). The phrasing of the study's research question implored us as researchers to be speculative, exploring possibilities. This did not mean that we would create a solution to a problem that we deemed was a fix, instead, we emphasized that there may be a number of possible ways to solve a problem and explore a selection of them. In contrast, Design Science is more concerned with creating a single solution that solves the defined problem.

3.2 Step-by-step Execution

We conducted pilot interviews with students at Stockholm University's Department of Computer and Systems Sciences (DSV). As a proxy for the physical museum experience, the participants were asked questions related to objects in a virtual museum experience. For our sample, we emailed museums in Stockholm, Sweden and found a date on which we could collect the study's data in their facilities. Those who visited the museum on the decided-upon date were asked to participate in the study and sign a consent form. With those who agree we conducted interviews which were documented through audio recordings. The interviews were held in reference and proximity to objects on display, and the objects differed for almost every interview. We then performed a thematic analysis of the interview data. The expected outcome of the analysis was characteristics of the objects that were of interest to the participants and ways that these could be visualized to support understanding of the object. The characteristics were then triangulated with the metadata in the museum's database. We use the term characteristic because the data is not formally listed as metadata in the database. The list of database metadata encompasses all metadata about every object that the interviews were in reference to, with duplicates removed. The results of the triangulation formed a basis for selecting characteristics for visualization in VR. This selection was made based on which characteristics could contextualize the object more in VR than in a 2D interface or a physical museum environment. We selected them through a prioritization matrix of relevance and technical feasibility.

For each selected characteristic we conducted brainstorming sessions through Miro (n.d.) for generating visualization ideas. The ideas and decisions were documented through screenshots and text files. The metadata visualizations were then prototyped as a VR experience for a selected 3D object. The prototype was interactively demonstrated to a group of participants at DSV.

3.3 Sample

3.3.1 Motivation for Cluster Method

The study applied the cluster sampling method which is suitable when the population of interest is large and geographically dispersed (Denscombe 2014). This was the case with museum visitors. It is difficult to study a population of this type, but it is feasible if it is broken down in clusters. The sampling method is useful when the population can be grouped in a location (Denscombe 2014). For our study, one cluster contained museum visitors at one museum.

3.3.2 Application of Cluster Method

When applying the method we began by contacting museums in Stockholm, Sweden. The museums were sent an email with a description of the study and a request for collecting data in their facilities. If more than one museum responded positively we would select the museum with collections primarily consisting of artifacts that could make use of the three dimensions in VR. For example, in the choice between museums with collections of paintings and collections of objects we chose the latter. The decision was also based on the available dates in order for the data collection to take place as early as possible. We then decided on a date and the visitors on that date became our sample. Visitors accompanied by children were avoided because the children may have been distracting for the participants. It was also important to ensure that no data were collected from minors (under 18 years old). We selected participants that were alone or almost alone in the room to avoid any disturbing noise or distractions.

3.4 Data Collection

3.4.1 Motivation for Semi-structured Interviews

Primarily, the data in this study was collected through semi-structured interviews. This method is useful in research projects using a qualitative approach (Denscombe 2014). In semi-structured interviews a set of questions are predefined (Denscombe 2014). This was useful for asking directly what information the participants were missing from the object. However, in addition to the predefined questions the method allowed us to ask participants follow-up questions to clarify their answers and expand on topics if the answers were unsatisfactory (Johannesson & Perjons 2014). This was also particularly valuable considering this study used an exploratory approach. Although Denscombe (2014) writes that the researcher should generally try to arrange for an interview to take place in private where the participant can sit down, we did not try to ensure this. For this study, there was a strong advantage of conducting the interviews at the museums, which risked that the interviews were not completely undisturbed. By asking participants questions while they were standing by the display object the questions were less hypothetical than they would have been behind closed doors without the object. The participants could answer questions about their experiences with the objects while they were experiencing it.

3.4.2 Motivation for Documents

The second method of data collection employed in this study was the use of documents. Specifically, we used documents containing metadata of the objects. The advantage of using documents is that they serve as a permanent record and can reveal data that is not immediately apparent (Denscombe 2014). This was useful in our study because for an object on display the metadata shown to the visitor is limited. Not all metadata is presented to the visitor, meaning that for us as researchers it was not immediately apparent by visiting the museum. Denscombe (2014) writes that to determine a document's validity the researcher must consider its representativeness, i.e whether the document represents a typical instance of the type. One way to consider this is by asking the museum which standard the document follows for its metadata. An example of a standard for metadata often used in the cultural heritage domain is DublinCore (2019).

3.4.3 Application of Data Collection Methods

The interviews were conducted with visitors in a museum, in proximity and relation to museum objects. The object which the interview was about was different for each participant. There were four main questions in the interview guide. The questions involved how the information available on the sign helped them understand the object and what else could help them understand the object (that was not written on the sign). The interviews were documented through audio recordings, with the specific objects written down as notes. The interviews were approximately 10 minutes and the interview guide is available in appendix A. After the interview data were collected we searched the museum's online database for the objects and wrote down their metadata, removing duplicates.

3.4.4 Questionnaires as Alternative Method of Data Collection

An alternative method for data collection was questionnaires. With questionnaires, participants can answer in their own time and in a location of their choosing (Denscombe 2014). This could have been advantageous in our study as there was a risk that interviews could be seen as intrusive to the museum experience. The visitors were there to experience the exhibits, not to answer our questions. By using questionnaires instead of interviews the participants could have answered when they decided they were done viewing an object. With interviews, we risked interrupting participants during their visit. However, there were three main disadvantages of using questionnaires for data collection in this study. First, the questionnaires would have needed to include a question on which object in the museum the participants were referring to, which would have given room for ambiguity unless they knew what the object identification numbers were. Second, a prerequisite for using questionnaires as a data collection method is that the questions are understandable to participants (Denscombe 2014). This study had a focus on metadata which is a technical concept that may have been unfamiliar to participants. Compared to questionnaires, interviews gave us as interviewers more space to explain this concept if needed and tailor the explanation to the participant's knowledge of it.

3.5 Thematic Analysis

3.5.1 Motivation for Thematic Analysis

The collected interview data was analyzed through a thematic analysis. Thematic analysis is a qualitative data analysis method that involves categorizing data into themes (Braun & Clarke 2006). The process begins by finding patterns in the data and defining those as *codes*. These codes are then categorized based on their common denominators and the amount of data justifying them. These categorizations are called *themes*. These themes are redefined iteratively, with continuous reference to the raw data (Braun & Clarke 2006).

The method is flexible and free from a theoretical framework to stay within. The coding process was inductive in the sense that we did not aim to fit the data into an existing theoretical framework, but also deductive in the sense that we were trying to identify patterns of relevant characteristics and techniques that could be useful for visualizing them and understanding the object. Additionally, a thematic analysis allows for a detailed exploration of data which can lead to insightful findings (Braun & Clarke 2006). The method is associated with qualitative data, which was in line with our approach. It was a suitable method for our study because we did not have a theoretical framework to adhere to, as there is no theoretical framework for metadata visualization in VR.

3.5.2 Application of Thematic Analysis

In this study, we applied the thematic analysis in line with the previous description. The interview data was imported to Taguette (n.d.) which is a useful tool for analyzing qualitative data. It allows for generating codes that are linked to the raw data. The interview data was divided into two parts and each researcher coded half of the data. Afterward, we switched and went through each others' datasets. When we were in disagreement, for example if one researcher thought the other researcher had missing or irrelevant codes, we discussed the case until we reached an agreement. The resulting set of codes was subsequently imported to Miro (n.d.) and we used this tool to develop themes. We chose to use Miro for this phase of the analysis because we could cluster the codes to define themes and get a useful visual overview of how the analysis was progressing.

As described in 3.2 Step-by-step Execution, the expected outcomes of the analysis were characteristics of the object and ways that these could be visualized to support understanding of it. The characteristics were then triangulated with the metadata in the museum's database. The results of the triangulation formed a basis for selecting characteristics for visualization in VR. The selection was made based on which characteristics had the potential for being more understandable in VR than in a 2D interface or a physical museum environment.

To further strengthen our analysis, we triangulated the interview data with the metadata in the database. According to Denscombe (2014), data triangulation involves cross-validating findings with a separate source of information. The triangulation with the metadata in the database did not increase the validity of the interview data. However, Denscombe (2014) writes that triangulation has a slightly different meaning in social sciences. Triangulation is applied by viewing a research topic from multiple perspectives and thus gaining a more complete picture (Denscombe 2014). This was how we applied triangulation in this study.

Lastly, we aimed to increase the reliability of the findings by employing strategies commonly used for intercoder reliability (ICR). O'Connor and Joffe (2020, p. 2) write that "ICR is a numerical measure of the agreement between different coders regarding how the same data should be coded". The benefits of ICR in qualitative research include improved transparency and systematicity in the coding process (O'Connor and Joffe 2020). We did not use numerical measures to ensure ICR in the thematic analysis, however, we used strategies commonly associated with ICR. In the coding process, we divided the dataset into two and assigned each dataset to each researcher. After each researcher had coded their dataset, we switched and coded each other's dataset. As one of the benefits of ICR is the increased transparency of the coding process (O'Connor and Joffe 2020), employing these strategies in our study could also help increase its reliability. In qualitative research, reliability is challenging to achieve as the results of such research are difficult to replicate (Denscombe 2014). However, transparency can be used as a proxy for reliability in qualitative research because it allows the reader to see whether "reputable procedures and reasonable decisions" can be identified in the study (Denscombe 2014, p. 298).

3.6 Prioritization Matrix for Characteristics Selection

A prioritization matrix is a method that helps designers compare and prioritize different ideas based on specific criteria (Gibbons 2018). In Gibbon's (2018) example (see figure 7) the axes are *value to the user* and *feasibility*. However, the criteria are adaptable to different design contexts. Our matrix used axes for relevance to the research problem and the technical feasibility to visualize the metadata in VR. The prioritization matrix provides a structured way to compare and evaluate ideas (Gibbons 2018). For our application we expected the prioritization matrix to result in a clear view of what characteristics were of highest priority. The matrix was documented with screenshots, and the reasonings for the characteristics placements in the matrices were written down in a text document.

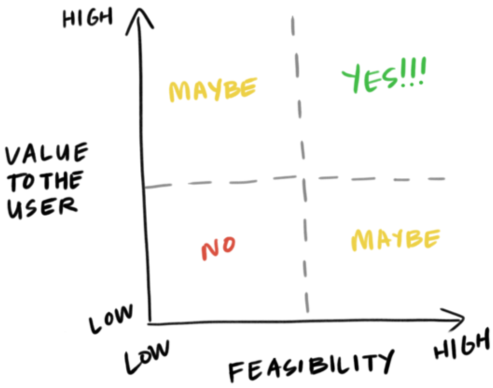

Figure 7: Example of a prioritization matrix based on the criteria value to the user and feasibility (Gibbons 2018).

3.7 Ideation for Prototype

Brainstorming is a method commonly used in RtD (Olson & Kellogg 2014) to help generate ideas quickly (Johannesson & Perjons 2014). The aim is to produce a diverse range of ideas, regardless of how unconventional or unrealistic they may seem initially. Designers are encouraged to share ideas without judgment and build upon each other's suggestions. After generating all the ideas, they are discussed and analyzed to determine their usefulness and feasibility (Johannesson & Perjons 2014). We conducted brainstorming sessions to generate ideas on how to visualize the selected characteristics. The participants of the brainstorming sessions were the two authors of this thesis and the ideas were documented with pen and paper.

3.8 Ethical Considerations

The key principles of research integrity are: reliability, honesty, respect and accountability (All European Academies (ALLEA) 2017). The principle of reliability concerns the quality of the conducted research and honesty concerns transparency. As described earlier, reliability in qualitative research can also be strengthened by transparency in the work. We draw on strategies from ICR in the analysis, and present the results and analysis exhaustively for the sake of transparency in this thesis. When describing the principle of respect ALLEA (2017) write that researchers must have respect for participants and also for cultural heritage. In our study, each participant was provided with a printed consent form with information about the study and its purpose, the procedures involved in the study, the known risks, and how their data was handled. The consent form is available in appendix B. The participant could choose to withdraw participation at any time despite having signed the consent form. Furthermore, we were mindful of visitors' museum experiences as our data collection may have been considered a disruptive event. We also followed social rules on how to behave in a museum, by, for example, not taking photos with flash or touching the objects on display. The fourth principle of research integrity is accountability which includes authors taking responsibility for the content in a publication (ALLEA 2017). This study will be published in Digitala Vetenskapliga Arkivet and we take full responsibility for the content of it. ALLEA (2017) further write that data must be kept confidential when required. We did not collect any personal information from participants and gave them pseudonyms in the data. These pseudonyms cannot be linked to any individual.

Fabrication, falsification and plagiarism define research misconduct (ALLEA 2017). This means that researchers must not fabricate results, manipulate them or claim that ideas or texts by others are their own. Proper credit must be provided to the original authors (ALLEA 2017). In this thesis, we used a referencing system consistently and communicated with the original authors when information has been collected from external sources. Lastly, ALLEA (2017) write that peer reviews are vital in conducting ethical research. This thesis was peer-reviewed twice and opposed once by students. It was also examined weekly by our supervisors who are senior researchers at Stockholm University.

4 Results and Analysis

This section presents the results and analysis of the pilot interviews and the main interviews. Firstly, we begin the section by describing how the pilot interviews were conducted and their results and then we describe how the main interviews were conducted. Secondly, a presentation of the thematic analysis outcome is provided. Thirdly, the results from the triangulation are presented. Lastly, the selection process and outcome is described.

4.1 Pilot Interviews

We conducted the pilot interviews with three students at DSV. As a proxy for the physical museum experience the participants were asked to answer questions related to objects in a virtual museum experience. Neither the Museum of Far Eastern Antiquities nor the Museum of Mediterranean and Near Eastern Antiquities have collections available in a virtual museum. However, the Museum of Ethnography does, so we used that for the interviews. We chose three objects in the virtual museum and let each participant view one and click to see its accompanying information. We then asked the participant questions related to the object and its written information. The main outcome of the pilot interviews was a defined need to make the interview questions more specific. We revised the interview questions to correspond to this outcome. For example, instead of asking participants what could be interesting or helpful to know about the object we instead asked what information could help their understanding of the object.

4.2 Main Interviews

We sent emails to seven museums in Stockholm and received five positive answers. Two museums did not respond. We decided to proceed with the study at the Museum of Far Eastern Antiquities. However, on the decided upon day for data collection we arrived at the museum and discovered it was closed due to a water leak. We called personnel and were offered to hold the interviews at the Museum of Mediterranean and Near Eastern Antiquities instead. Together with the Museum of Ethnography and The Museum of World Culture these museums are part of the National Museums of World Culture. Therefore, the personnel could arrange for us to conduct the interviews at a different museum on short notice. The interviews were conducted at the Museum of Mediterranean and Near Eastern Antiquities which was a suitable alternative. We had previously contacted this museum but had not received a response. The museum's objects and associated metadata are stored in a database called Carlotta, accessible at: https://collections.smvk.se/carlotta-mhm/web. During three days we held interviews with 12 participants. As per the description of how the sampling method was applied, the participants were either alone or almost alone in the room. They were either not accompanied by children or a different adult than the study participant took care of the accompanied child in a different room than where the interview was held. The interviews were conducted in association with 11 different objects (two interviews were conducted in association with the same object). In section 4.6 these objects are referred to as interview objects. Each participant was given a pseudonym which starts with the letter P for participant and ends with a number representing the order in which they were interviewed. The interviews were conducted in either English or Swedish depending on the participant's preference, but in this section the quotes in Swedish have been translated to English.

4.3 Thematic Analysis

4.3.1 Coding

The interview data was uploaded to Taguette for coding. The data was divided in two and we coded one half each - six interviews each. Following this, we switched interviews and coded each others' interviews. The result was 166 codes spanning a variety of subjects. For example, ethical guidelines, personal associations, time travel and object characteristics. The codes are available in appendix C. The generated codes were exported as a PDF file and as a XLSX file. The PDF file was useful for finding the interview quotes connected to the codes and the XLSX file gave us the opportunity to easily import the codes to Miro.

We coded data deductively, highlighting data related to the characteristics of objects, why participants were interested in certain characteristics, how they would prefer to obtain information on these characteristics, how their understanding of the object could be supported and their expressed feelings. These perspectives were defined before the coding process for guidance. However, during the coding process other perspectives emerged as well.

4.3.2 Categorization

In Miro, the codes were imported as post-it notes. They were categorized by grouping together codes with common denominators and then named. This gave us a visual overview of the categorized data, which was useful for making the data digestible for working with. We originally generated 23 categories but increased these after iterations to 27. These 27 categories can be found in appendix D. Also, figure 8 shows a screenshot of the revised 27 categories in Miro.

Figure 8: A screenshot of the revised 27 categories in Miro.

The content of the categories were in many cases self-explanatory by the category names, however, we provided comments to a few. *Characteristics of Objects* was generated as a result of participants directly expressing characteristics of the objects. For example, the category included the codes *texture*, *weight* and *size of the object*. Other categories contrasted this one because they included indirectly expressed characteristics of objects, more on this later. *How Objects are Related* was a category that included primarily three perspectives: how the object's components fit together, how the object is related to a different object that is missing (either from the exhibit, that it has not been found, or an imagined object) and how the object is related to surrounding objects in the display. Two interesting examples of this category were: one participant was reflecting on how a fish hook (object in the display) would be connected to a fishing rod (imagined object or object that has not been found) and another participant wondered how a mummified cat fit into its coffin (the object was a coffin with a mummified cat inside of it). In *Perceived Knowledge* we found a frequently occurring theme that participants felt intimidated by our interview questions as they expressed that they had low domain knowledge. We assured them that we are not experts in the cultural heritage domain nor were we examining their knowledge in the domain. More relevant in this category, however, was that participants answered our questions and interpreted the object based on their previous knowledge. This could be, for example, their knowledge of the historical era, the process of mummification or spiritual beliefs. *Layers of Information* was a result of participants expressing that they wanted to be able to choose either the amount, type or complexity of information about the object to digest. The data that constituted *Reasonings/Interpretations* showed that participants drew conclusions on missing information based on the information that was available. For example, one participant concluded that the object was heavy because its material was stone. In this example, the weight was not available information but the material was. Unsurprisingly, the codes in *Personal Associations* varied widely. One participant associated the mummified cat object with their personal pet, another associated the die object with similar dice from today and a third reflected on Sweden's role in other countries' cultural history (this perspective was included in the exhibit). Lastly, the category *Speculations/Questions* is interesting because it demonstrated that participants were left with unanswered questions about the object after having viewed it and read the accompanying sign.

In order to generate themes we tried examining the interview data to see which categories and associated codes were prevalent in combination. The result of this step can be seen in figure 9. We found that the arrows clustered around: *Context*, *Purpose*, *Usage*, *Manufacturing*, *How objects are related*, *Layers of information* and *Following the thread/Narration*. These categories were grouped in two themes, namely *Characteristics to Support Understanding* and *Techniques to Support Understanding*. The remaining categories were subsequently placed in one of these two themes. Afterward, we examined each category and its raw data again to find characteristics or techniques to support understanding that could be extracted, without the categories' names explicitly representing the characteristics or techniques. The results of these iterations are presented in 4.2.3 Characteristics to Support Understanding and 4.2.4 Techniques to Support Understanding.

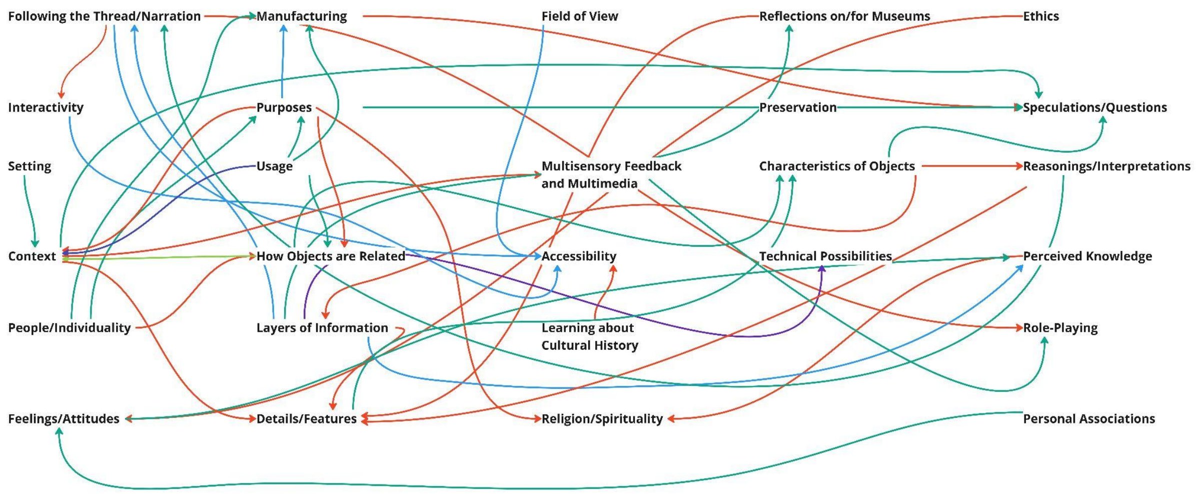

Figure 9: Categories connected based on whether they were prevalent in the interview data in combination. The purpose of coloring the arrows was simply to make it easier to view the categories.

4.3.3 Characteristics to Support Understanding

Characteristics was one of the two final themes that constituted the analysis outcome. This theme consisted of two subthemes, namely *Directly Stated Characteristics of Objects* and *Thematized Characteristics of Objects*. *Directly Stated Characteristics of Objects* consisted of codes capturing characteristics of objects that participants directly expressed. Examples of these codes were *weight* and *texture*. To avoid overlapping characteristics some codes were grouped and defined as one characteristic. For example, the codes *Year/Time not available* and *Time period of object* were combined with others and defined as the characteristic *Year/Time of object*. These characteristics could be triangulated with the metadata documents without further analysis. Table 1 shows the defined characteristic in the left column and the codes that the characteristic is based on in the right column.

Characteristic	**Code(s)**
Year/Time	Year/Time not available Year/Time of creation is interesting Age of object is fascinating Time period of object
Location of discovery	Geographical information missing Discovery location interesting but missing
Contents	Speculating on the contents of the object Speculating on condition of object inside tomb Signs help understand purpose and contents
Interior	Curiosity of object's contents and interior
Purpose	Signs help understand purpose and contents
Layers of the object	Different layers Layers of the object Signs help understand layers of the object
Shape	Shape of the body after mummification Shape of the object
Weight	Weight
Texture	Texture
Material	Material of the object
Manufacturer	Who created the object?
Size	Size of the object
When the object was retrieved by the museum	When the object was retrieved by the museum
Historical Significance	Historical significance not clear

Table 1: The left column includes the defined characteristics and the left column includes the codes that form the basis for the characteristic. This table shows the construct of the sub-theme *Directly Stated Characteristics of Objects.*

As the name suggests, *Thematized Characteristics of Objects* consists of characteristics that were defined after thematization. These characteristics were defined in a variety of ways and iteratively. They were defined from single categories, multiple categories or combined codes (for example, the characteristic *How the Object is a Component* combines multiple codes from the category *How Objects are Related*). Figure 10 depicts a screenshot of the theme *Characteristics to Support Understanding* in Miro, demonstrating how it was constructed. Three characteristics do not have accompanying arrows, namely *Manufacturing*, *Usage* and *Setting*. This is because they were already categories.

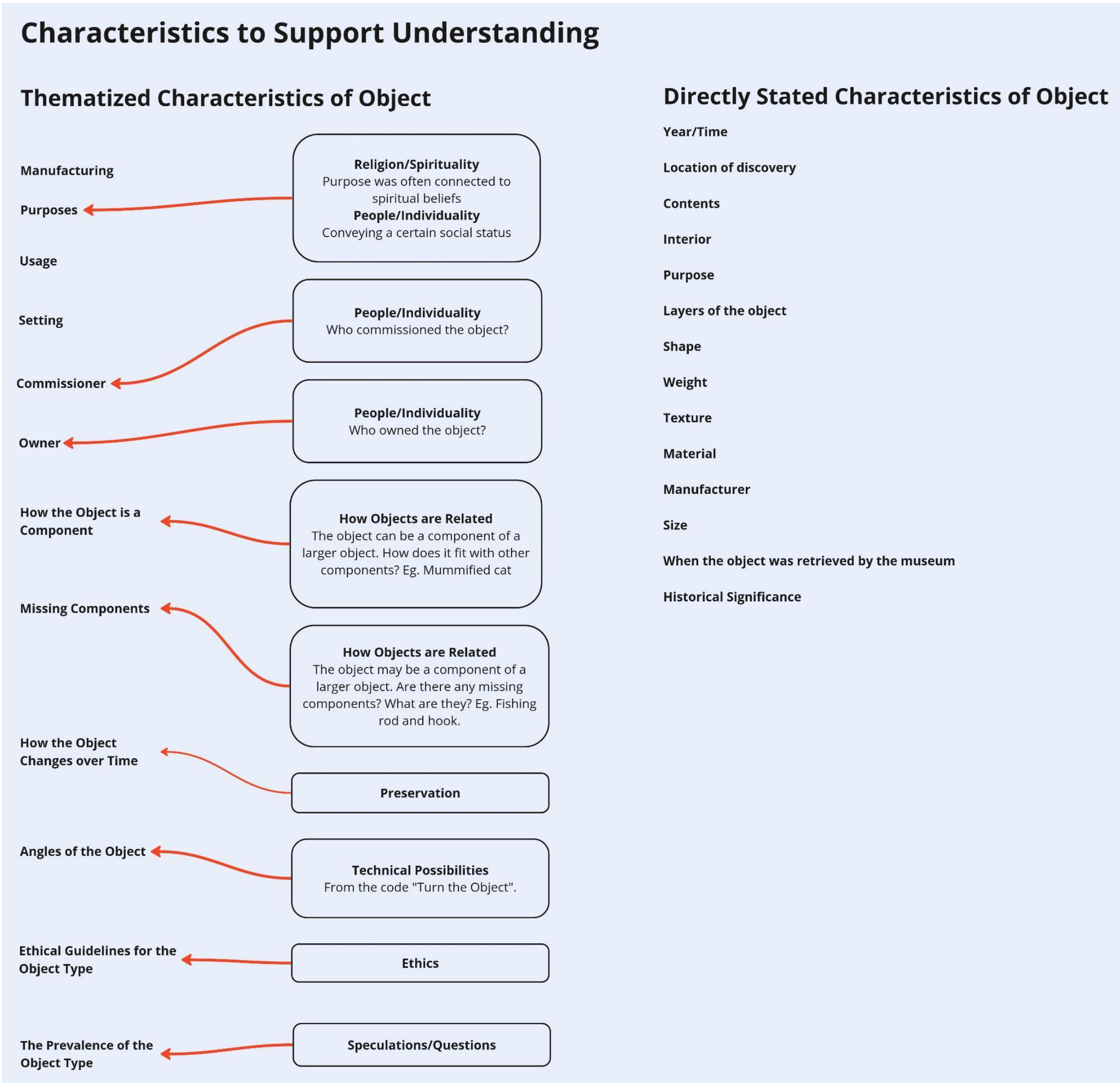

Figure 10: The construct of the theme *Characteristics to Support Understanding*. The bold typeface texts in the frames are categories. The standard typeface texts in the frames are comments. The red arrows show from which categories the characteristics were defined.

To exemplify a few characteristics we provide a set of interview quotes. In the following two quotes by P2 and P5 the characteristic *How the object is a Component* is exemplified. In the interview with P5 the interview object was a coffin for a mummified cat. The third quote exemplifies the characteristic *Missing components* and P10 was interviewed about a fish hook, for reference.

"It would be cool if you could do like a diagram or something of what the inside would look like, kind of how it would all fit together." -P2

"How do these mummified cats fit into this coffin" -P5

"I would then like to see what they most likely looked like when they did it and then how they look with those things and then maybe the rest of the fishing rod". -P10

In the next three examples the characteristics *Setting* and *Manufacturing* are exemplified. In part, we defined the characteristic *Setting* based on the first two quotes by P12 and P5. The third quote by P3 exemplifies *Manufacturing*.

For reference, P12 was interviewed about a false door from a tomb, P5 about a coffin for a mummified cat and P3 about a set of dice.

"The display can be a little bit more like what it should look like in the real tombs." -P12

"But yeah, how the graves were in their absolute intact form. That would be cool to see." -P5

"Yeah but like how they… but how you achieve the patterns. I mean, you can guess your way to how they achieved the number patterns and all but that information is not available. That would have been interesting". -P3

Lastly, we present two quotes that exemplify multiple characteristics. In the first quote P5 is interested in both *Manufacturing* and *Setting* and even mentions auditory feedback (which is included in the technique *Multisensory feedback* in the next section). P5 was interviewed about a coffin for a mummified cat. In the second quote P10 is interested in both the *Manufacturer* and the *Usage*. P10 was interviewed about a pair of fish hooks.

"But if it felt more like you were at the place where this, these things were from the beginning. And it felt like you were in one of those tombs and saw them at their like, original right place. And the way they installed it. That would be interesting. And with the sounds one perhaps would be surrounded by". -P5

"Maybe who made them? If you were someone who specifically worked with just making fish hooks or if maybe they made them themselves, like those who fished. Like how they were used, if special fish were used for them and they had other hooks for other fish". -P10

4.3.4 Techniques to Support Understanding

In addition to the final theme *Characteristics to Support Understanding* the analysis also resulted in the final theme *Techniques to Support Understanding*. The techniques in this theme were defined similarly to how characteristics were defined in *Thematized Characteristics of Objects*. Participants described various techniques that according to them could help them gain understanding of the object. These could be techniques for understanding the information already available to them better, or techniques for understanding information that was not available to them (information they felt was missing). As with the characteristics in *Characteristics to Support Understanding* the techniques in this theme were defined from single categories, multiple categories or combined codes (for example, the technique *Estimating Missing Characteristics* combined multiple codes from the category *Reasoning/Interpretations*). One technique, namely *Layers of Information*, included a number of aspects regarding the information, for example its detailedness and complexity.

In addition to the defined techniques for understanding the object, we added a comment based on the category *Reflections on/for Museums*. This comment states that a person's technique for understanding a museum object can depend on context, for example who they are visiting the museum with and how much time they have to spend in the museum. This was written as a reminder that all defined techniques are affected by the context. Figure 11 depicts a screenshot of the theme *Techniques to Support Understanding* in Miro, demonstrating how it was constructed.

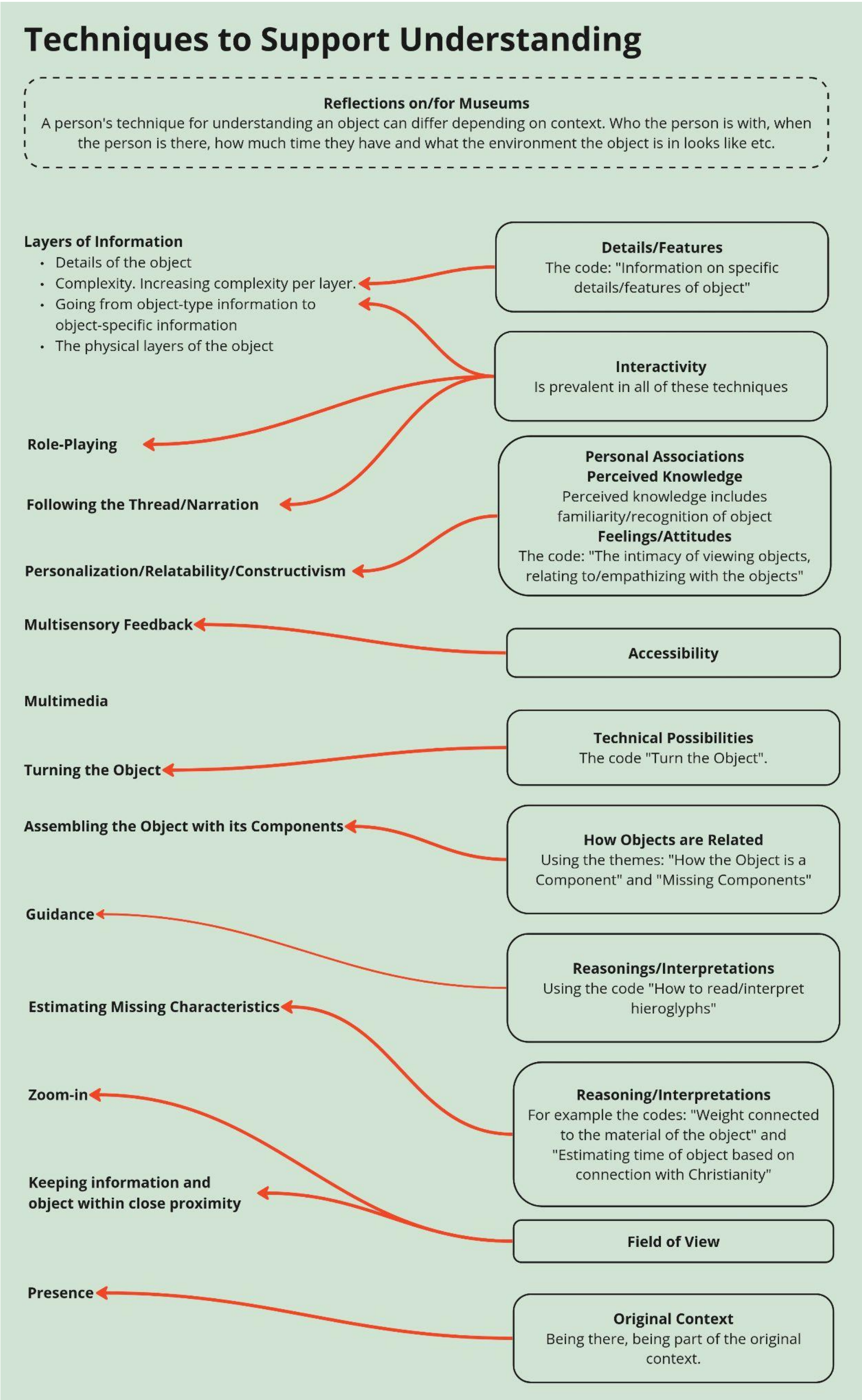

Figure 11: The construct of the theme *Techniques to Support Understanding*. The bold typeface texts in the frames are categories. The standard typeface texts in the frames are comments. The red arrows show from which categories the techniques were defined.

What follows are a set of quotes from the interview data exemplifying a number of techniques. In the first three quotes the participants are exemplifying the technique *Layers of Information*.
"...here I would otherwise like to have a lot of information about the different layers [...] So, that's why I thought the screen was one of those I could like see an understanding in a simple…" -P7

"It can get weighed down by the facts and at the same time speak of material and deepen the religion aspect." -P9

"That you go through and get to see different layers and get to see like, get a different understanding of what is inside the wrappings and [...] it can be the case that, there can be a small thing somewhere that it doesn't say much about, but there must be a lot more knowledge about these particular things. It's about maybe getting to choose how much you assimilate around something. As I said, if you're a person like me that preferably reads everything then it can get a bit much". -P4

In the following quote P12 exemplifies the technique *Role-Playing*. P12 was interviewed about a false door from a tomb. In the same display there was a bird which is the bird P12 is referring to in the quote. The wishlist that P12 speaks of is a reference to the hieroglyphs on the false door.

"To be the bird. Or if you're a character maybe that you're the king and then you get to like see what you're doing and then all the important things or what you want as a wishlist and how you make that". -P12

In the final four quotes the technique multisensory feedback is exemplified.

"For me it would be texture to be able to feel and see the actual textures across the object. Very interesting." -P11

"...makes it so you are in some way assimilate it more. Especially if there is both, both sound and text." -P8

"Yeah, feel things. Getting to experience that sense". -P3

"And with the sounds one perhaps would be surrounded by". -P5

4.4 Triangulation

The characteristics from both *Directly Stated Characteristics of Objects* and *Thematized Characteristics of Objects* were triangulated with the metadata associated with the interview objects in the Carlotta database. Firstly, we searched for each interview object in the database and documented its metadata (from the database) in a list. Duplicates were removed. This resulted in 59 types of metadata. Six of these were unclear and we emailed the database personnel and asked them to clarify. The most relevant answer we received was that the data had been previously stored in a different database in English, so in the current database metadata was at times listed twice but in different languages (Swedish and English). Also, for the metadata *Dimensions* three values were expected: height, width and depth. However, sometimes the word length was used instead of the word depth.

Secondly, we matched the characteristics with the database metadata. 10 characteristics did not match with any database metadata. These were:

- Angles of the Object
- Commissioner
- Ethical Guidelines for the Object Type
- Historical Significance
- How the Object Changes over Time
- Interior
- Manufacturer
- (Original) Owner
- Texture
- Weight

However, *Angles of the Object* could be found in the images of the object in the database. Out of the 15 characteristics matching database metadata eight of them matched the metadata *Description*. This does not mean that for every object's *Description* metadata these eight characteristics could be identified. Rather, it means that for some objects, often only one, the characteristic was mentioned in the *Description* metadata. In appendix E a table of all database metadata and matched characteristics is available. The following are examples of the *Description* metadata for a corn mummy and a pair of fish hooks respectively, both of which were interview objects. The first description contains the characteristic *contents* and the second contains the characteristic *manufacturing*.

"Coffin in the shape of a falcon. The coffin contains an Osiris shaped pseudomummy. A so-called corn mummy." (Carlotta, n.d.)

"Fishing hook carved from a mussel shell." (Carlotta, n.d.)

The results of the triangulation highlighted the level of informativeness from certain types of metadata. In the examples above the *Description* metadata contains the characteristics *contents* and *manufacturing*. However, the information one can extract about the characteristics based on the description is quite limited. This is also the case for certain other types of metadata, for example *Country - Findspot*. As seen in appendix E this metadata was matched with the characteristic *Setting*. The name of a country might give a person an idea of what the setting of the object was, but the information is limited to whatever the person knows about the country from memory. It is also not specific.

4.5 Selection of Characteristics

The last step in the analysis was to select characteristics for implementation in a prototype. This selection was made based on which characteristics could contextualize the object more in VR than in a 2D interface or a physical museum environment. We used a prioritization matrix in the selection process. The x-axis represented the characteristic's relevance to the research problem and the y-axis represented its technical feasibility. Figure 12 shows the results from this selection process.

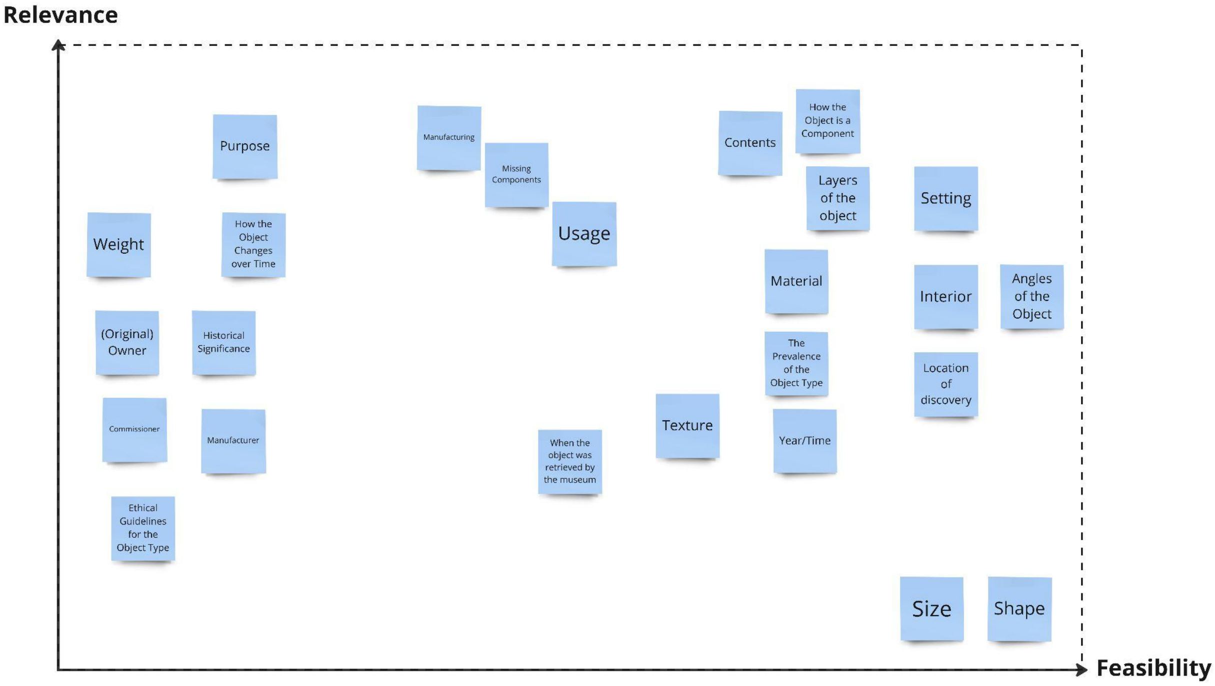

Figure 12: The results from the selection of characteristics for implementation.

The weight of an object is notoriously challenging to replicate in VR and therefore it was determined to be of low technical feasibility. *Owner*, *commissioner* and *manufacturer* were deemed unfeasible because they would require skills in 3D-modeling which we do not have. Our reasoning was that to visualize the commissioner we would need a person in VR which was difficult for us to create. *How the Object Changes over Time* was deemed unfeasible because of resource scarcity - we were unlikely to find 3D objects depicting the same object in different stages of decay. Both the *Historical Significance* and *Purpose* were deemed unfeasible because they would increase the size of the VR project. We would either need very specific 3D-models or to create them, and then code their interactivity. *Ethical Guidelines* was a characteristic that lacked sufficient data to be of relevance. *Size* and *Shape* were deemed feasible but not relevant. These characteristics can easily be observed in a physical museum setting.

The results showed that the following characteristics were highly feasible and highly relevant:

- Setting
- Layers of the Object
- How the Object is a Component

5 Design and Implementation

In this section, we describe the process of designing and implementing the prototype. The purpose of this prototype was to demonstrate how the selected characteristics can be visualized in VR to support users' understanding of a search result as a 3D object. At the end of this section, we include the results from an interactive demonstration. During one day we asked four people at DSV to participate in the demonstration of the prototype and provide feedback on it. The participants interacted with the prototype and their feedback on the experience is presented in this section.

5.1 Selected Object

The object selected for conveying the characteristics is a musical instrument, specifically a drum and its drumsticks. Figure 13 shows the object. The drum was created during the 20th century and it is from Nigeria. Its 3D counterpart was retrieved from The Małopolska Virtual Museums (n.d.).

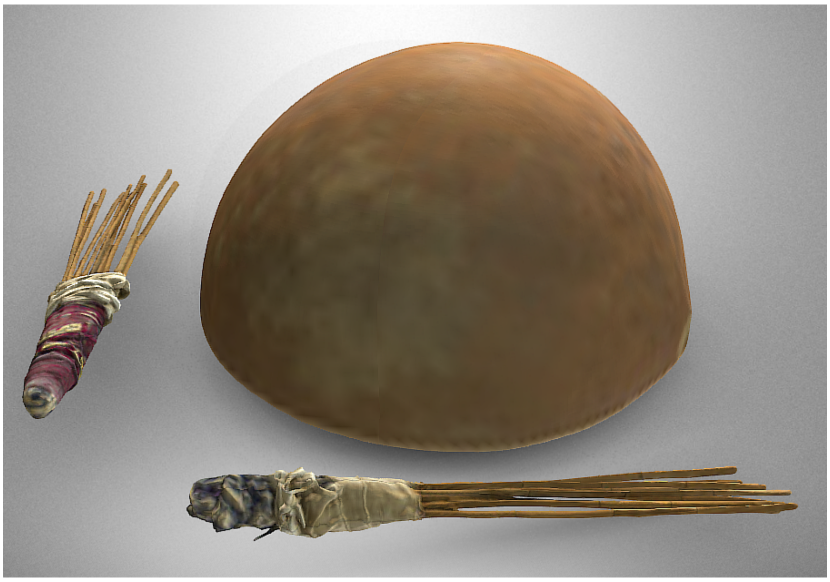

Figure 13: The object selected for conveying the characteristics. It is a musical instrument, specifically a drum and its drumsticks (The Małopolska Virtual Museums n.d.).

5.2 Selected Techniques and Updated Characteristics

Following the object selection we explored the design space through brainstorming. By iteratively refining the design ideas it became clear that the selected characteristics from 4.7 needed updating. We chose not to visualize the characteristic *Layers of the Object* because the object we had selected did not have multiple "physical" layers in the 3D scanned version. The characteristics *Manufacturing*, *Usage*, *Angles of the Object* and *Size* were included in the selected characteristics. During the selection process, we were uncertain whether visualizing *Manufacturing* and *Usage* required simulating humans. That is why they were deemed less feasible than the originally selected characteristics. However, during the brainstorming, we found that these could be visualized without simulating humans. *Angles of the Object* and *Size* were unforeseeably visualized during the design and implementation, which we regarded as a positive consequence. The following is a list of the updated characteristics visualized in the VR prototype:

- Setting - Location
- Manufacturing
- Usage
- How the Object is a Component
- Angles of the Object
- Size

The selected techniques used to visualize these characteristics are:

- Layers of Information
- Multisensory feedback
- Following the thread/Narration

Multisensory feedback could be simply implemented using audio and haptic feedback. *Layers of Information* was highly prevalent in the data and was therefore given priority in the prototype. The use of *Following the thread/Narration* as technique was unforeseen, and occurred naturally as the technique *Layers of Information* was used. We return to this topic in 5.4 Visualizations. This unforeseen use of *Following the thread/Narration* was regarded as a positive consequence.

5.3 Tools

Meta's Oculus Quest 2 was used for this project, which consists of two controllers and a VR headset. The Oculus Quest 2 was used with Unity for developing the prototype. Unity is a 2D and 3D content creating software (Unity n.d.) that allows one to create VR simulations and experiences.

5.4 Visualizations

In table 2 we present each selected characteristic and a description of how they were visualized. These visualizations are the results of our brainstorming sessions. For each characteristic, we conducted a five minute brainstorming session to generate ideas on how it could be visualized, with each of the two researchers in this study as participants. We had selected a 3D object before the sessions and therefore the ideas were generated with this object in mind. After each session, we presented and discussed the ideas and selected one based on how well it could contextualize the object and in turn support understanding of it. For each description, we also include a reference to its corresponding figure. The figures are presented below table 2.

Characteristic	**Visualization**
Setting - Location	Planet Earth as a virtual object in VR. Nigeria was pinpointed in the correct location on continental Africa. See figure 13.
Manufacturing	A virtual Calabash tree with a Calabash fruit hanging from it. The fruit could be taken apart which resulted in the drum. See figure 14.
How the Object is a Component	The fruit could be taken apart and put back

	together again. The drum was therefore a component of the fruit. See figure 15.
Usage	The drum could be played in VR by striking it with its drumsticks. See figure 17.
Angles of the Object	The drum could be rotated. See figure 16.
Size	The drum was true-to-size. See figure 17.

Table 2: A description of how each characteristic was visualized, with references to the descriptions' corresponding images.

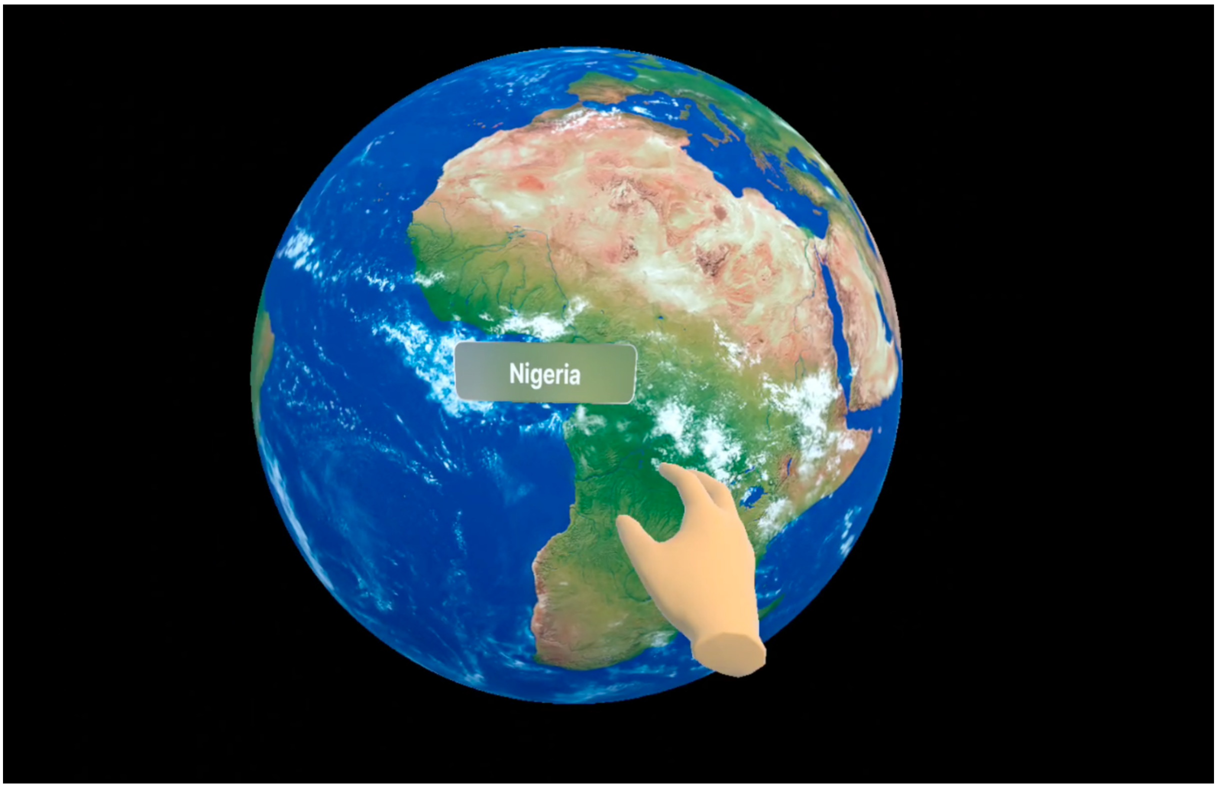

Figure 14: Planet Earth as a virtual object in VR. Nigeria was pinpointed in the correct location on continental Africa. This was the visualization for the characteristic *Setting*.

Figure 15: A virtual Calabash tree with a Calabash fruit hanging from it. The fruit could be taken apart which resulted in the drum. This was the visualization for the characteristic *Manufacturing*.

Figure 16: The fruit could be taken apart and put back together again. The drum was therefore a component of the fruit. This was the visualization for the characteristic *How the Object is a Component*.

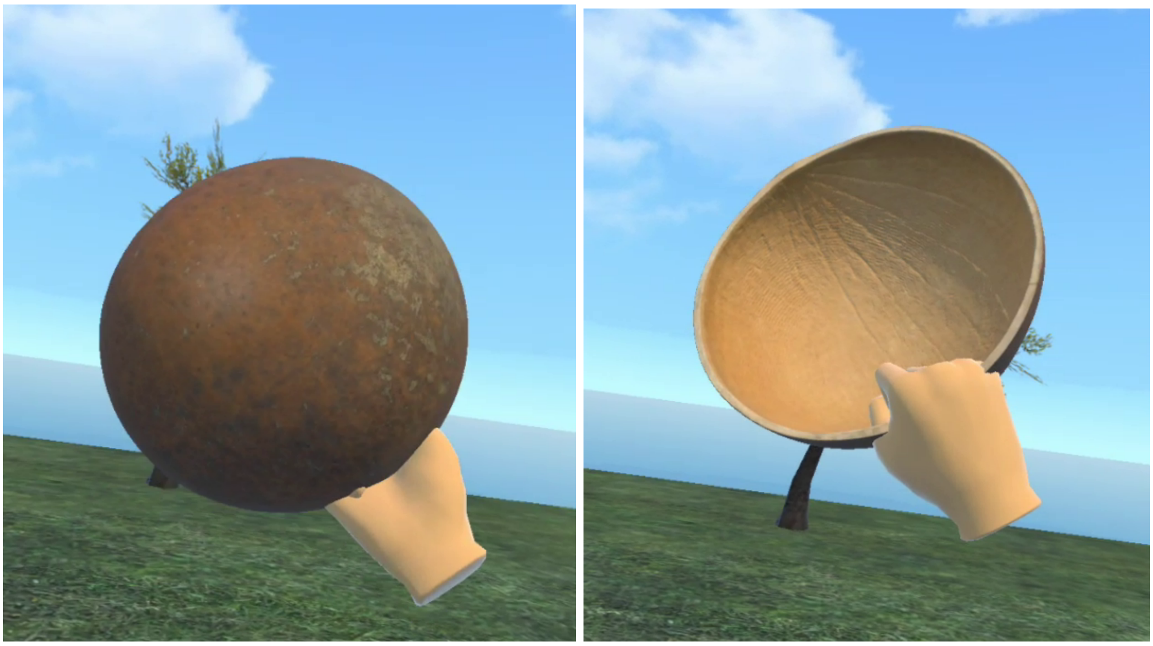

Figure 17: The drum could be rotated. This was the visualization for the characteristic *Angles of the Object*.

Figure 18: The drum could be played in VR by striking it with its drumsticks. This was the visualization for the characteristic *Usage*. This figure also exemplifies *Size*.

Multisensory feedback was used as a technique to visualize *Usage*. While striking the drum with its drumsticks, the user could hear the sound it produced and feel vibrations in their hands (VR controllers). The technique *Layers of Information* was employed by segmenting the VR experience into three "layers". In the first layer, the setting of the object was visualized, i.e. the location. In the second layer, *How the Object is a Component* and *Manufacturing* were visualized. In the third layer, *Usage* was visualized. *Following the thread/Narration* was used as a technique in the sense that there was a connection between the different layers and each layer built on its previous one. For example, after having clicked the country Nigeria on Earth (layer 1), the user was in a garden of calabash trees in Nigeria (layer 2). Not intentionally designed for in the layers, *Size* was visualized when the user could see the drum in relation to other objects and *Angles of the Object* was visualized as the user could rotate the drum.

5.5 Implementation

The implementation of the prototype was carried out using the Unity package XR Interaction Toolkit, along with objects obtained from the Unity Assets Store and Sketchfab. The prototype featured a VR environment where the controllers were represented as virtual hands for interacting with objects. The user could navigate within the virtual space either by physically walking or by using the joystick on the controllers.

The prototype consisted of two scenes in Unity. The first scene shows planet Earth, accompanied by a button labeled "Nigeria." The Earth globe object was sourced from the Unity Assets Store, while the button was created using Figma, which is a tool for designing interfaces. When pressing the button labeled "Nigeria," the user transitioned to the second scene, which shows a grass field covered with calabash trees, with one tree including a calabash fruit. The grass field was a plane object with a grass texture. This texture, together with the tree and fruit objects, were sources from Sketchfab. Within this second Unity scene, the user could interact with the fruit.

The fruit object was actually three objects: the first was the green fruit and the second and third objects were two drums inside the fruit. By reaching out their virtual hand towards the fruit, users could hear the word "Calabash," indicating the name of the fruit. Users could then grasp one of the drums. Once the user grasped the drum, a table with two drumsticks appeared in front of the user where the user could place the drum. The user could then pick up the drumsticks and use them to strike the drum. For every strike to the drum, an audio file was played with a drum sound and the controller vibrated.

5.6 Interactive Demonstration

The prototype was tested by four participants. Three participants were students in game development and one participant was a professor in human-computer interaction. All participants were affiliated with DSV and were recruited at DSV. They signed consent forms, available in appendix F. We started the demonstration by describing our study briefly and explaining that we were not testing the technical aspects of the prototype, but rather the visualization of the information, whether this supported users in their understanding of the object and how. The participants were aware before interacting with the prototype that the object in question was a drum and its drumsticks. We provided them with guidance on how to use the controllers and asked them to think aloud while interacting with the prototype. The participants' interactions with the prototype were video-recorded through the VR headset. After their interactions, we asked them two main questions and audio recorded their answers. The two main questions were: “What can you know about the drum?” and “Considering that we are studying how well these visualizations can support users' understanding of the object, is there anything you think was missing from the prototype?”. Using the recordings, we wrote down the key points from the demonstration. They are available in table 3.

Participants’ Comments	**Our Comments**
What you can know about the object	

The drum is made from a fruit that grows on a tree.	Only one participant knew the drum was from Nigeria.
The drum can produce sounds by striking it with its drumsticks.	
Size of the drum.	By comparing the size of the drum to the size of oneself in the VR environment.
How it feels to play the drum.	
The fruit was hollowed out and dried to manufacture the drum.	Because the drum is hollow and it has a darker color than the fruit
The fruit is divided in half to manufacture the drum.	
What is missing	
Difficult to know which side is up and which is down.	
How information is prioritized and what is of high or low priority.	
Which time period the drum is from	
Context of use. How the context is connected with the drum.	
Who the original user was.	
Similarity between the information about the location (Nigeria) and the environment with calabash trees and grass.	There is a discrepancy in the setting. The environment did not match the participants expectations.
What type of fruit it is.	One guessed a pear and one guessed a coconut.
Which country the drum is from.	Unclear to two participants.
Technological Challenges	
There is a learning curve in using the controllers. The focus on how to use the controllers can get in the way of the main task of finding information about the drum to gain understanding of it.	
Speculations	
The drum likely has other usages. For example, if it is rotated it looks like a bowl that can be used for cooking.	

There is likely a tremendous amount of information about the object that is missing from the prototype.	
Additional Comments	
One participant described an interest in seeing the drum's original user use it. The participant pointed out that although she was a user of the drum in the prototype, she lacked information about the original user.	

Table 3: The key points from the demonstration.

6 Discussion

This section discussed the answer to the research question, the use of RtD as an approach, the study's ethical and societal implications and its limitations in terms of validity and reliability. This study's research question is: "How can descriptive metadata of a 3D search result object be visualized in VR to support users' understanding of the object?". The VR experience can be segmented into different layers of information to support understanding of an object. Importantly, the sequence in which the layers are presented need to provide a coherent narrative to the user. To support understanding, metadata related to how things work and how they are related can be visualized. Examples include visualizing how the object was manufactured, how it was used and how it fits with other components. Concerning the design practice of visualizing metadata in VR, designers should use exploratory ideation methods that allow them to see how their visualizations can embed multiple metadata.

6.1 Metadata

The definition of metadata is, according to Gartner (2016), a subjective construct to communicate information for a specific purpose. They can be communicated in different ways to help people understand the content (Gartner 2016). The characteristics we have worked with may not in all cases be listed in the Carlotta database, but, in line with Gartner's definition, they are metadata.

6.2 Unforeseen Design and its Implications

Throughout the design process, we discovered that characteristics that were not originally selected for implementation due to their infeasibility were, actually, technically feasible if we rethought the design. We regarded this as positive outcomes of the brainstorming sessions. Similarly, the use of *Following the thread/Narration* in addition to *Layers of Information* was regarded as an unforeseen positive consequence of the design. However, these two techniques are, to a degree, in conflict with each other. The particular sequence in which the layers of information were presented created a narrative in the sense that the events (layers) were connected with each other. During the design process, we reflected on whether we could reverse the sequence in which the layers were presented. That would have resulted in the following sequence: visualizing *Usage* (layer 1), visualizing *How the Object is a Component* and *Manufacturing* (layer 2) and visualizing the *Setting* (layer 3). This was deemed problematic because the manufacturing process would be reversed. In 1.1 Background we wrote that the metadata contextualizes the object and can support user's understanding of it during the search process, but with our final sequence for presenting the layers, the metadata is decontextualized because the object is missing. Had we not informed the participants in the demonstration that the selected object was a drum and its drumsticks, they would not know what the metadata visualizations were in reference to. This is also problematic in terms of the design's extensibility. According to Zimmerman, Forlizzi and Evenson (2007, p. 500), "[e]xtensibility is defined as the ability to build on the resulting outcomes of the interaction design research". They describe this quality as a criterion for evaluating interaction design research (Zimmerman, Forlizzi & Evenson 2007). If our design for *Layers of Information* was extended to virtual museums, visitors might see metadata that is in reference to different objects, and not know which object they were in reference to until layer 3.

6.3 The Search Process

In 2.1 Searching in VR, we describe a general description of the search process as follows: “(a) Identification of an information need (b) Selection of information sources (c) Query formulation (d) Sending the query to the system (e) Getting results in the form of information items (f) Examining, interpreting, and evaluating the results (g) Reformulating the query or stopping the searching” (Karwowski, Rizzo & Rodrick 2003, p. 187). In our prototype, the information item in phase (e) is represented as a search result in the form of a 3D object. For examining and interpreting the result (object) in phase (f) we provide users with metadata in the prototype. The metadata can be used to examine and interpret the object. We conducted an interactive demonstration with participants as an informal evaluation of the prototype. The data from these demonstrations show that participants struggled with identifying Nigeria as the original location of the object. The process of manufacturing and usage, however, was clear. As such, the results indicate that our prototype lacked support for users’ interpretation of the setting metadata. Based on the demonstration comments, we suggest three improvements to the design that could help support users in this phase of the search process. These suggestions are highly influenced by the specific design of and selected characteristics in our prototype: a) Connect the location with the environment by employing the technique *Following the thread/Narrative*. Give users the sense that they are traveling to the location, b) strive for a balance between the user’s expectation of what the setting is like and what it is actually like to reduce discrepancy between the two and c) give users time to identify where they are and preferably let them reason their way to an answer instead of simply providing the answer through, for example, a label.

6.4 The Role of VR in Information Seeking

The results from 4.6 Triangulation highlighted the level of informativeness from certain types of metadata in the database. While some metadata could be effectively communicated through text, for other metadata the information one could extract from the text was quite limited. Examples of alternative ways of visualizing these metadata are by using images and audio. Using VR technology is not necessary to communicate images and audio, but it can be used for that. VR goes beyond those mediums and offers immersive functionality through embodiment equipment such as head-mounted displays, providing users with the opportunity to physically engage in psychological immersion (Fan, Jiang & Deng 2022). In turn, users of VR can, for example, hold objects, rotate them, put them together and experience them in different environments. Neither 2D displays nor museums with the object placed in a glass display offer these interactive possibilities, and they may be more useful during search in VR.

6.5 An Understanding of the Object

In 2.6 A Definition of Understanding we provided definitions of data, information, knowledge and understanding, and explained how a person moves from one level to another. Gartner (2016, p. 11) writes that “[i]nformation allows us to answer such pithy questions as “who?”, “what?”, “when?” or “where?”. Knowledge allows us to answer “how?”, particularly “how things (concrete or abstract) work?”. Understanding allows us to ask “why?”, particularly “why are things the way they are?””. In these terms, our demonstration results show that the participants could primarily extract knowledge about the 3D object. For example, participants knew how the object is manufactured and how it is used. Regarding the level of understanding the demonstration results show that participants assumed the object could be used in other ways than as a drum, for example as a bowl if rotated. This hints at an answer to the question “why is the object used as a drum?, with the answer being related to its rotation. We can also see that one participant was missing a prioritization of what information is important. The prioritization of information depends on what question one wants to answer. If the question is "why is this drum of historical significance?", then finding an answer is difficult with single visualizations of characteristics. Perhaps the relationship between these characteristics, the object's purpose and its similarities with objects from today need to be conveyed. If so, a more creative approach of allowing users to piece together information may be preferable to merely providing users with the information, as the system then guides the users to ask their own questions. Mondado (2010) explains that understanding is contextually bound to ongoing action. Studying how these actions (piecing together information) reflect users' understanding of the object (why this drum of historical significance) calls for investigating how the context (metadata) mediates this relationship. Given this, future studies building on ours could investigate how metadata visualizations mediate the relationship between users' understanding of a search result as an object and their actions in a VR experience.

6.6 The Use of Research Through Design

In RtD, "design researchers focus on how design actions produce new and valuable knowledge. This knowledge can take many different forms including novel perspectives that advance understanding of a problematic situation; insights and implications with respect to how specific theory can best be operationalized in a thing; new design methods that advance the ability of designers to handle new types of challenges; and artifacts that both sensitize the community and broaden the space for design action" (Zimmerman & Forlizzi 2014, p. 168). An example of a novel perspective that may help understand a problematic situation is the *Layers of Information* sequence dilemma as described in 6.2 Unforeseen Design and its Implications. Regarding the operationalization of theory in a thing, we return to the search process. Karwowski, Rizzo and Rodrick's (2003) general description of a search process is a summary of multiple theories of the search process from decades of research in information seeking (Liu et al. 2021). We operationalize the specific phase of the search process in which a person examines and interprets results. This is operationalized in VR by providing metadata as tools to interpret the 3D object, and we visualize these tools in alternative ways than through text. Zimmerman and Forlizzi (2014) write that, in RtD, design researchers may use new methods to produce new knowledge. We do not use new methods in the study but rather employ conventional research methods and design practices in combination. The authors also write that the method may be used to "broaden the space for design action" (Zimmerman and Forlizzi 2014, p. 168). Our study has broadened the design space for metadata visualization by proposing a design that highlights questions that have not yet been asked in this new field of research. For example, what is the most useful way of visualizing metadata in VR search and how is this mediated by the use case, i.e. the search task?

The benefits of RtD are that it allows design researchers to "identify opportunities for new technology or for advancements of current technology [which provides] research engineers with inspiration and motivation for what they might build [,...] undertake problem framing that helps identify important gaps in behavioral theory and models [and also] discover unanticipated effects and provide a template for bridging the general aspects of the theory to a specific problem space, context of use, and set of target users" (Zimmerman, Forlizzi & Evenson 2007, p. 497). To apply this to our study, the benefits of our research are that we have identified opportunities for the design of metadata visualization in VR to support understanding of the data by highlighting the limitations of what conclusion we can draw (see 6.5 Understanding of the Object). The unanticipated effects of the design process were focused on the sequence of *Layers of Information* and the prevalence of characteristics not intentionally designed for.

6.8 Ethical and Societal Consequences

VR equipment is expensive, which can create a financial barrier. This can limit access to VR to a privileged group that can afford these technologies. This raises ethical concerns about inequality and exclusion, as not everyone has equal opportunities to explore the virtual world. Furthermore, VR can provide an alternative way of experiencing museums, particularly for individuals facing physical or geographical barriers. VR can potentially change the museum experience by allowing people to visit museums from anywhere in the world virtually. However, the usage of VR technology requires financial resources, which can be challenging for museums that rely on funding as it requires allocating resources for equipment, development and maintenance, potentially impacting other areas of museum operations. This is of particular concern in countries where museums generally receive public funding, as it becomes a question of how the people's taxpayer money is spent. In Sweden, museums tend to fluctuate between being publicly and privately funded, depending on political leadership. In countries such as Germany (Berlin.de 2021) and France (Pauget, Tobelem & Bootz 2021) museums are generally publically funded.

Furthermore, VR experiences heavily rely on visual elements, which make them inaccessible for individuals with visual impairments. Consequently, an ethical concern arises from the imperative to ensure equal access and opportunities for all individuals.

6.9 Limitations

This master thesis is 16000 words long, despite the limit being 10000 words. We acknowledge that we exceeded the word limit recommendation but it was justified. We included a major section called 5 Design and Implementation which is not in the thesis requirements, but necessary for this study. Sections about the prioritization matrix and triangulation were also included which extends the thesis word count. The limitation is that the word count exceeds the limit, but it was necessary in order to report on the study.

6.9.1 Validity

According to Denscombe (2014), maintaining validity in qualitative data can be challenging. One challenge is the inability to replicate a social environment, making it difficult to ensure that the observed situation is representative of reality. Consequently, the validity of qualitative data cannot be guaranteed. Denscombe (2014) writes that qualitative data often relies on extensive previous research. For this study, there was a lack of previous research in the area of metadata visualization and human information interaction in VR, and this is considered a limitation in terms of this study's validity.

Another challenge mentioned by Denscombe (2014) is the risk of qualitative data being taken out of context. This occurs when individual words or sentences are isolated without considering their original context. Researchers may then form their own interpretations based on incorrectly represented views of the participants. To address this issue, the presentation of results should incorporate tables, figures, and quotes to reflect the original context accurately (Denscombe 2014). We included tables, figures and quotes in the presentation of our results in line with this suggestion, with the quotes being the main source of context.

6.9.2 Reliability

While the use of strategies associated with ICR, such as dividing the dataset and coding between researchers, strengthens the reliability of the findings, it is not guaranteed that the study can be replicated to produce the same results. It is important to acknowledge the presence of certain factors that may impose limitations on the reliability of our findings. One factor is the subjective nature of qualitative analysis. Qualitative research involves the interpretation and understanding of data, which can be influenced by researchers' perspectives (Denscombe, 2014). Nonetheless, it is worth noting that the findings are derived from evidence gathered in a real-world setting, thus strengthening the reliability of the study (Denscombe, 2014). Moreover, the study's reliability is further strengthened by the transparency of the analysis process, particularly through the application of data collection methods and the presentation of the results.

7 Conclusion

This study's research question is: "How can descriptive metadata of a 3D search result object be visualized in VR to support users' understanding of the object?". The answer is: by segmenting the VR experience into different layers of information, specifying a sequence in which the layers are presented that builds a narrative and provides users with multisensory feedback.

Regarding users' understanding of an object in VR, we encourage future studies to evaluate the strategies' supportiveness. This is because our demonstration was quite an informal evaluation and indicated that users could extract knowledge about the object but only a limited level of understanding. These evaluative studies can take comparative approaches and evaluate the level of support in users' understanding of an object when the metadata is visualized as text versus through alternative visualizations. We also encourage future studies on how to group visualization techniques with categories of metadata in order to find which techniques are optimal for which metadata to support users' understanding of informational objects in VR. Lastly, future studies can investigate how metadata visualizations mediate the relationship between users' understanding of a search result as an object and their actions in a VR experience.

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Appendix A – Interview Guide

Interview Guide in English

Documentation: Audio recordings
Time: 10 minutes

What to say before:
Thank you for participating in the study.
There are no right or wrong answers.
We have not studied these objects beforehand so we know little about them ourselves.

1. What brought you to the museum today?
2. This object in front of you, can you please describe what you see?
    a. Are there any features of the object that catch your eye, that you find interesting?
    b. What associations do you make when you see the object?
3. The information on the sign, how does it help you gain understanding about the object?
    a. What can you know about the object's purpose or function?
        i. What would you need to understand that better?
    b. What can you know about the object in relation to the historical time period?
        i. What would you need to understand that better?
    c. What can you know about the object's value? Why it is in this museum?
        i. What would you need to understand that better?
4. If you disregard what can be written on a sign, what could help you gain an understanding of the object? What more could you know?
    a. How? Why?
    b. Example:
        i. If you could hold the object, take it apart, rotate it.
        ii. If you could renovate this room.
        iii. To understand how the object was used in its original context.

Appendix B – Consent Form for Interviews

Participant's pseudonym:

Consent Form for Participation in a Research Study

Purpose of the Study

This study explores how metadata of objects can be visualized in virtual reality. Virtual reality is a technology that allows users to feel immersed in a 3D virtual environment. The Metaverse is an example of virtual reality. In this study metadata is defined in terms of information about objects, such as the artist (information) behind a sculpture (object). Usually this type of information is available in text, but this study explores alternative ways (visualizations) to communicate this type of information.

Procedures

The study collects data through interviews with participants. The interviews are expected to take approximately 10 minutes.

Risks

There are no known risks involved with participation in the study. Participants can choose not to respond to interview questions or cancel the interview at any time. After you sign the consent form, you are still free to withdraw your consent at any time and without giving a reason.

Handling of Data

Data is collected through audio recordings. The data will be analyzed and used for research purposes. Each participant is assigned and provided with a pseudonym that will be used to distinguish between answers in the data analysis and resulting publications. These identifiers are completely anonymous and cannot be linked to any individual in the study. The audio recordings are only used for analysis and will not be published. If you withdraw your consent from the study before the data collection is completed, your data will be returned to you or destroyed. You can withdraw your consent by contacting the researchers and state your pseudonym.

Contact Information

The study is carried out by Stella Millwood and Leo Nordén as part of their Master thesis in Human-Computer Interaction at the Department of Computer and Systems Sciences at Stockholm University.

If you have questions at any time about this study, you can contact the researchers through one of the following email addresses:

Stella Millwood: stella.millwood@dsv.su.se   Leo Nordén: leno0630@student.su.se

Consent

I have read and understood the provided information and have had the opportunity to ask questions and receive answers. I give my consent to participate in the study and am aware that my participation is voluntary. I am aware that I am free to withdraw my consent at any time without providing a reason. I confirm that I am at least 18 years old.

Participant's Signature ________________________ **Date** _________________

Researcher's Signature ________________________ **Date** _________________

Appendix C – Analysis Codes

A guide is a good source of knowledge	Estimating time of object based on connection with Christianity	Morbid humor	Speculating on the original context
Age of object is fascinating	Ethical aspects of displaying deceased people as objects	Multisensory feedback	Statue not interesting to examine and take apart
App for listening to information	Ethical aspects of displaying other countries' cultural heritage	Museum environment	Stimulate multiple senses
Appreciating being able to learn about other countries' cultural heritage	Exciting	Museum is more accessible today than before	Stretching the object
Appreciating effort behind mummification	Exploring the original setting oneself	Narration	Sweden's role in other countries' cultural heritage
Appreciating effort in terms of time	Exploring the original setting from the perspective of a character/role/animal	Narration voice	Switching places - if that were my personal object then...
Appreciating how advanced the culture was	Familiarity/Recognition of object	Narration voice can support understanding	Symbolism
Associating material/decorations with historical time period	Fragility of object	Not learning anything new - confirming previous knowledge	Tactile feedback
Associating mummified animal with burying personal pet	Geographic accessibility	Object is detached from original context	Tactile memory
Associating mummified animal with personal pet	Geographical information missing	Object subject to studies	Take a piece of the object
Associating objects with socio-economic class	Historical significance not clear	Objects as symbols for social status of people from that time	Text can be inaccessible
Associating with similar artifacts from today	How an object's components fit together	Objects can give insight into the technological advancements of a culture	Texture
Assuming object is a replica	How hieroglyphs are composed	Objects/people that accompanied the object	The ability to ask questions

Auditory feedback	How the material changes over time	One object can be representative of other objects from that time	The commonality of this type of object
Behavior: either reading everything or almost nothing	How the object was used	Ornaments make the object stand out	The intimacy of viewing objects, relating to/empathizing with the objects
Being at the original site in the historical time	How the world has changed since the object's time	Peoples' ideologies	The intricacy is impressive
Being the archeologist - finding the features oneself	How to read/interpret hieroglyphs	Perceived lack of general knowledge of historical time	The object was used together with a different object
Blaming oneself for missing information	Impressed	Personally choosing information to gain understanding	The object's function
Posture and Angle	Impressed with objects condition/preservation	Positive toward connecting objects and their information with numbers	The value placed in spiritual practices
Calculating age based on year	Information from different museum's sources are repetitive	Prefer museums with old artifacts	Thoughts on efforts by museum curators
Choosing how much information to consume	Information on specific details/features of object	Presented information depends on curator	Time period of object
Chronological order	Interest in a country's cultural heritage is related to specific historical era	Previous knowledge	Time travel
Concept of object's original owner	Interest in images and films	Process of composition is interesting	Too much information can be overwhelming
Connecting fragments of information	Interest in learning about handicraft	Process of mummification	Too much information can hamper ability to follow the thread
Connecting religion/spirituality with emotions	Interest in more information on work process	Proximity between object and information	Too much information can hamper understanding
Connecting the effort in creating the object with values	Interest in moving the object around	Purpose	Turn the object
Connection between object and specific museum	Interest in object's original context	QR-code for more object-specific information	Using number to connect information on the sign with the object
Critical attitude toward condensing complex information	Interest in original intact setting	Regularly visits museums	Values interactivity

Curation	Interest in seeing the rest of the object - how it was connected to other objects	Religion/Spirituality	Was the object created for personal use or as a work task?
Curiosity of object's contents and interior	Interest in the object's aging process	Remembering the experience	Weight
Depiction is rudimentary	Interest in who used the object	Shape of the body after mummification	Weight connected to the material of the object
Difference in spiritual beliefs and practices then and now	Interpreting material based on surrounding artifacts	Shape of the object	Weight connected to the size of the object
Different layers	Intimidation - related to perceived level of knowledge on cultural history/specific era	Signs can give rise to new questions	What are the ethical guidelines?
Different objects can attract different age groups	Layers of the object	Signs help understand layers of the object	What the hieroglyphs mean/convey
Difficult to read the signs	Learning about a country's cultural history	Signs help understand purpose and contents	What was the original need for the object?
Difficult to see details of artifact	Learning about other cultures' heritage	Simple drawing of the interior	When the object was retrieved by the museum
Digital screen provides understanding	Limitation of signs - they just tell rather than show	Size of the object	Who created the object?
Discovery location interesting but missing	Location of sign - placing it in the field of view	Socio-economic class	Who you are visiting the museum with can affect your understanding of the object
Drawing conclusions based on size of the object	Matching the museum architecture with the collection	Speculating on condition of object inside tomb	Work process
Empathizing with mummified animal's owner	Material of the object	Speculating on the contents of the object	Year/Time not available
Enlivening the experience	Mindset of the creator	Speculating on the object's original condition	Year/Time of creation is interesting

Appendix D – Analysis Categories

Following the Thread/Narration
Manufacturing
Reflections on/for Museums
Speculations/Questions
Field of View
Interactivity
Purposes
Accessibility
Preservation
Reasonings/Interpretations
Usage
Ethics
Perceived Knowledge
Role-Playing
Characteristics of Objects
Multisensory Feedback and Multimedia
Personal Associations
Technical Possibilities
Setting
How Objects are Related
Accessibility
Interactivity
Context
Learning about Cultural History
People/Individuality
Layers of Information
Feelings/Attitudes
Details/Features
Religion/Spirituality

Appendix E – Database Metadata

This appendix shows metadata for the interview objects that were available in the Carlotta database (left column) and characteristics from the thematic analysis that could be matched with the database metadata (right column). We also include comments on what the database metadata are in reference to.

Database Metadata	**Analysis Characteristics**
Alternative id	
Acquisition Institution/who it was acquired from. Includes where that institution/person acquired it. If it was bought: Also includes price and where it was bought. Includes year and date sometimes.	When the object was retrieved by the museum
Acquisition, Swedish	
Acquisition number	
Context Findspot/Year/Tomb number. Usually the space the object was found in, for example a tomb or house.	Setting Year/Time
Comments Relevant comments including when and where it was x-rayed.	
Condition Whether there are any missing or damaged parts of the object.	Missing Components
Cf_Publications Can be specific or general references. The purpose is to refer the reader to references for similar objects.	
Country - Findspot	Setting Location of discovery
Country, Swedish - Findspot The country in which the object was found.	Setting Location of discovery
Description, Swedish	Purpose Usage The Prevalence of the Object Type Manufacturing Layers of the object Shape Historical Significance Contents
Description	Purpose Usage

	The Prevalence of the Object Type Manufacturing Layers of the object Shape Historical Significance Contents
Dimensions In centimeters: length, width, height and depth. Only three different dimensions are listed here, but it can vary whether they use length or depth depending on the object.	Size
Date - Printed	
Depth / Djup	Size
Exhibition, showcase	
Exhibition, showcase - Current Image of the current showcase displaying the object.	
Exhibition, Part of - Current The part of the exhibition that the object is currently in.	
Exhibition, Part of - Previously Image of part of the previous exhibition the object has been in.	
Exhibition - Current The current exhibition that the object is in.	
Exhibition - Previously Previous exhibition the object has been in.	
Egypt, Number in Exhibition The object number in the exhibition.	
Event - Was Present At	
Egyptenutställningen 2014, English - Label The text on the sign.	
Egyptenutställningen 2014, Swedish - Label The text on the sign.	
Geographic name, alternative Alternative geographic name for the city/region the object was found in.	Setting Location of discovery
Geographic name, alternative - Swedish	Setting Location of discovery
Height / Höjd	Size
Inventory number	

Keyword	
Loan in - Current Where it is currently loaned in and since when (year).	When the object was retrieved by the museum
Loan out - Previously Where the object was loaned to and when (year).	
Length / Längd	Size
Material	Material
Material, Swedish	Material
Name - Depicted The person the object depicts.	
Name, Acquired from Name of the person the museum acquired the object from.	
Name - Photographer Name of the photographer who took the image of the object in the database.	
Name - Owner The name of the owner can be an institution, for example the Nobel Foundation.	
NegNo The number for a negative photograph of the object. The number is searchable in the database. The number is, according to employees at Carlotta, presumably interchangeable with the metadata *PhotoNegNo*.	
Object Consists of keywords that describe the object. Can be clicked which leads to a search with that keyword.	
Object, Swedish	
Original register Which register the object was originally registered at. That information could also explain which museum the object once belonged to.	
Place - Findspot City/Region in which the object was found.	Setting Location of discovery
Period The span of time (years), also the name of the period.	Year/Time
Period, Swedish	Year/Time
Publications Usually scientific publications related to the object.	
Published text	

PhotoNegNo The number for a negative photograph of the object. The number is searchable in the database. The number is, according to employees at Carlotta, presumably interchangeable with the metadata *NegNo*.	
Photograph Number - Is Object Example For Link to an image that exemplifies the object. For example if the object is a door the image depicts the tomb that the door was originally in.	How the Object is a Component
Reference - Published in A book	
Serie nummer	
Title	
Title, Swedish	
Time - Manufacturing, earliest When the object was manufactured at the earliest.	Year/Time
Time - Manufacturing, latest When the object was manufactured at the latest.	Year/Time
Text1, Text2, Text3 Related to the metadata *PhotoNegNo*.	
Week - Object of the week When the object was the *object of the week* in the database. Year and month.	
Width / Bredd	Size

Appendix F – Consent Form for Demonstration

Consent Form for Participation in a Virtual Reality Demonstration as part of a Research Study

Purpose of the Study

This study explores how metadata of objects can be visualized in virtual reality. In this study metadata is defined in terms of information about objects, such as the artist (information) behind a sculpture (object). Usually this type of information is available in text, but this study explores alternative ways (visualizations) to communicate this type of information.

Procedures

Data is collected through a video-recording of the participant's interaction with the prototype and an audio-recording of the participant's comments after the interaction. The demonstration is expected to take approximately 10 minutes.

Risks

When using the virtual reality prototype there is a risk that the participant experiences dizziness or nausea, similar to motion sickness. If you experience these symptoms, you are encouraged to remove the headset and interrupt or stop the demonstration. The researchers will help with this if the symptoms occur.

Handling of Data

The collected data will be analyzed and used for research purposes. Each participant is assigned a pseudonym to be used in the analysis and resulting publications, and these are anonymous. The audio-recordings and video-recordings will not be published. If you withdraw your consent from the study before the data collection is completed, your data will be returned to you or destroyed.

Contact Information

The study is carried out by Stella Millwood and Leo Nordén as part of their Master thesis in Human-Computer Interaction at the Department of Computer and Systems Sciences at Stockholm University. If you have questions at any time about this study, you can contact the researchers through one of the following email addresses:

Stella Millwood: stella.millwood@dsv.su.se Leo Nordén: leno0630@student.su.se

Consent

I have read and understood the provided information and have had the opportunity to ask questions and receive answers. I give my consent to participate in the study and am aware that my participation is voluntary. I am aware that I am free to withdraw my consent at any time without providing a reason. I confirm that I am at least 18 years old.

Participant's Signature ______________________ **Date** ________________

Researcher's Signature ______________________ **Date** ________________