# Towards Browsing Repositories of Spatially Oriented Historic Photographic Images in 3D Web Environments

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**Figure 1: Overlaying photography and 3D model in a 3D web environment. Images: Alte Synagoge (Thümling 1870), Dresden Synagoge (Bildarchiv Foto Marburg. Unknown artist 1939)**

## ABSTRACT

Archives and museums store vast collections of historical images of urban areas and make them publicly available through online platforms. Many of these images, often containing historic buildings and landscapes, can be oriented spatially using automatic methods such as structure from motion (SfM). Providing spatially and temporally oriented images of urban architecture, in combination with advanced searching and 2D/3D exploration techniques, offers new potentials in supporting historians in their research.

We are developing a 3D web environment usable to historians to spatially search online media repositories containing historic photographic images. We combine 3D models of historic buildings with spatially oriented images, replacing text-based searching through meta-data with spatial and temporal browsing with respect to given focus points in historic city models.


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## CCS CONCEPTS

**•Information systems →Digital libraries and archives; •Human-centered computing →Web-based interaction;** *Interactive systems and tools;*

## KEYWORDS

Spatial browsing, Photo databases, WebGL

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# 1 INTRODUCTION

Art history as a scientific discipline has a long tradition. Various methods have been developed to analyze works from different artistic genres: painting, sculpture, and architecture. The expansion of working tools towards digital methods does not only offer manifold possibilities of support to the scholars, but also opens a wide field of scientific issues and research methods. Especially the field of urban history can benefit from those innovations, due to the fact that it stands on a nodal point between the conventional artistic genres with their specific exploitation and the tight reference to the human being as creator and recipient of — as well as actor in — urban settings.

A substantial number of institutions are archiving historical images of urban areas. Many of them provide access to these images in digital form via online platforms, where users can explore these huge repositories by searching for specific keywords. While the meta-data usable for browsing are often incomplete, imprecise, vague, and not standardized, keyword-based searching is often still useful to experts. However, due to the mentioned shortcomings, historians with spatial research questions, or those who want to get an overview of historical images for a point of interest, will have difficulties to find the desired content. Many scholars relying on visual media note that currently online searching for images and information is "counter-productive", due to the huge amount of irrelevant data they come across, or because of their own limited technical abilities (Beaudoin and Brady 2011). A lot of the existing tools for research platforms and applications stem from computer science and do not necessarily meet the needs of scholars from humanities (Dudek et al. 2015).

Providing spatially and temporally oriented images in combination with advanced searching and 2D/3D exploring techniques, where users can navigate to a region of interest, offers new potentials in supporting historians in their research. Especially in urban areas, the change of architecture and cityscapes over time is interesting for experts as well as locals or tourists.

In this paper, we are introducing our work on a 3D web interface to image repositories that focuses on the combination of (historical) 3D models and images of architecture, to provide a spatial as well as temporal mode of exploration in addition to a meta-data based access.

# 2 RELATED WORK

Following the ground-breaking work of Snavely et. al. on exploring photo collections in 3D (Snavely et al. 2006), there have been multiple developments to arrange and browse contemporary image databases, as well as to create 3D models of current architecture from these image databases using photogrammetric methods. There also exist multiple approaches to make available 3D models of — current as well as historic — cities in Cultural Heritage (CH) settings in digital installations in museums, but also through the web. The Google Arts and Culture program (Google 2016) makes photo collections of museums available online, and also integrates contemporary images of architecture inside Google Street View. This works very well for dense photographic source material. For historic photography, the documented record in contrast is often too sparse to provide a satisfying *photo tourism* experience.

## 2.1 Time-varying 3D city models

A simple approach to explore spatially oriented images are interactive 2D maps. Google Maps/Earth and Flickr are just two examples offering this feature that is mainly used for modern, touristic photos. Introducing the third dimension to basic 2D browsers and viewers can enhance the visualization of images in relation to the depicted objects. The user is then no longer restricted to an orthogonal top view of a map, but can also navigate in custom angles and take up the position and orientation of the photographer of the picture. The user obtains a more detailed understanding of the distribution of the taken photographs, enabling a more subtle access to understanding the photographer's intentions. Additionally, extending 2D maps even with a 3D model of the area of interest can enhance the understanding of the building situation and from where the photograph has been taken (Schindler and Dellaert 2012). Such 3D models of urban areas can be either retrieved from city departments (Gaillard et al. 2015), or automatically reconstructed from a huge amount of (touristic) photos from the internet, i.e. Structure from Motion (SfM) (Agarwal et al. 2011; Snavely et al. 2006). However, these models are focused on present buildings and often serve only as comparison to the historic state of construction.

A 3D city model representing the historic urban situation and visualizing historical images from several decades, clearly has to deal with the time-varying aspect of buildings which may appear and disappear over time. Hence, the representing 3D models need to be equipped with the construction dates, e.g. beginning and end of the building's existence. This requires that the city model should not just consist of some huge connected 3D objects, which is the usual output of SfM, but to be segmented into buildings, parts of buildings or even construction phases.

Samuel et al. (Samuel et al. 2016) focus on the documentation of the change in urban landscape. Thus, their individual 3D models are linked to images (and other documents) that document the construction, demolition, and modifications of the real world objects. The documents are spatially localized in the 3D city model. One of the challenges is how to visualize these documents according to their reliability, concerning especially textual documents, and quantity. As some spots might be well documented, 3D representations of these documents might occlude or intersect each other. Schindler et al. (Schindler and Dellaert 2012) aim for the exploration of vast collections of historical photographs via a time-varying 3D city model, building on their earlier work on automatically inferring temporal order of images and reconstruction of 4D city models using SfM (Schindler and Dellaert 2010).

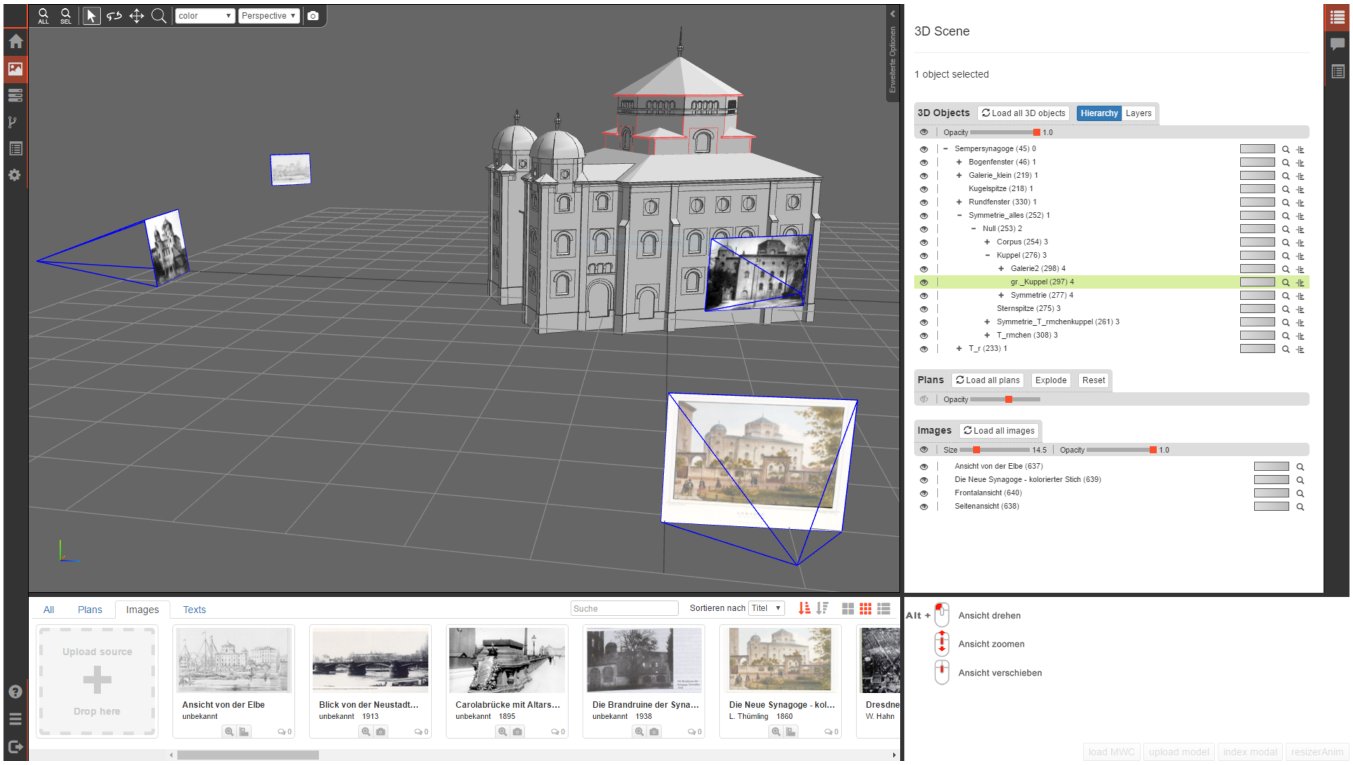


**Figure 2: Overview of 3D browser prototype interface (top left: WebGL view of 3D models and spatially placed images, top right: object browser, bottom: 2D image browser). Images: Alte Synagoge (Thümling 1870), Ansicht der Synagoge von der Elbe (SLUB/Deutsche Fotothek. Unknown artist 1847), Synagoge (Bildarchiv Foto Marburg. Unknown artist 1935, 1939)**

## 2.2 3D content delivery on the web

The usage of 3D data in the web has heavily evolved in recent years, since the introduction of WebGL making third-party browser plugins obsolete. In addition, computational resources on client's machines increased enormously. Due to bandwidth limitations, first approaches in the nineties and early noughties focused on remote rendering, delivering only images to the user (Yoon and Neumann 2000), as well as on multi-resolution and progressive compression of 3D models (Fogel et al. 2001).

To guarantee a smooth user interaction with current client-based rendering approaches, data needs to be efficiently transferred from the server to the client (e.g. web browsers), where it needs to be processed efficiently. To minimize data complexity, 3D models are usually compressed to transmission formats like glTF (Robinet and Cozzi 2013), CTM (Geelnard 2009) and others (Limper et al. 2013). To decrease latency while loading, huge 3D models need additional treatment. While the remote rendering approach seem to be no longer as widely used today, progressive loading and multi-resolution rendering algorithms are still topic in recent developments, especially in web-based environments (Limper et al. 2014; Ponchio and Dellepiane 2015). Extensions to glTF support transfer of binary data (Cozzi et al. 2014). Scully et. al. (Scully et al. 2016) provide glTF extensions to support multipart meshes as well as streaming of binary data buffers with progressive encoding, to reduce memory footprint on memory limited devices and to increase performance.

Additionally, 3D models are often processed server-side to multiple level of details (LOD) and segmented into tiles (Gaillard et al. 2015). Using this approach, only 3D objects close to the camera are loaded and displayed in detail, while objects further away are small-sized and less detailed. Objects outside the viewport might not even be transferred to the client. These so-called 3D tiles are working similar to 2D tiles familiar from map services and are maturing in specification (Cozzi and Lilley 2016).

## 2.3 Georeferencing and orienting images

To be able to spatially display photos of buildings with respect to a given city model, the position and orientation of the photographer is needed for georeferencing photographs. In a photogrammetric context the position of the camera is known as exterior orientation. For the computation of this exterior orientation, and thus the localization of photographs, a spatial resection can be applied. XYZ-coordinates of a minimum of three non-collinear object points are required for this purpose. It is hard to find absolute coordinates for historical buildings purely from sparse historical photography. If there is substantial temporal and spatial overlap in the historic images, structures that are no longer existing can still be mapped into a coordinate frame featuring current architecture, as described

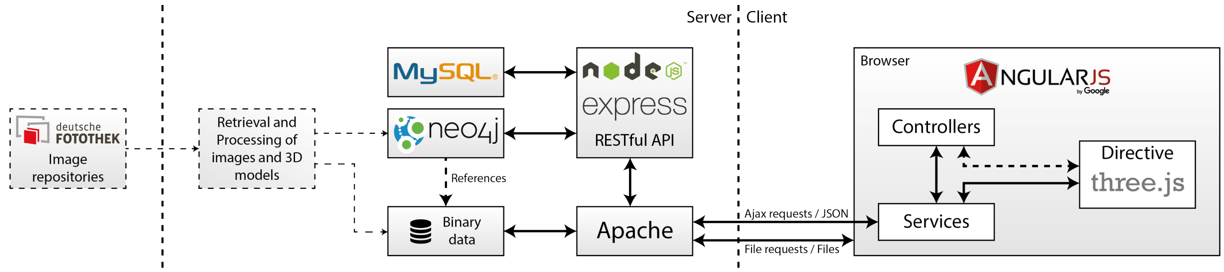


**Figure 3: Architecture overview of the introduced web-based 4D image browser**

by Schindler et. al. (Schindler and Dellaert 2012). Sometimes, object points could be set on today's structures, if the object did not change too much over the time. This is why current models of the observed buildings are absolutely essential. Existing 3D models of cities, such as models available through respective land register administrations in different LODs, can be used for this purpose.

Individual buildings can also be recorded by laser scanning as well as by cameras or modeled using SfM and 3D modelling software (Stojakovic and Tepavcevica 2009). Maiwald et. al. try to combine historic images with contemporary images of architecture to create historic 3D models of cityscapes (Maiwald et al. 2017) where radiometric and geometric quality of the historic sources are not sufficient for SfM approaches.

## 3 SPATIALLY ORIENTED IMAGES AND MODELS IN 3D WEB ENVIRONMENTS

Europeana (europeana labs 2014) provides access to various european CH media repositories in the form of a REST interface as well as a SPARQL API, making databases of historic photos available to third party software. In the early development of our image browsing prototype, we chose to only include a manual selection of images from these extensive databases. To be able to spatially embed historic photographs of city architecture in a 3D model, the original position of the photographer has to be extracted from these pictures. At a later stage, we hope to feed the spatial location computed by SfM, the thereby created 4D city model, as well as an estimated date of recording, back to the original repositories in the form of camera matrices and time stamps. For the time being, these data items are stored in our own application server database. As 3D models, we employ both manually reconstructed buildings, as well as a virtual 3D city model of Dresden (Amt für Geodaten und Kataster und Stadtplanungsamt, Landeshauptstadt Dresden 2013) for our use-case scenario.

### 3.1 Browsing Image Databases

The architecture of our prototypical web application can be seen in Figure 3. The implementation follows the single-page application (SPA) approach. For the server side, we make use of the graph database *Neo4j* for data storage with references to multiple LOD buildings and city models. *Node.js* together with the web application framework *Express.js* is used to build a RESTful API. The relational database *MySQL* is only used to store user credentials. In future, the retrieval of images from repositories and their processing to gain orientation and 3D models will be supported by an automated process.

In the browser, we use the SPA framework *AngularJS* providing model-view-controller (MVC) and model-view-viewmodel (MVVM) architectures. The basic components are controllers, services, and directives. Controllers are used to define the logic behind the different views. Services are for organizing and sharing code across the application and can be injected into all other components. Thus, database requests are implemented via services. Directives are used to attach specific behavior to a DOM element. In this case, the 3D content is embedded within a directive employing the JavaScript library *three.js* as a higher level API for 3D graphics.

### 3.2 Graphical User Interface

In our prototype browser, the 3D viewport forms a central part, allowing a variety of interactions (see also Figure 2 for an overview of the developed GUI). The 3D viewport and the rest of the web application, containing temporal and object-based browsing in traditional HTML user elements, need to communicate effectively with each other. However, directives and controllers have their own scopes, the communication between these instances is done indirectly via a service. Due to the deep integration, one of the ready-to-use 3D viewers was considered not to be an option. Additionally, the all-purpose WebGL framework *three.js* allows the implementation of custom features, rendering options, and real-time manipulation of the models, as it suits the needs of the application.

On the right side of the user interface we provide an object browser to select 3D models, parts of 3D models, and images to navigate to (see also Figure 2). When selecting an image in the object browser, the viewpoint is transitioned to the reconstructed point in space and time where the photographer has taken the photo. The object browser can also be used to blend between photographs and 3D model in the 3D viewport as can be seen in Figure 4.

Users can also still use an integrated keyword-based meta-data browsing approach through the image browser at the bottom of the screen. The 2D image browser shows the images in local vicinity of the selected point of interest. Selection of images can be reduced by providing keywords as a filter to the meta-data contained in the image records.

### 3.3 Data integration and storage

Operating with large amounts of media data requires a sustainable database concept. Historical images and their meta data fall in the scope of cultural heritage (CH). The CIDOC Conceptual Reference

**Figure 4: Sequence of blending between photograph and 3D model in the browser prototype. Image: Synagoge (Bildarchiv Foto Marburg. Unknown artist 1935)**

Model (CRM) (FDIS 2014) is a standard ontology in this field and is adopted by many projects. It provides definitions and a formal structure for describing the implicit and explicit concepts and relationships used in cultural heritage documentation. In its form as an ontology, it is also suitable for semantic web technologies, so that newly created data can be queried by other institutions via an access point. In contrast, geospatial information systems usually store their data in elaborated geo databases (e. g. PostGIS) to perform spatial queries. However, there is also an extension to CIDOC CRM covering this aspect (Doerr et al. 2013). With regard to data interoperability and standardization, Samuel et al. (Samuel et al. 2016) extend the CityGML standard with historical images and other linked documents.

Due to the employment of CIDOC CRM as the underlying data model, the datasets are highly connected. To efficiently query this graph-like structure, we have chosen the graph database *Neo4j*. Integrating the 4D model databases with the existing image repositories will offer potential for scalability in later stages of the project.

### 3.4 Limitations

3D models of digital reconstructions can rapidly grow to tens or hundreds of millions of polygons, depending on the size of the reconstructed objects and supported level of detail. Since these models can easily engross several hundreds of megabytes, it can take rather long to load and render them in a web browser. Thus, our 3D models are converted into the compression file format OpenCTM (Geelnard 2009), reducing the file sizes by more than 90% in our scenarios. Although OpenCTM contains lossy compression mechanisms, leading to some decimals of vertex positions and normals being discarded, it is sufficient for display purposes. The resulting number of polygons to render are, however, still the same. Depending on the computing power of the client, the frame rate in our prototype starts to drop at around 1 million visible polygons in highly hierarchical 3D models. User experience slowly decreases at around 2 million polygons. To support more complex models, further optimization as outlined in Section 2.2, i.e. progressive loading, multiple LODs as well as 3D tiles to bring down the geometric complexity, will be necessary.

## 4 CONCLUSION AND FUTURE WORK

With a web-based application in mind, existing approaches and technologies covering diverse aspects were reviewed. Most of the solutions to integrate 3D models with photos of architecture rely on 2D map services. These are easy to integrate into web pages, as they provide map material and satellite images, and their APIs offer extensive geospatial functionalities. However, the provided maps show only a planar view of the current situation. The extension towards 4D city models, i.e. 3D spatial models that are changing over time, is considered to be beneficial with respect to a better identification of the region of interest, and a better understanding of the urban building situation regarding the photographer's position.

Inspecting time-varying 3D city models instead of analyzing convolutions of sometimes improperly annotated images helps historians to better understand the historic urban situation and might also offer a point of entry to non-experts into the topic. Towards this goal, we have introduced a prototypical image browser that allows the combination of 4D geometry of buildings with historical photography stored in media repositories.

There are already some approaches and applications dealing with historical images or 3D city models. Most of these are limited regarding useful features for scientists and all of them lack support for existing workflows with respect to historians and their research. An application equipped with useful features that are developed in cooperation with the target group will be able to support researchers in their work. The introduction of 4D city models, however, holds some challenges regarding technology, accessibility as well as usability. For many of these aspects, existing state-of-the-art technology can be adopted. Further concepts concerning the integration and visualization of spatially and temporally fragmented 4D models into an existing 3D environment need to be elaborated in detail.

In a preliminary study, we identified a focus group of researchers working in the domains of digital humanities, archives for digital, historic images, digital art, and architectural history. A study on digital workflows is currently performed to acquire further input on the needs of these researchers. Further studies in this area will bring forth tools and applications to support digital research. If archives and image repositories recognize new ways to support scientific work, users of virtual archives can benefit extensively from effective searching functions and tools which allow browsing to be performed not only content- and theme-based, but also location-based.

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