

Article

Increasing Access to Cultural Heritage Objects from Multiple Museums through Semantically-Aware Maps

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Abstract: Geographical information is gaining new momentum as an analysis and visualization tool for collections of cultural objects. It provides all kinds of users with new opportunities to contextualize and understand these objects in ways that resemble our ordinary spatially-located experience and to do so better than textual narratives. The SeMap project has built an online resource that shows more than 200,000 cultural objects through spatiotemporal maps, thus enabling new experiences and perspectives around these objects. Data come from the CER.ES repository and were created by a network of more than 100 Spanish museums. This article explains the refinement of the data provided by the repository, mostly by adding a semantic structure thanks to the CIDOC-CRM ontology, and by simplifying the exceedingly complex terminologies employed in the original records. Particular attention is paid to the methods for geolocating the information, as well as adding temporal filters (among others) to user queries. The functionalities, interface, and technical requirements are also explored at length.

Keywords: visualization; ontology; spatiotemporal map; cultural heritage



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1. Introduction

Digital transformation in recent decades has led to a renewal in access to culture and the management of collective memory. The evolution of new information and communication technologies has led to a substantial change in work, research, and learning, among other activities, in contemporary society [1]. The digital era has changed ways of accessing and managing information, allowing greater possibilities and favoring accessibility [2]. These technological advances have benefited the digital information models used in the heritage field, increasing the availability of digital information and open access to data related to cultural heritage. However, in the digital era, most of the initiatives developed for the management of information related to heritage assets are isolated and siloed within independent repositories, thus lacking data relationships. This information is often not very dynamic, or even static. In addition, the information gathered and published must be sustainable over time, making it difficult to generate new content or disseminate real knowledge. Without taking these premises into account, it is impossible to activate real safeguarding initiatives, hence negating any possibility of benefiting cultural heritage.

Digital tools have changed our understanding of cultural heritage, for instance, the association between cultural assets and their environment, location, background, etc. Geolocation and the visualization of spatiotemporal data have contributed to their dissemination. It is clear that the increasingly frequent use of high-precision digitization technologies for the location and documentation of works guarantees their protection, care, and even restoration with great precision. Despite these benefits, efforts involving museums are

only slowly gaining traction. Some initiatives have demonstrated the integration of geo-referenced heritage information [2,3]. Moreover, digital content that facilitates and favors accessibility can be created through GIS (Geographical Information System), allowing the creation of a multimedia industry linked to the development and conservation of cultural heritage [4]. GIS technologies are excellent tools for visualizing and interacting with the digital documentation of many types of heritage, from small pieces to historic buildings or environments [5]. Furthermore, they are not only apt for visualization but also for the study of tangible and even intangible heritage assets. The information obtained from these technologies can be applied in practice, using digital data to work with cultural heritage objects for spatial analysis, conservation, dissemination, monitoring, research and even education.

Funding for culture is always scarce. This is what makes digital tools essential in the search for sustainable solutions over time that avoids not only the loss or material dispersion of information but also the disappearance of knowledge. The response to the problems posed by cultural heritage necessarily involves dynamic research that is interconnected in many directions. Multiple disciplines need to collaborate in order to decipher the current needs and shortcomings of cultural heritage [6]; digital tools can help to reinforce heritage values [7]. Digital technology and the science that accompanies it imply a new way of facing the complexity of heritage, allowing us to confront it and avoid reductionist solutions [8].

Nowadays, GISs are considered by many studies to be effective, flexible, and integrating tools from the perspective of information management and knowledge [9]. They are an ideal tool for documenting cultural heritage, as they allow different disciplines to be implemented and heritage to be spatially located. Moreover, their graphic versatility and recent use in dissemination platforms have made GIS a good educational tool for our entire society [2]. Due to these advantages, in the last decade, many GIS-based tools have been developed for the representation of heritage, some of them involving both temporal and spatial dimensions [10–15]. However, as data become more complex, so does visualization, often leading to ad hoc solutions. An alternative is the use of the so-called knowledge-assisted visualization tools. Indeed, adding semantic information to the data helps to identify patterns and harness knowledge. This is usually carried out by creating ontologies which, in computer science, “defines the basic terms and relations comprising the vocabulary of a topic area as well as the rules for combining terms and relations to define extensions to the vocabulary” [16]. One of the most interesting aspects of supporting the information in a knowledge graph is the possibility of inferring knowledge, for instance, finding similarities between instances of the network. In this way, ontologies can be used to represent complex models of information in which semantic content plays an important role and can be used to infer hidden knowledge from data.

However, most visualization tools are standalone applications that handle small datasets and/or do not use ontologies. For instance, only a few of the aforementioned works acknowledge that their domain data are supported by a Knowledge Graph [10–12]. Oftentimes, the data are just displayed on a bidimensional map, lacking an interface for the user to visualize the relationships between data. Although these tools can arrange and filter data, especially by time, tools that filter spatial data and time simultaneously are very scarce [12]. Additionally, the volume of data managed by these tools is very uneven: some include almost half a million objects [10,11], while others are based on a reduced set of data [13,15]. We believe that such unstructured approaches can be improved by using ontologies since ontologies can be employed both to store the data that need to be visualized as well as define how to visualize them.

In this paper, we present the results of SeMap, a research project which aims to offer innovative dissemination of movable cultural assets kept in medium and small-size museums, linking them semantically to spatiotemporal maps, so users can access said data more intuitively. We show the methodology developed in the scope of this project [17] for the spatiotemporal representation and interaction of more than 200,000 digitized cultural

heritage objects, using a combination of map-based tools and web services that retrieve information from a Knowledge Graph; the tool can be accessed from [18]. It is built on objects that are cataloged in a network of Spanish museums set up by the Ministry of Culture and Education, which are currently accessible through a web portal [19]. SeMap provides a new way of accessing said information: on the one hand because it provides a spatiotemporal map that expands the possibility of exploring data in comparison to the list of items that CER.ES currently provides, and on the other hand because the data are embedded in a knowledge graph it is possible to retrieve knowledge from it, e.g., by looking for similar objects. Additionally, SeMap combines different visualization and filtering strategies to offer an intuitive and innovative way to navigate through the map, finding objects of interest and accessing individual object descriptions, namely: filtering options, free text search, deep search (considering synonyms), a temporal scale, mapping objects according to two different locations (museum and provenance), a side-bar gallery and a 3D gallery. Therefore, SeMap combines GIS tools, graphical representations, and knowledge-assisted visualization.

The paper is structured as follows. Section 2 describes the CER.ES collection and the data processing followed in SeMap, focusing on spatiotemporal information and other properties and describing their semantic relationships. Section 3 describes the technical details of the SeMap visualization tool. Section 4 shows the results of validating tool functionality and the response to the system when it is used by simultaneous sets of users. Finally, Section 5 offers some conclusions and outlines future work in this area.

2. Data Processing

2.1. The CER.ES Collection

CER.ES is a collective online catalog that brings together information and images of cultural assets of the Digital Network of Collections of Spanish Museums. Through its website [19], general and advanced searches can be made in every participating museum, as well as in a selection specified by the user (Figure 1). In addition to this, it is possible to navigate between the collections using hypertext and the characteristics that identify them (types of object, author, iconography, place of provenance, cultural context, etc.). It is also possible to consult the catalog of each of the museums or even a group them by typology, location, etc. to make more specific searches within the 118 museums which make up this database, including, for example, archaeological museums, fine arts museums, contemporary art museums, decorative arts museums, ethnology and anthropology museums and costume museums. There are also general museums, specialized museums, and public and even private museums throughout Spain. The contents are also available on the HISPANIA network and EUROPEANA.

The aim is to make digital content concerning the collections accessible online and to disseminate this content. All these museums base their data on DOMUS, a tool developed by the Spanish Ministry of Culture and Sport to unify the way collections are cataloged. This system was created in 1993 with the aim of establishing standardized protocols for Spanish National museums, which included an integrated automated system for museum documentation and management. The DOMUS system provides terminological control tools [20] that allow the proper identification and classification of cultural assets housed in Spanish museums. These controlled vocabularies can be classified into two groups: specialized dictionaries, which bring together terminology specific to their corresponding subject area (ceramics, numismatics, and furniture) and generic thesauri, which are applicable to the cataloging of all types of movable and immovable cultural assets.

CER.ES has a clear commitment to facilitate universal access to culture and to provide citizens with cultural content; it provides unified access to the cultural assets of Spanish museums.

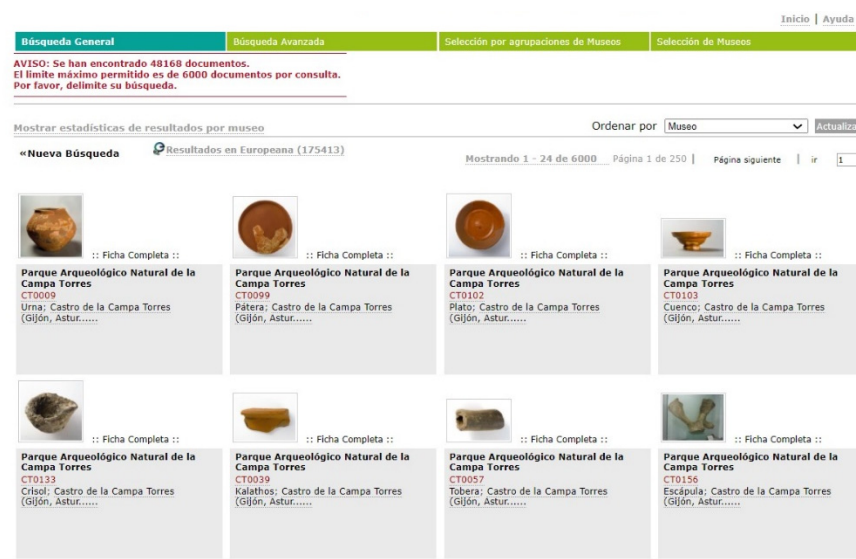


Figure 1. A search for “cerámica” on the CER.ES website.

2.2. Integrating the CER.ES Collection in SeMap

The integration of the CER.ES collection in the interactive map developed under the SeMap project was possible thanks to a collaboration between researchers at the Universitat de València and museum technicians from the Collections Area, Sub-Directorate General of State Museums (*Subdirección General de Museos Estatales*, SGME), from the Spanish Ministry of Culture and Sport. The total amount of data provided by SGME to SeMap (in September 2020) was 239,836 cultural heritage objects with various typologies, and 78,074 items with “document” typology, which includes documents, photographs, films, etc. The information on cultural heritage objects in the CER.ES network that was accessed is made up of the following fields: the museum that houses the object, the inventory number of the object according to each museum, the object identifier, and inventory (unique for each museum), the name of the object, a description, the author, the dimensions, the typology of the object, the name of the specific place of provenance of the object, the name of the city, region or country of provenance, the object material, and dating.

The integration of said data into SeMap was carried out in three phases: firstly, relating the objects to the CER.ES thesauri; next, georeferencing them; and finally, giving uniformity to some fields with high heterogeneity. These phases are described in the following sub-sections.

2.2.1. Relationship to CER.ES Dictionaries

The intended purpose of the data is that they can be consulted, in a usable form, through the interface of a web application. However, this is very complex to reconcile with the number of terms in the different thesauri. For example, the *Diccionario de Denominaciones de Bienes Culturales* [21], used to determine the typology of an object, has 8727 different terms. This vast number of terms means that it is rather complicated for the average user, such as a high school student or a tourist, to choose the typology of the objects to be searched for among the menus. This classification may be deemed appropriate for the classification of a cultural heritage object in a scientific or academic environment; however, for the average user, such complexity is unnecessary and sometimes incomprehensible. As the aim of the project is to disseminate cultural heritage to as many people as possible, a much smaller classification was made, by conceptually grouping terms. The same was carried out with the rest of the fields that can be related to dictionaries in the CER.ES network. This step was carried out by the domain experts involved in the project and was validated by the SGME. The thesauri used and the simplifications are:

- Typology of the object, references to the “*Diccionario de Denominaciones de Bienes Culturales*” CER.ES thesaurus [21]. A total of 8276 terms were reduced to classification with 16 items.
- Material of the object, references to the “*Diccionario de Materias*” CER.ES thesaurus [22]. A total of 1841 terms were simplified to a set of 21 elements.
- Techniques employed, references to the “*Diccionario de Técnicas*” CER.ES thesaurus [23]. A total of 1355 terms were reduced to 20 items.

Even though the institutions that generated the data are users of the DOMUS system, there is still a large amount of data with high variability in terminology. A software application was developed to solve this problem. The processing consists of comparing the number of occurrences of the words in the classification text, and their synonyms, through the WordReference API [24], with those of the dictionary terms, both preferred and alternative. A scoring system is applied, depending on whether the terms are together, separate, synonymous, or not. When the score obtained was very low, a manual process was used to classify them correctly.

2.2.2. Data Georeferencing

To display the data on the map canvas we considered both the provenance of the object and its current location (i.e., a museum). Obtaining the geographic coordinates of the current location was straightforward, as for all the museums there is a specific address. To that end, we used the geocoding services of Google Maps [25] and Geonames [26].

However, obtaining the geographic coordinates of the objects’ provenance was complex. The provenance is understood as the place where the object was before being sent to its current location, so it must not be mistaken for the place where the object was produced. These types of objects, many of which are several centuries or even thousands of years old, may have had several owners, and thus they have been kept in different places. Each object has a place of provenance (e.g., country, toponym, etc.) and a name of the specific place, or site from which it comes (e.g., a monastery, site, etc.). In any case, the geolocation of provenance is a complex issue for several reasons:

- Said information is not available: The field is empty, or it contains the word “unknown”.
- The information is uncertain, due to its granularity. The name of a country or a region is known, but not the specific place. For example, Place Name (Kazakhstan, etc.).
- The name of the place is not known, but the specific name is, which can generate a lot of ambiguity as there can be different locations with the same specific name. For instance, Place Name: “Parroquia de Ajofrín”. This place references a church, with the only reference to Ajofrín. In this case, it is a village with three churches, but it could be “San Juan”, instead of Ajofrín, and there are many churches in the world with this name.
- The name of the place is known, but the specific name is too generic. For example, Place Name: Alcaraz; Specific Place: “El Jardín”. In the municipality of Alcaraz, there are several places that are called “El Jardín”.

As for the geocoding of the location, Google Maps and Geonames APIs were used. Generally, several results were obtained for each request. An algorithm was designed that processed all the results and, depending on the level of similarity of the results with the data, the position was given as valid or invalid. Of a total of 117,681 data with provenance information, 28,725 were given as valid with the Geonames API and 67,399 with the Google Maps API. Finally, a total of 96,124 data were accepted as valid. The obtained result showed that the Geonames API worked well with administrative data (municipalities, regions, provinces, etc.), while Google Maps gave better results with non-administrative names (names of palaces, convents, etc.).

2.2.3. Considering Data Heterogeneity

Usually, the cataloging of cultural heritage objects involves heterogeneity, since the information was introduced by human beings with different criteria. Additionally, it has to be taken into consideration that the CER.ES collection involves 118 museums and thus their own catalogs, so this fact is especially evident. The most affected fields were the dimension and the dating of the object, due to different units of measurement, separators, etc. This heterogeneity is easy to detect and correct using computer technology.

In addition, cataloging terminology was considered in relation to dating, for example, the term “ca” refers to an approximate dating, the same as the character “?”, or the letters “BP” mean (in English) “Before Present”, which indicates that the dating is the number of years prior to the current date. The latter is generally used in dating fossils, etc., where an error of 100 years is more than acceptable.

2.3. Design of the SeMap Knowledge Graph

Since the type of information that is supported is strongly related to cultural heritage, we decided to use the model proposed by CIDOC-CRM [27]. As this model is a theoretical proposal, we used an OWL implementation that is freely distributed by the University of Erlangen [28].

Mapping a domain dataset against the CIDOC-CRM model is an open process. Fortunately, there are several projects that have carried this out [29,30] and the CIDOC-CRM organization itself has developed several guides on how to do this [31]. The results of these works, and the guidelines, were analyzed by the SeMap team to perform the mapping process.

The first important decision in this mapping is the conceptualization of the different types of objects. The most used options are to specialize the *E22 Man-Made Object* class, from CIDOC-CRM, which represents any object created by human beings, or to indicate the type through the *P2 has type* property. This property allows the object to be related to specializations of the *E55 Type* class. In SeMap, it was decided to make specializations of the different main types and sub-types.

In addition to the typology of the object, various considerations were used to work on the location, production, provenance, material, technique, authorship, representation of the object, and dimensions of the object. In the next sub-sections, the adaptations, classes, and properties of the CIDOC-CRM model as used in SeMap are explained in detail. The ontology schema used in the SeMap Knowledge Graph can be consulted in the project's public GitHub repository [32].

2.3.1. Production

To represent the production of the object in the ontological model, the CIDOC-CRM class *E12 Production* is used, and it is related through the property *P108 has produced* with *E22 Man-Made Object*. This class has the properties:

- *P4 has time-span* (which will be used to indicate the production time). This time is entered as a range of years, if possible, since in the data provided it is usually indicated that way.
- *P8 took place on or within* (to be used to indicate the place of production).

2.3.2. Location

Nowadays, all CER.ES objects are in museums that can be precisely located on a map. As museums are actors that have legal recognition, the most appropriate CIDOC-CRM class to represent them is class *E40 Legal Body*, which inherits from class *E39 Actor*, the following properties:

- *P74 has current or former residence*, whose value is an instance of the *E53 Place* class: used in SeMap to represent spatial location information.

- *P49 has former or current keeper*, whose value is an instance of class *E18 Physical Thing*, which is the superclass of *E22 Man-Made Object*. In this way, we link the object with the place where it is being preserved, the museum.

2.3.3. Provenance

To represent the provenance of an object, CIDOC-CRM resorts to the legal field [27], but this information is not always available and it is complex, especially with ancient objects or objects where this process has undergone several iterations, as is usual [33]. Due to this, and the fact that there is no legal information on the transfer of the objects in the CER.ES data, we decided to simplify this problem, leaving the possibility of modifying it open if there is more information on this subject.

Therefore, to reflect the provenance of the object, it was represented in the data by a place; we include the provenance place and link it to the place in the Museum where it is currently exhibited with the *E9 Move* class. Semantically, this is not the most appropriate, since, although the movement was carried out, it does not have to be direct and there is no additional information associated with this movement.

2.3.4. Material and Technique

To support information about the material and the technique used in the production of the object, the *E12 Production* class of CIDOC-CRM is used. This class has the properties:

- *P126 employed*, which establishes an M:N relationship with class *E57 Material*. In SeMap, the instances of the *E57 Material* class are references to the Material Dictionary [22].
- *P32 used general technique*, which establishes a relationship with the *E55 Type* class, which in SeMap is used to reference terms from the Dictionary of Techniques [23].

For the mapping process with the different thesauri, the techniques described in Section 2.2 of this work were applied.

2.3.5. Representation

To represent in the Knowledge Graph the references to the images associated with the object, the *P138 has representation* property of the *E22 Man-Made Object* class was used, which establishes a relationship with the *E36 Visual Item* entity. The different links with images to the object were associated with instances of this class.

The provided data only specified how to build the link of the image with the museum and inventory fields. There are many objects with more than one image, but the number of images is not provided. For this reason, only the link for the first image is built and stored in the Knowledge Graph.

2.3.6. Authorship

The authorship of the object was represented with the *P14 carried out by* property of the *E12 Production* class, which establishes a relationship with the *E39 Actor* class.

2.3.7. Dimension

CER.ES objects have several associated dimension data. Sometimes they are two-dimensional data (length, width) and sometimes depth is considered. Additionally, in multiple objects, the dimensions of various parts of the object are specified. The latter happens with several picture frames, where the dimensions of the frame and those of the canvas are specified.

To represent this information in the SeMap Knowledge Graph, the *P43 has dimension* property was used, accessible from the *E22 Man-Made Object* class, which establishes a relationship with the *E54 Dimension* entity.

3. Design and Implementation of the SeMap Web Application

The SeMap web application was implemented using the VUE.js framework [34], which allows the generation of dynamic and modular web applications. In addition, the

Vuetify [35] module was used to generate a modern and intuitive user interface. The geographic representation of objects within the web application was implemented by making use of the Leaflet [36] library. This library contains a series of tools that facilitate the task of developing interactive maps.

The interface consists of the map canvas, a filtering menu, and the settings and help menus (Figure 2). In the settings menu, users can choose between showing the objects according to their provenance or their current location (museums). They can also change the base cartography in order to modify the appearance of the map. The help menu gives information about the project and shows a legend. These left-side bar menus can be hidden, as indicated in the figure. The map canvas is the central part. It shows a map with markers, representing clusters of all the objects. It contains buttons for zooming and hiding/showing the temporal scale. The filtering menu is located on the right upper side of the map canvas, and it allows filtering through specific fields, or by free text. Additionally, a side-bar gallery appears when inspecting a single object (refer to Section 3.5) and a 3D gallery appears when inspecting clusters of 30 or more objects (refer to Section 3.6). The main functionalities of the map are described in the following sub-sections and the full implementation is available at the project's public GitHub repository [32].

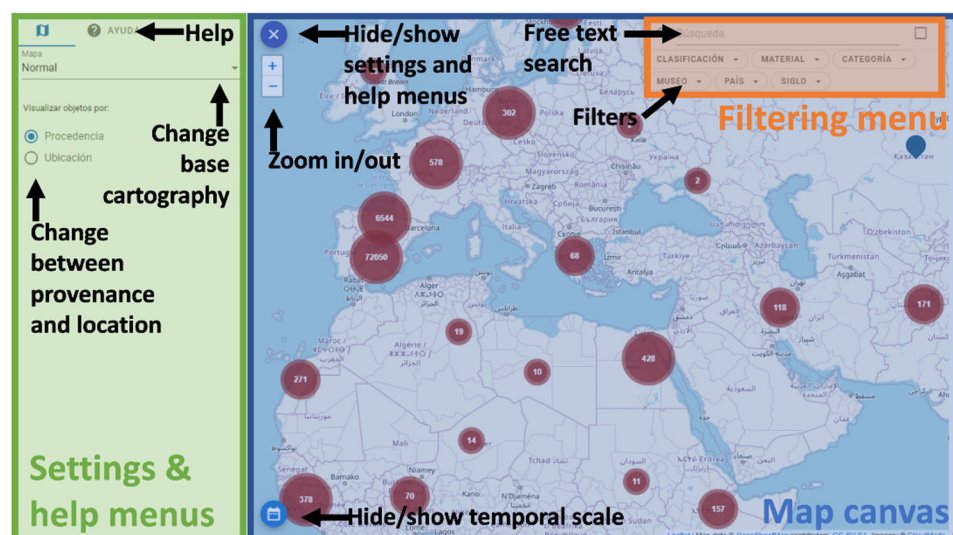


Figure 2. Overview of the elements integrated into the SeMap tool [37].

3.1. Connection with the Knowledge Graph

The SeMap Knowledge Graph is installed on a server with the Linux CentOS operating system, which is supported by the Virtuoso [38] virtualization platform. This system was chosen because it is designed to support a large volume of data and complex relationships. In addition, this system has a Rest API that allows queries in SPARQL [39], accessible from a web application.

When the application starts, the web connects through a GET type request with the Knowledge Graph API to request the information concerning all the objects present in the Knowledge Graph. The returned information only contains the necessary properties to be able to locate the objects on the map and to be able to apply the search filters. The latitude and longitude coordinates allow the positioning of the objects using the Leaflet library. In addition, numeric identifiers for object properties that may be interactively filterable are requested asynchronously. In this way, the size of the data to be sent by the server is minimized. When the web application has the data, it is loaded into the Leaflet library structure. This process is represented in Figure 3. In the initial, and filtering data processes, the user interface invokes a web service that executes a SPARQL query to the knowledge graph, which retrieves the minimum properties per object. A similar process is performed

when the user asks for the object information, but in this case, the maximum amount of information related to the object is returned.

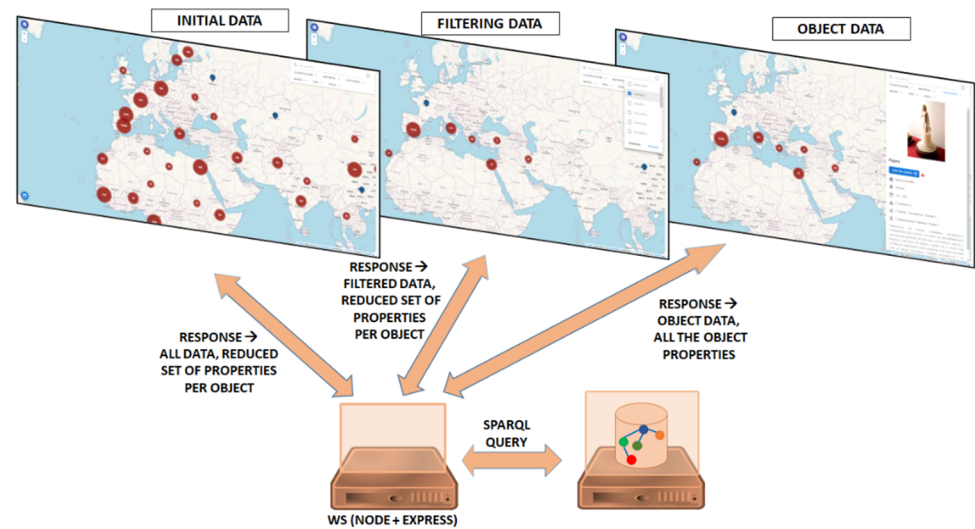


Figure 3. Diagram with the Knowledge graph connection from the web application user interface. All the interactions (Initial, Filtering, Get object data) invoke a web service in order to gather the data, the execution of these web services creates and executes a SPARQL query to the knowledge graph.

3.2. Visual Representation and Interaction of Objects on the Map

The Leaflet library has a plugin that allows geolocated data to be gathered in the form of “clusters” that group and ungroup markers depending on the map’s zoom level. In SeMap, the number of clustered objects in single circular markers is indicated with the markers’ size and a label. We considered three marker sizes: small for less than 30 objects; medium from 31 to 300 objects; and large for more than 300 objects (Figure 4a). On the other hand, blue drop-like markers contain only one object. For those markers that, with a maximum level of zoom, have less than 30 objects, clicking on them causes a spiral to appear, showing markers for individual objects. This is exemplified in Figure 4b, for a cluster of 24 objects.



Figure 4. Markers, where: (a) example of clusters (small, medium, and large markers) and a single object (in blue); (b) example of accessing a cluster of 24 objects.

Additionally, when the mouse hovers over one of the clusters, a blue area appears that indicates the area covered by said cluster; an example can be seen in Figure 5 for two different levels of zoom. In Figure 5a, the blue area indicates the area covered by the objects clustered in a single marker, which contains a total of 1057 objects. Similarly, in Figure 5b, the blue area indicates the area covered by the cluster of 565 objects.

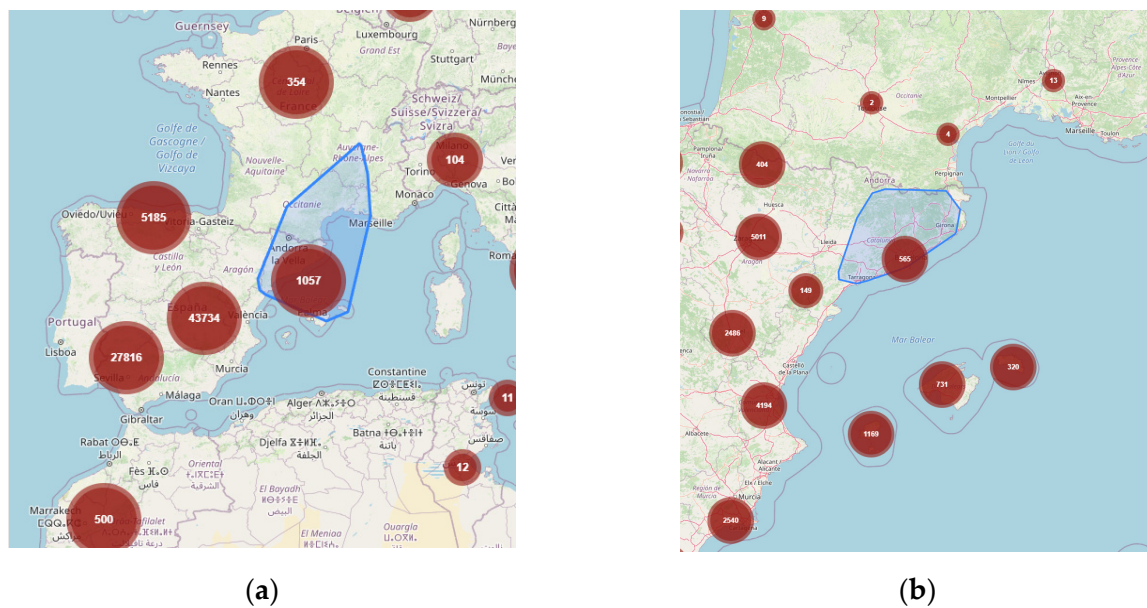


Figure 5. Areas covered by a single cluster, where: (a) an example of a cluster of 1057 objects; (b) an example of a cluster of 565 objects.

3.3. Filtering Options

As explained above, filters can be applied both through specific fields and by a free text search. The available filtering fields are classification (which corresponds to the technique in the knowledge graph), material, category (which corresponds to typology in the knowledge graph), museum, century, and country, as listed in Table 1. For each of the fields, the number of items and some examples are given. The filtering option works in an incremental way. Thus, new filtering options are applied in addition to the previous ones until the user resets them. If different items are selected within a single field, the OR operation is applied, while for different fields, the AND operator is applied.

Table 1. Summary of the filters according to the field and items. Note that some terms have been translated into English in the current paper for the sake of clarity.

Field	Number of Items	Examples of Items
classification	20	ceramics, basketry, common, construction, leather, sculpture, photography, etc.
material	21	adhesive, additive, varnish, leather, solvent, fiber, etc.
category	16	fine arts, ceramic, scientific, document, teaching, ethnographic, etc.
museum	118	Biblioteca Nacional de España, Centro de Arte Dos de Mayo, Casa Museo Lope de Vega, etc.
country	129	Afghanistan, Germany, Saudi Arabia, Argentina, Armenia, Australia, Austria, Belgium, etc.
century	60	39th century B.C., 21st century

The free text search finds the occurrences of the exact text entered in the name of the object, author, description, typology, material, and technique. If the “deep search” option is activated, the search algorithm also considers synonyms of the entered words. The gender (e.g., *amarillo* vs. *amarilla*), accents, and the number of words are omitted in the search.

3.4. The Temporal Scale

When pressing the hide/show button of the temporal scale (see Figure 2), a slide bar showing different centuries appears at the bottom of the map canvas, as depicted in Figure 6. Users can then navigate through this timeline, in order to show objects of a given time period. For instance, Figure 6a shows objects belonging to the 19th century, while Figure 6b shows objects belonging to the 11th century. Therefore, it works as an additional filter to those applied by users in the filtering menu. If the timeline is closed, all the objects are shown again, i.e., temporal filtering is not applied.

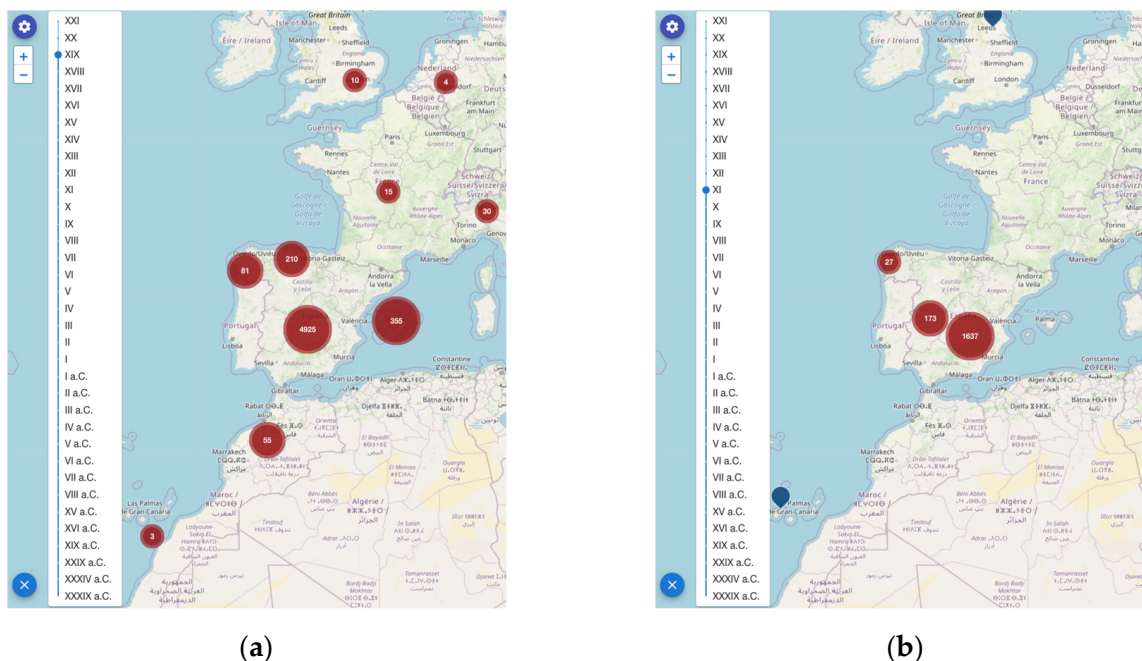


Figure 6. Example of the temporal scale, where: (a) 19th century; (b) 11th century.

3.5. Integration of a Side-Bar Gallery

Access to individual objects is possible thanks to the integrated side-bar gallery (Figure 7). This gallery opens after clicking on one of the drop-like markers, which refer to a single object as explained above. The information depicted in this gallery is taken from the CER.ES catalog, which was facilitated by the museums. Specifically, the side-bar gallery shows (in this order): a picture of the object; its name; the link to the full catalog of the object in the CER.ES collection (“VER EN CERES” button); the museum where the object is currently located; the author; provenance; dating (from–to), classification; material; category; similarity; and a short description. Specific icons were used for the fields that represent the attributes of objects (e.g., dating, author, etc.). A pop-up indicates the meaning of said icons as seen in Figure 7, for the icon related to classification.

As mentioned above, one of the most interesting aspects of supporting the information in a knowledge graph is the possibility of inferring knowledge, such as finding similarities between instances of the network. In SeMap, we include said information when accessing a single object for the properties: category, classification, and material. In order to assess the degree of similarity, we use basic rules based on percentages of coincidence, in such a way that: objects with more than 80% of the same items for a single property, i.e., between 80% and 100% are highly similar; objects with between 30% to 80% of the same items for a single property are similar; objects with between 0% to 30% of the same items for a single property are poorly similar; and objects with less than 0% of the same items for a single property are non-similar. Then, we count the total number of objects which are highly similar, similar, poorly similar, and non-similar, and give the percentage between brackets for each of the properties. An example of the said calculation is given in Table 2. In this table, we show a

total of seven objects, which would be the result of a query made by a user. From these objects, the user selects one of them, i.e., the “selected object”. Internally, we compute, for each of the objects and properties, the degree of similarities with the selected object, taking this as a reference. Finally, the user will be able to see the percentages of similarities of the selected object with the rest of the objects (last row in Table 2) in the side-bar gallery (Figure 7).

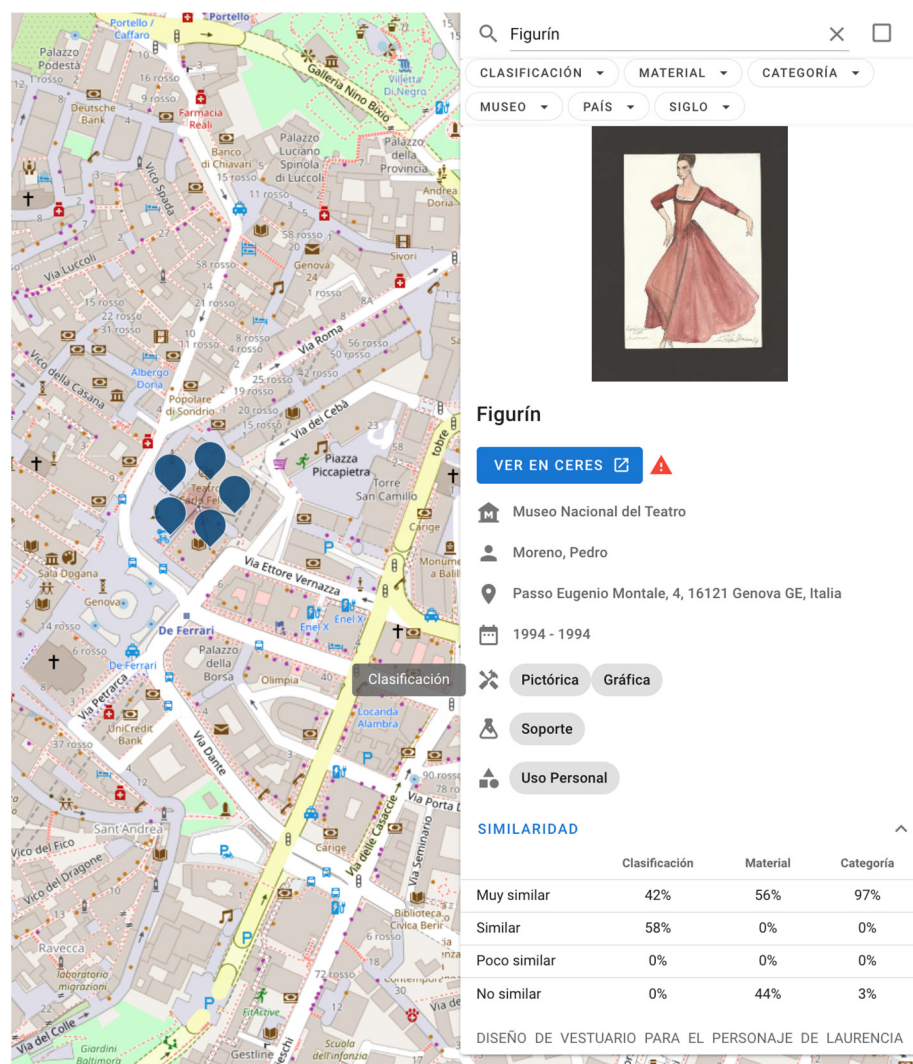


Figure 7. The side-bar gallery showing the information about one of the objects.

3.6. Integration of a 3D Gallery

The 3D gallery scene is displayed when there are many objects in the same location. As explained before, if there are less than 30 objects with the same location the system displays all the objects around the place in a spiral shape (see Figure 4b), and then the side-bar gallery can be opened for each of them. On the other hand, if there are 30 or more objects, the system brings up an emergent window showing a 3D gallery scene where the user may visualize the pictures of the object following four different geometrical arrangements (plain, sphere, helicoidal, and grid). Figure 8 shows examples of said geometrical scene arrangements. The user may navigate freely over the scene and may click on a picture to access the information about that object in the side-bar gallery.

Table 2. Example of how the similarities between a selected object and the rest of the objects are computed for each of the considered properties (category, classification, and material).

	Category [% Coincidence with Selected Object] -> Similarity	Classification [% Coincidence with Selected Object] -> Similarity	Material [% Coincidence with Selected Object] -> Similarity
Selected object	Indústria	Metal, Común	Materia prima, Materia elaborada inorgánica, Madera
<i>Object 1</i>	Bellas Artes [0%] -> non-similar	Común [50%] -> similar	Madera [33.33%] -> similar
<i>Object 2</i>	Indústria [100%] -> highly similar	Común [50%] -> similar	Madera [33.33%] -> similar
<i>Object 3</i>	Cerámico [0%] -> non-similar	Común, Escultórica [50%] -> similar	Materia prima, Madera, Piedra [66.66%] -> similar
<i>Object 4</i>	Indústria [100%] -> highly similar	Cestería [0%] -> non-similar	Madera [33.33%] -> similar
<i>Object 5</i>	Indústria [100%] -> highly similar	Metal, Común [100%] -> highly similar	Madera, Materia elaborada inorgánica [66.66%] -> similar
<i>Object 6</i>	Cerámico [0%] -> non-similar	Cerámica, Común [50%] -> similar	Aditivo, Materia prima, Materia elaborada inorgánica [66.66%] -> similar
Similarities of selected object with the rest	Highly similar: 50% Similar: 0% Poorly similar: 0% Non-similar: 50%	Highly similar: 16.66% Similar: 66.66% Poorly similar: 0% Non-similar: 16.66%	Highly similar: 0% Similar: 100% Poorly similar: 0% Non-similar: 0%

For the implementation of the 3D gallery, we made use of the CSS3DRendered class, which allows the visualization of HTML and CSS content as a three-dimensional scene. These resources are developed based on the Periodic Table sample, published in a public GitHub repository [40].



(a)



(b)

Figure 8. Cont.

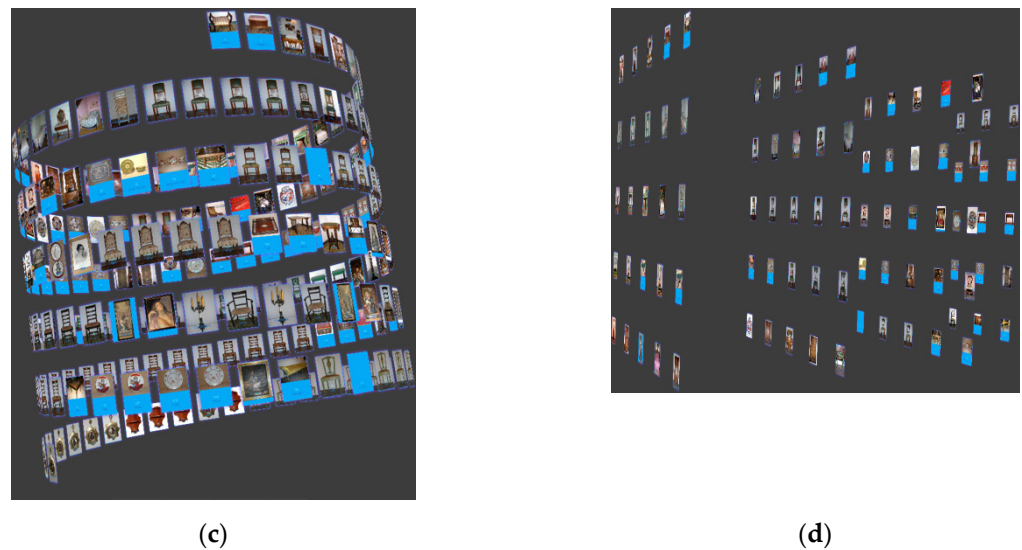


Figure 8. Different arrangements of the 3D gallery: (a) plain; (b) sphere; (c) helicoidal; (d) grid.

4. Results

To verify that the results of the SeMap project would be adequate for the end-user, the functionality and the response to the system when it is used by a simultaneous set of users were evaluated. Reaching this goal with traditional evaluation tools is very complex because the content is generated in a dynamic way and it manages a dataset with a large number of objects. Fortunately, due to the marked increase in web application development that has generated dynamic content based on JavaScript technology; some applications capable of evaluating these kinds of web applications have recently been released.

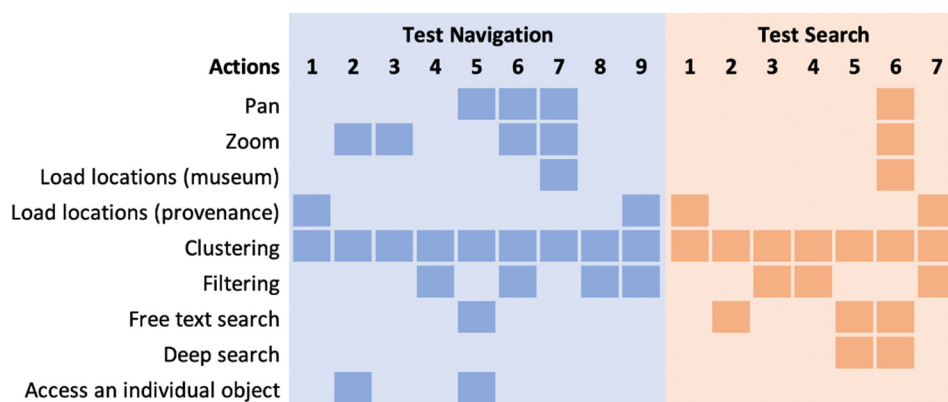
One of the most used is K6 [41]. This tool is used to perform functionality and stress tests with the SeMap web project. The tool allows constructing a load test from a user session recording, and after this step, configuring the number of simultaneous users, adjusting additional settings, and executing the tests. To evaluate the system, two tests were recorded: Test Navigation and Test Search. Test Navigation aims to evaluate the response and functionality of the system to the initial user interaction: navigating the map, clicking on objects, and activating basic interface filters. On the other hand, Test Search aims to evaluate the functionality and response of the system to free and deep text searches combined with the activation of basic interface filters.

Both tests were executed with 20 and 40 virtual users. The description of the steps for each of the tests is summarized in Table 3, where Test Navigation consisted of nine steps, and Test Search consisted of seven steps. Additionally, Figure 9 relates each step with the actions taken on the map for both tests. As can be seen, clustering appears at each step because the actions of zoom, activating or deactivating filters, and free text search involve a re-clustering, either because of the scale of the map (when zooming) or because of the number of objects on the map changes.

The results of the tests are depicted in Figure 10 and summarized in Table 4 for both Test Navigation and Test Search for both 20 and 40 users. The table depicts the number of HTTP requests and errors, the maximum requests per second, the maximum and average response times in milliseconds, and the average number of requests per second.

Table 3. Description of the stress test steps for Test Navigation and Test Search.

Step	Test Navigation	Test Search
Step 1	Initial load. Show all objects.	Initial load. Show all objects.
Step 2	Zoom in on the map until you see the town of Requena in the province of Valencia. Click on the isolated object that appears there.	Write in the free search the text “Silla” (“Chair”)
Step 3	Zoom out, so that you can see the entire Iberian Peninsula and activate the Material> Textile filter.	Activate the filter: Material>Wood
Step 4	Activate the filter: Category> Religious.	Deactivate all filters and return to the initial situation.
Step 5	Navigate to the town of Bolea in Huesca and click on the only object in the town.	Type “silla madera” (“wooden chair”) in the free text search and activate the deep search check.
Step 6	Deactivate the material filter and the category filter. Activate the Country>Italy filter. Navigate the map so that you see all of Italy.	Activate display by provenance. In the free teach search, type “silla madera” (“wooden chair”) and activate the deep search check. Navigate through the map until you see the Iberian Peninsula.
Step 7	Activate display by provenance. Navigate to Spain to see the museums in Spain that have objects from Italy.	Deactivate the filters, activate display by provenance, and return to the initial situation.
Step 8	Deactivate the country filter and activate the Technical>Wood filter.	-
Step 9	Deactivate the filters and from the configuration button view the objects by provenance.	-

**Figure 9.** Graphical representation of the actions taken on the map at each step for both Test Navigation and Test Search.

As can be seen, Test Navigation shows very good results for the two considered numbers of users. The response times (maximum and average) are below one second and very similar with both 20 and 40 users, even though there are twice as many requests in the second case. On the other hand, these results are not so good for the Test Search. With 20 virtual users, there are problems when performing the deep search as 20% of the requests are not resolved at the time of the deep search. These problems become more acute in the 40-user test, as there are twice as many requests. In this test, the application was rendered inoperative.

The main stress situation is when all the users are using the deep search at the same time. However, this is not the most common process. For this reason, it could be concluded that the system may work with 30 simultaneous users without performance problems, but deep search use must be controlled in order to guarantee a good response from the application.



Figure 10. Graphs with the performance of the tests as produced with the tool K6, where: (a) Test Navigation, 20 users; (b) Test Navigation, 40 users; (c) Test Search, 20 users; (d) Test Search, 40 users.

Table 4. Summary of the results of the stress tests considering both 20 and 40 users.

Test and Number of Users	HTTP Requests	HTTP Errors	Max. Requests Per Second	Max. Response Time (ms)	Avg. Response Time (ms)	Avg. Request Per Second
Test Navigation 20 users	623	0	4.33	867	288	2
Test Navigation 40 users	1326	0	8.33	879	302	3
Test Search 20 users	442	103	10	59,745	2230	1
Test Search 40 users	764	181	23	59,746	3647	2

5. Discussion

The fact that the different and varied collections are shown on a single map makes it possible to see how they were shaped, and their local and intercultural exchanges. In this sense, the SeMap tool could be used for multiple purposes, including the management of cultural heritage from different perspectives, such as preventive conservation, as GIS can link Cultural Heritage with its territory and the information might be filtered with different values such as materials, techniques, and others [42]. On the other hand, data collected through GIS might be used for storytelling, which later can be used by museums in their dissemination purposes [43]. Finally, these kinds of experiences will become extremely helpful for tourism [44]. SeMap could also include a vision of cultural diplomacy since our map shows the current and previous locations of the collections. This means that in certain museums, for example, it is possible to work on decolonization by clarifying the provenance of the pieces housed in Spanish collections. Finally, a large part of Spanish cultural diplomacy comes from the Instituto Cervantes, as well as from the Ministry of Culture, which created CER.ES. As mentioned in [45], cultural diplomacy favors exchanges of ideas and cultural values represented in cultural heritage; these values also form the identity of a country's different territories. In addition, SeMap is designed for the general public, which favors the dissemination and accessibility of diplomatic relations.

It is also worth mentioning the semiotics considered in SeMap as a relevant topic in GIS [46]. Semiotics is especially important in the creation of thematic maps, where symbols are commonly used to represent categorical variables that can be combined with other aesthetics, such as color and size, which can embed other attributes of the spatial objects. SeMap is a tool where users can query a knowledge graph and retrieve a spatiotemporal representation of their results, allowing access to the full catalog of a single object. This is a different technique from the current CER.ES search engine, and where SeMap provides something new. As the CER.ES catalog, involves objects from over 100 museums, there is high heterogeneity in the data (objects with different materials, categories, etc.). When visualizing such a huge number of objects on a single map (i.e., SeMap), we need to cluster objects, and each cluster involves objects of very different natures. In such a scenario, symbols referring to a specific attribute cannot be applied when showing the clusters. Instead, what we do is provide users with all the richness of the objects when selecting one of them and depicting it on the side-bar window, where symbols representing specific attributes of the objects are shown.

Finally, the fact that SeMap involves keeping the data in a knowledge graph provides additional advantages. For instance, in SeMap we included the percentages of objects which are similar to the selected one (according to its category, material, and technique), as part of the object information (see Section 3.5). One of the most traditional algorithms for detecting similarity between the nodes of a knowledge graph is known as semantic similarity [47]. This algorithm consists of assigning weights between the different edges of the graph, and the paths with the most weight between nodes would determine the most similar nodes. There are several applications where this technique was used, e.g., [48,49]. However, the main problem with this algorithm is the cost of applying it directly to large datasets, which makes it not suitable for SeMap, where the response must be gathered in real-time. Instead, we applied basic rules for assessing the similarity of objects based on percentages of coincidence for each characteristic, as schematized in Table 2.

6. Conclusions and Further Work

The spatiotemporal representation of cultural objects is a fast-growing area of research within data visualization. It adds an especially rich perspective to the analysis and enjoyment of cultural heritage. The humanities have traditionally focused on the study of individual objects of great symbolic, historical, and aesthetic value, but digital technologies are now making quantitative approaches possible, based on large datasets representing the abundance of objects kept within museums and collections, at least among some categories

of cultural objects. These approaches were unfeasible before the advent of Geographical Information Systems and digital information at large.

Technology alone is not enough to implement these new visualizations. Access to datasets with an appropriate level of standardization and quality is the absolute basis for any such effort. In this regard, the CER.ES dataset is an extraordinary resource within the Spanish-speaking cultural milieu, bringing together data from over 100 museums and more than 200,000 object records. Refining the information homogeneity and adding semantic connections to it is the next step, and one area where the SeMap project provides very useful insights for future developments.

Some challenges remain, mostly regarding the mapping of the data to existing controlled vocabularies and geographical name gazetteers. Search functionalities and the user interface are always open to further improvement, as are technical performance and computing infrastructure requirements. For instance, to enrich the search of authorship, we plan to add a link to the Getty Union List of Artist Names dictionary [50], and to the catalog of Authorities of the National Library of Spain [51]. The results available so far from SeMap are already very promising, transforming a resource made by and for specialists into a service useful for general and educational audiences. Additionally, we will explore the possibility of additionally defining semantic communities as in [52], in order to both enrich the semantic relationships and reduce the time taken to find similar objects.

Interdisciplinary collaboration between ICT engineers and scholars in the humanities takes time and effort, but projects such as this prove to be the way forward in all areas of the digital humanities. The technology and the standards are mostly ready; the data are becoming increasingly available, and more resources will follow suit.

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