HISTORICAL PHOTOS AND VISUALIZATIONS: POTENTIAL FOR RESEARCH

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ABSTRACT:

The interdisciplinary research group on four-dimensional research and communication of urban history (Urban History 4D) aims to investigate and develop methods and technologies to access extensive repositories of historical media and their contextual information in a spatial model, with an additional temporal component. This will make content accessible to different target groups, researchers and the public, via a 4D Browser and an Augmented Reality app for mobile devices. One goal is to improve the accessibility of media repositories and develop suitable solutions for data preparation and information research, making extensive use of visualizations. An interdisciplinary approach is taken to ensure that visualizations for research are comprehensible and meet scientific standards. The investigation of spatial visualizations of image repositories and their visual representation in a coherent context includes frequencies, directions, and perspectives within the image material, which can be grasped through quantitative methods. This paper introduces two main investigations into (1) quantitative data visualization with photography and (2) the plausibility and perception of 3D reconstructions.

1. INTRODUCTION

The Urban History 4D project[1] investigates and develops approaches to repositories of images of the city of Dresden. Images and plans provide information on the appearance and architecture of the city as well as their development over time. Access to the information repositories relevant for both the general public and scientific research is usually challenging (Lazarinis, 2011). The main aim of the project is to improve the accessibility of the data through visualizing, spatializing, merging, structuring, and annotating historical photographs in a virtual 3D model. A further ambition is to investigate and develop methods and functionalities that support the analysis and processing of historical photos. On the one hand, the photographs serve as a database for creating 3D models. On the other, they will be included in quantitative analysis addressing research questions from art and architectural history.

The aim of the paper is to present what the interdisciplinary research group is working on in the context of visualizations. Two main perspectives are introduced:

(1) Quantitative data visualization with photography and (2) the plausibility of 3D reconstructions and their perception. One of our research goals is to better meet the needs of users, especially researchers in the field of art and architectural history, as well as tourists, when interacting with digital tools: What will be helpful for researchers working with the 4D Browser especially in investigation, contextualization and general research issues? What information can be retrieved from the visualizations of the image-based data? How plausible are 3D reconstructions in users' eyes?

2. VISUALIZATIONS AND PERCEPTION

The purpose of visualizations is to convey information very quickly and support an insight into the underlying data. The aim is discovery, decision making, and explanation of the visualized data. User perception, needs, and expectations are key factors in the success of visualizations. This paper aims to introduce researchers to different ways of data and information visualization, taking advantage of digital technology. Visualizations facilitate the handling of large sets of scientific data, making it easier to identify phenomena in the data. Their objective and reproducible nature increase their value for reasoning within scientific communities and publications, but they also suggest a precision and reliability that can easily cause misjudgment of validity (Card et al., 1999).

Visualizations in general are defined as "the use of computer-supported, interactive, visual representations of data to amplify cognition" (Card et al., 1999). Khan and Khan (2011) conclude that cognition in this context means: "the power of human perception or in simple words the acquisition or use of knowledge" (Khan, Khan, 2011).

A distinction has to be made between data visualization, information visualization and scientific visualization. This is certainly also because terms seem to be used synonymously in different scientific disciplines (Dörk, 2008; Goldfarb et al., 2011). As Dörk (2008) defines, the difference between

[1] www.urbanhistory4d.org

information visualization and scientific visualization depends on the data to be visualized: "Scientific visualization is mainly concerned with the visual representation of data that has some kind of inherent spatial structure. Information visualization (InfoVis) in contrast focuses on the visual representation of abstract data that usually lacks any inherent spatial structure." (Dörk, 2008). Khan and Khan (2011) give a supplementary definition: "Data visualization is the study of representing data in some systematic form, including attributes and variables for the unit of information" (Khan, Khan, 2011). Whereas Information visualization is described as: "a research domain that concentrates on the use of visualization methods to assist people understanding data and evaluate or analyse data. Information visualization is the transmission of abstract data through the use of interactive visual interfaces." (Khan, Khan, 2011). In contrast, scientific visualization "helps to understand physical phenomena in data, mathematical models, […] and glyphs." (Khan, Khan, 2011).

Different disciplines investigate different types and requirements of data and information visualizations (Nguyên, Worring, 2008). Windhager et al. (2019) give a comprehensive review of information visualization approaches to digital cultural heritage collections based on the state of the art in techniques and design. Requirements for data and information visualization from an interdisciplinary perspective are rare but there is a broad consensus that the recipient should easily understand the meaning of the visualized data without too much effort and cognitive load (Mayr et a., 2016; Chen, 2005).

The challenge is to design and implement visualizations that are a reliable, comprehensible and scientifically sound representation of the content. So both aesthetic and didactic design-oriented visualizations of complex, diverse, and extensive data sets provide a more user-centric approach to information access and knowledge acquisition. As the volume of cultural data increases, it is argued that human information processing through visual abstraction could improve the acquisition of information (Liu, 2014; Dörk, 2008). Digital humanists who visualize data or information do so in order to digitally present cultural collections of libraries, archives and museums to a broad audience, to process and visually decipher them and thus make them accessible. Data and information visualizations should aim to support users in information seeking, exploring, understanding, and analyzing data through visual exploration (Mayr et al., 2016).

The Urban History 4D research project is developing a 3D web environment to enable researchers, e.g. art and architectural historians, to search and access historical photographic images in a spatial context. One major feature of this approach is quantitative data visualization to improve understanding of the photographer's position in the urban built environment. The historical images are spatialized in a 3D environment and visualized by spatial, object-based orientation visualization. In the field of digital humanities, this kind of data visualization and representation is unique. The user can create such visualizations using simple to complex distributions of the data in the model space, employing various techniques like heat map visualizations (see Section 3.3 and 3.4). The visualization of phenomena produces new visual information by connecting model and image. The task here is to use the quantitative visualizations as a basis to visually represent the relationship between object, image, and space in order to create a visual impression of concentrations of images. In this way, new questions can be developed or expanded on image material for e.g. art history. This feature is conceived as a prototypical exploration enabling the user to explore visual phenomena in 3D space. Next, usability and user experience techniques will be used to gain user-centered feedback on perception and plausibility. So evaluation taxonomies for information visualisations should be user-centred or target-group-oriented and, according to Lahm et al. (2012), include the following questions: (1) How do recipients perceive data visualizations? (2) How do scientists interact with the visualized data? (3) What is the added value for scientists concerning possibilities offered through data visualization? Investigation concerning user perceptions will help to identify and assess possibilities to support research using the visualizations within the 4D-Browser.

Humans perceive visualized information through images and digital 3D reconstructions in two stages: first, extracting properties and second intensively scanning for details. The difference lies in the intensity. The first stage is an initial attentive perception (pre-attentive processing) seeking to grasp the main features, an initial idea and realization of the basics, and to understand how the visualization of the data presented can be used. In the second stage, the user focuses more deeply on perception of the context by a comprehensive slow scanning of the details (Rodrigues-Jr et al., 2015). Further, the user is concerned with abilities of contextualization or contrasting existing knowledge—which later become important in analyzing the visualizations. It is assumed that the understanding of visualizations—the initial step, the attentive recording—is decisive concerning the acquisition of knowledge (Ware, 2013).

3. QUANTITATIVE VISUALIZATIONS FOR RESEARCH

Most digital image repositories present their content and photographs in tiles that users can browse. Browsing image galleries has been a common way to access the content und search for certain images for a long time (Besser, 1990). However, a different approach uses geographic positions to display and contextualize information (Fabrikant, Buttenfield, 1997). This method has potential to uncover and visualize certain phenomena linked to the initial acquisition of images.

The 4D Browser[2] (Figure 1) of the Urban History 4D project is used to link digital images and their actual location making it possible to present resources directly, providing valuable support for historical research. Users of virtual archives can benefit extensively from effective functions and tools to search based not only on content and theme, but also on location.

Currently the 4D Browser of the project provides an accessible collection of 1070 historical images which come from the Deutsche Fotothek[3]. These images where handpicked and included in the 4D Browser to demonstrate functionalities and severe as data for usability testing. Several functionalities which support the presentation and analysis of the content are introduced in this chapter.

3.1 Visualization of the photographer`s perspective in the 4D Browser

Photographs within the 4D Browser are spatialized in a virtual 3D city model combined with a map underlay (Figure 1). The spatializing also called geo-referencing of photographs refers to the reconstruction of the geographic position of the camera during acquisition. Small pyramids indicate the direction of the

[2] http://4dbrowser.urbanhistory4d.org

[3] http://www.deutschefotothek.de/

https://doi.org/10.5194/isprs-archives-XLII-2-W15-405-2019

camera (Figure 2). Currently, the photographs are geo-referenced manually. A (semi-)automatic solution is intended, but unfortunately, several existing approaches cannot be easily adapted for historical images (Maiwald et al., 2017).

Figure 1. 4D Browser with location-based photographs, map underlay and timeline

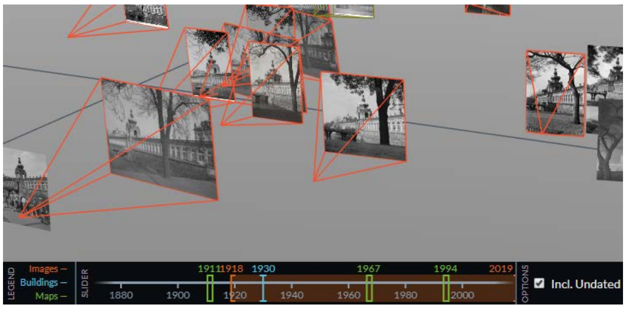

Figure 2. Timeline and photographs with pyramids indicating the direction of the camera

In order to keep the 3D presentation clear, all images are displayed in clusters. A number indicates how many images belong to a cluster, giving a first impression of the distribution of images (Figure 1). When zooming into the 3D model, the clusters adjust according to the image distance on the screen, which can be customized or switched off completely in the settings.
The metadata, specifically the date, can be used to filter the images using a timeline (Figure 2). Thus, the 4D Browser can be used to investigate images and their information related to time and space—a novelty for image repositories.
Especially for art and architectural historians, the 4D Browser application offers new research functionalities and helps to answer specific questions regarding perspectives. From which location and direction has a certain historical object frequently been photographed? Did the photographers' acquisition habits change over time? This may lead to further discussion on the importance of specific buildings during certain times. How did photography influence the way a city was perceived? What effect did a client have on the photographers' portfolio and the documentation of a city over time?

3.2 Visualization of changes over time

The addition of a timeline within the 4D Browser makes it possible to show how the cityscape, architecture and acquisition behavior changed over time. The timeline (Figure 2) supports the selection of (1) a time span for photographs, (2) a point in time for the 3D model, and (3) maps corresponding to a certain date. In combination with the spatialized presentation of historical photographs, this offers an innovative tool to research the perception of the city in temporal and spatial terms and their connection. Any information relevant for the timeline is stored in the metadata. For images we rely on the metadata from the Deutsche Fotothek. The entry 'date' (Figure 10) usually refers to the time a picture was taken, but mix-ups with the digitization or other dates are possible. This issue connected to metadata is well known (Beall, 2005).

3.3 Visualization of the accumulation of pictures within the 4D Browser

The heat map is a two-dimensional data visualization that uses colors and their perceived temperature. It helps to quickly and intuitively detect phenomena within large amounts of data.
In our case, a heat map is created that visualizes the most popular positions of photographers (Figure 3), based on the filtering of desired images for analysis and the distribution of the photos. All images within a set radius are used to create the heat map.

Another option for a heat map visualization is to project the existing photographs onto the corresponding buildings to indicate which building parts have been documented (Figure 4). A grid is used to calculate the coverage, which is than translated into the color-coded visualization. This heat map visualization can serve as a valuable tool to investigate the correlation between the documentation and the perception of a city and help to answer questions regarding: Where were the most popular spots for photographs at a certain point in time? Which areas of the city or parts of buildings were never or hardly ever photographed? Another area of application is 3D reconstruction of historical architecture, since this heat map visualization gives a straight forward overview of available and missing building documentation.

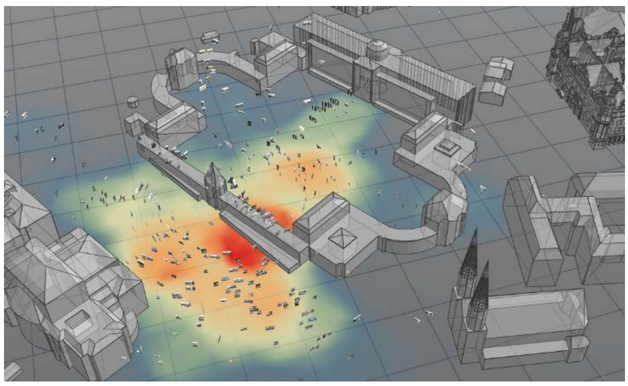

Figure 3. Heat map showing accumulation of photos (red: more photos, blue: fewer photos)

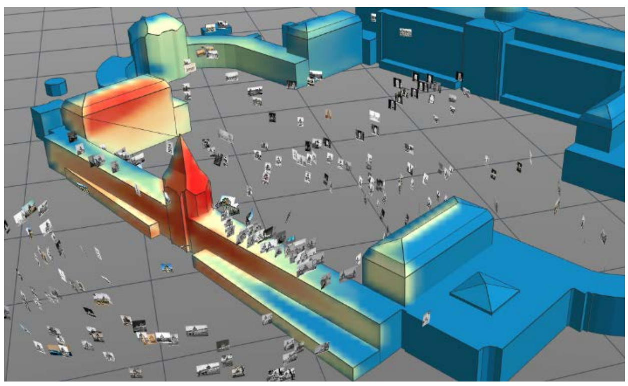

Figure 4. Heat map showing which building parts were often (red) and hardly (blue) photographed

3.4 Visualization of the most common directions of photographs in an area

The photographer’s position during acquisition is a common research topic. Additionally, the direction or angle of photographs carries a variety of information (Figures 5–8). Which objects were most popular based on their appearance in photographs? Are there preferred angles for certain buildings? Are acquisition angles connected to surroundings? Do they change over time? An analysis of photo acquisition of a large area provides information on the preferences connected to buildings and the depiction of cityscape, life and culture. We would like to introduce four options for visualization that emphasize the directions in which the cameras were pointing.

Radar chart visualization (Figure 5) is a clustered, two-dimensional visualization of popular acquisition angles. The color coding is linked to the number of photographs in a cluster (clustering described in section 3.1). The directions of all photographs in a cluster are used for the calculation. The biggest deflection of the bubble shapes corresponds to the main direction, and the variance of the calculation is indicated by the width.

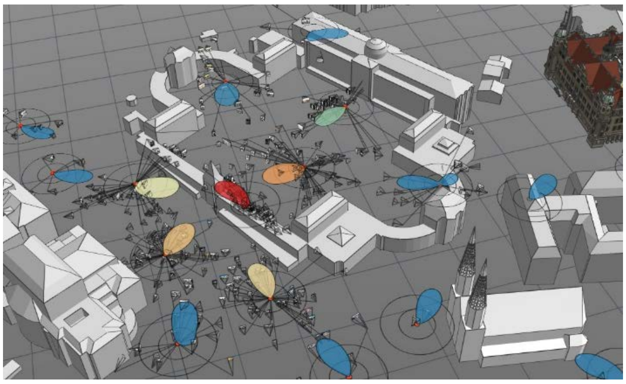

Figure 5. Radar chart, visualizing the most popular angles (big deflection of bubble shapes) of photographs

Radial fan visualization (Figure 6) is similar to the radar chart. The full 360° circle around the center of a cluster is evenly divided into 16 segments. All images with a direction that corresponds to a segments are used to calculate the size of a segment. The longest segment indicates the main direction. The color coding corresponds to the size of the segments.

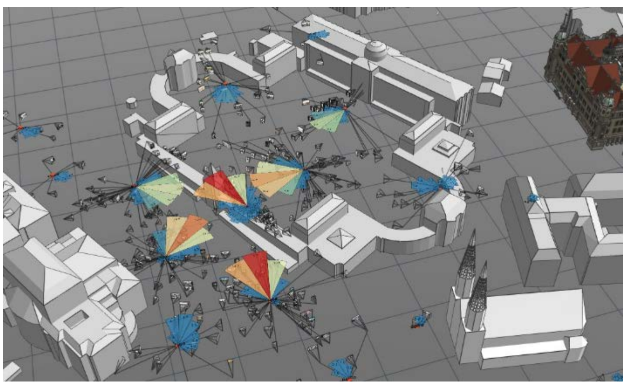

Figure 6. Radial fan, visualizing the most popular angles (red) of photographs

Vector field visualization (Figure 7) is a two-dimensional visualization of vectors on a regular grid. The color coding indicates the spot with the most images (red) similar to the heat map. Each arrow is calculated using the average direction of photographs on the grid. Therefore, it emphasizes only the most dominant direction.

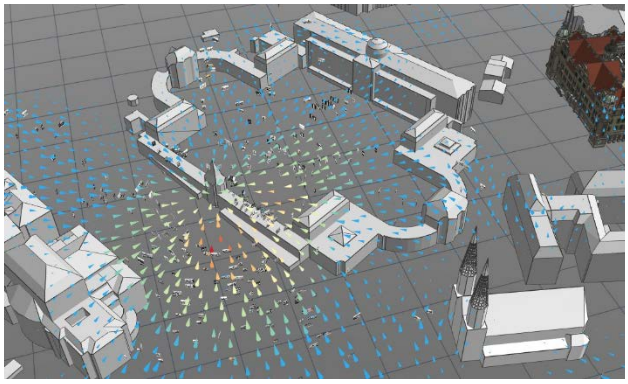

Figure 7. Vector field, visualizing the average acquisition angle for a certain area

Flow visualization (Figure 8), unlike the vector field, shows changes in direction in close proximity. The particles are animated and therefore reveal the point of interest.

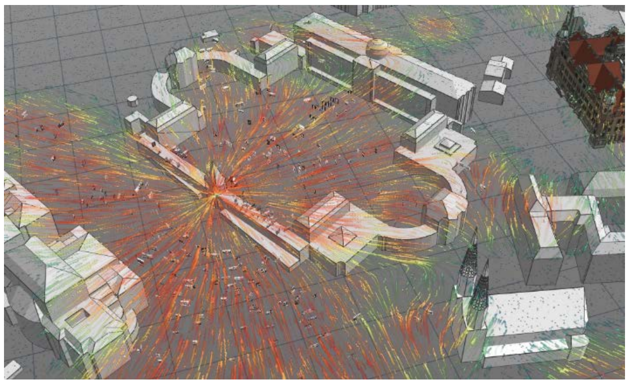

Figure 8. Flow visualizing popular angles for photos

3.5 Approach to visualize uncertainties

As a very heterogeneous user group, even within the humanities, scholars either need or prefer visual outputs that provide new insights into data or they want numeric outputs for further analysis or assessment (Given, Willson, 2018). Relying on methods from several disciplines, the aim is to satisfy both needs when it is possible.

Since geodetic processes are almost always presented with several uncertainty measures, it is necessary to visualize those values for internal and external evaluation. Uncertainties are conventionally represented using schematic drawings, confidence ellipses (in 3D: ellipsoids), distribution curves, error vectors, and heat maps (Niemeier, 2002; Torge, Müller, 2012). Adding the photogrammetric perspective, it becomes necessary to visualize uncertainties, for instance in image processing, feature matching, calibration, and orientation of historical images.

Since all these errors add up to the final camera position X, Y, Z and the camera angles ω, φ, κ (= exterior orientation of the camera) it is reasonable to give the user a guiding value for the accuracy of the determined positions and orientations. The focal length of historical images is especially often unknown, which negatively affects the position accuracy in terms of the view direction of the camera. Further image and object differences hamper automatic image orientation (Maiwald, 2019).

We propose visualizing the accuracy of the camera position in the interface using an error ellipsoid centered at the principal point of the camera. The uncertainty values of X, Y, and Z derived by a bundle adjustment are used for the length of the three semi-axes of the ellipsoid (Figure 9).

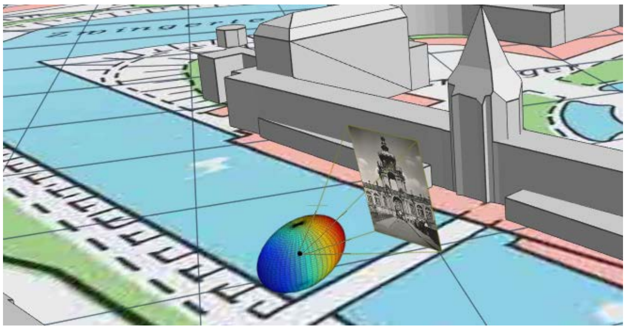

Figure 9. Error ellipsoid representing the uncertainties of the camera position of a single image after the bundle adjustment (mock-up)

After transformation of the coordinates into a global coordinate system (UTM, WGS84) the accuracies of the angles and the positions can be shown in the datasheet of the respective image (Figure 10).

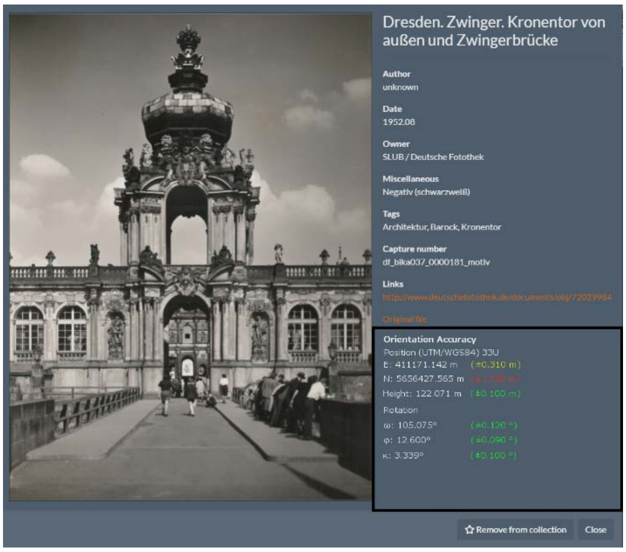

Figure 10. Data sheet of the depicted image showing additional accuracy values for the exterior orientation of the camera (mock-up)

Possible 3D points are created by a Structure from Motion (SfM) workflow using historical images (Maiwald et al., 2017). Thus, it becomes necessary to visualize the uncertainties of the 3D points, especially when those are derived from images dating from different periods. Several studies have shown that the accuracy of 3D geospatial data can be visualized in various ways, such as with heat maps or shading (Dübel et al., 2017; Herman et al., 2018; O'Banion et al., 2018; Zuk et al., 2005).

4. PERCEPTION AND PLAUSIBILITY OF 3D RECONSTRUCTIONS

Besides images, which have been the focus of the previous chapter, the 4D Browser also uses 3D models to visualize the city scape of Dresden at different times. Very simple block models emphasize the arrangement and dimensions of buildings while providing little information on their actual appearance.

Due to the limited amount of historical images, we rely on manually reconstructed models. Within virtual reconstruction projects, historical buildings usually have to be reconstructed manually to show different building phases. Such digital 3D reconstructions of architecture which no longer exists are highly dependent on historical sources such as plans, sketches, and photos. As information is often missing from historical documents, the reconstruction process is based on interpretation. So the resulting 3D model inevitably includes uncertainties. The question is how to indicate these knowledge gaps in a final visualization. No standards of how to visualize hypotheses in 3D models exist so far (Wittur, 2013; Münster et al., 2019), making it necessary to discuss this issue.

User studies provide an approach to investigate the perception of 3D models. The investigations in this area focus on plausibility connected to source fidelity and perception of generalized building versions.

4.1 Pilot study estimating plausibility of 3D reconstructions

The pilot study focused on how virtual representations of structures are perceived. The study involved 21 persons and employed methods from usability testing. Regarding the perception of virtual 3D models, relatively little visual information is needed to allow observers to distinguish buildings from each other or to identify a single building and to gain information about its spatial relation and shape (Münster, in print).

Quality assessment of 3D modeling in historical contexts is an adjacent issue. The most important criterion is source fidelity and plausibility (Münster, 2013). In contrast to textual research results, in digital 3D reconstruction a decision has to be made regarding the historical form to be modeled, even in the case of missing or inconsistent findings.

To test empirically, we selected one of our former projects—a reconstruction of the Piarist Church in Vienna (Jahn, 2015). For testing we used a version derived from the finally approved outcome by including three mistakes. In this latter version we changed radiometric properties by adding a gold-colored braid, as well as geometries, by removing the chapels and reshaping the apsis wall. A survey presented both renderings, with sources (ground plot, side view) and a short questionnaire asking for a rating of plausibility, with open-ended questions about the reasons (Figure 11).

Figure 11. Survey front end

Preliminary results from eight participants with previous experience in 3D modeling showed disparate findings. The overall rating seems arbitrary and was justified by various arguments focusing primarily on visual quality and geometrical plausibility. Only one participant identified the missing chapels—the most obvious alteration. In contrast, three participants named false positives. Only one participant said they felt unable to judge properly. Preliminary implications are that even experts may have neither common strategies to judge complex visual content nor common criteria for plausibility. Moreover, most recipients were not aware of these limitations, the rate of finding mistakes was low, and only the most obvious mistake was found. Despite the facts that these are preliminary findings, the study design lacks a control group, and the question wording, testing materials, and technical settings may create bias, it seems reasonable to conclude that expert judgments about visualizations are arbitrary and correspond little to each other.

4.2 First approaches to investigate the perception of 3D reconstructed ruins

Expert judgements will also be important to an upcoming study on perception of 3D reconstructed ruins: As there is a timeline included in the 4D Browser the user can dive through time from ca. 1850 until today. During this period the cityscape of Dresden changed, so buildings which are no longer extant today have to be 3D reconstructed in the 4D Browser. This will be exemplified with the case of the Sophienkirche, a Gothic church erected in the thirteenth century at the Postplatz in Dresden (Schreier, Lauffer, 2014). This square was subject to several extensive architectural transformations in the twentieth century, and the church burned down in February 1945 during the Second World War. It remained as a ruin until its remnants were completely removed between 1962 and 1964. For more than 15 years the partly destroyed Sophienkirche shaped the appearance of the square. To document this transitional phase, a 3D model was created, referring to historical sources like the ground plan and photographs. As few historical photographs depict the Sophienkirche during this period from all sides and perspectives, several details of how the ruin looked like are not known. With these gaps in the documentation, hypotheses have to be made.

As with visualizations of hypotheses in 3D models of historical architecture, no general standards exist for visualizing a ruin as a digital 3D model based on historical sources. This may be because ruins which no longer exist are hardly ever depicted in 3D models; an exception is Rashid and Rahaman (2016).

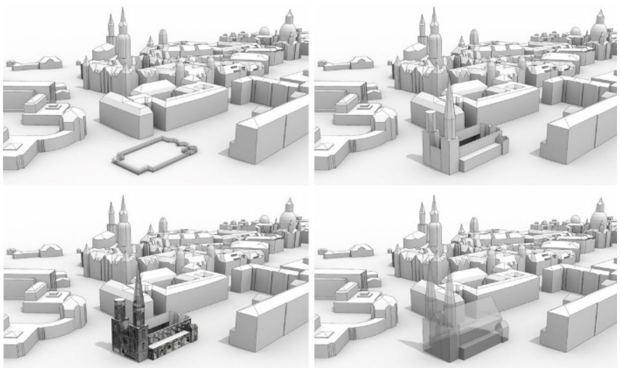

Figure 12. 3D model of the ruined Sophienkirche: abstract reconstruction, reduced to footprint as transparent visualization (top left) (not displayed: solid footprint model); geometric reconstruction, showing remaining parts without (top right) and with (bottom left) textures of historical photographs; transparent visualization of the shape of the church before its destruction (bottom right)

Different visualizations of the ruin were developed. These depictions encompass different concepts of how to visualize a destroyed building: as an abstract footprint, an architecturally detailed ruin, and a complete but transparent building. These models show varying levels of detail and also vary in their appearance (Figure 12).

Transparency is one way to depict uncertainties in 3D models. Kensek et al. (2004) list several projects that use this visualization method. Geometric 3D reconstructions of historical architecture are often textured, either with preset material depictions, colors or (historical) photographs (Messemer, 2016). The footprint of a building which is no longer extant refers to the shape of the ruins, which often only consist of the surrounding walls (Coralini, Vecchietti, 2007).

An upcoming user study will investigate which one of the visualizations (Figure 12) depict a ruin adequately in the eyes of the users. That is, the aim is to gain insight into the perception and perceived plausibility of these visualizations. Students of art history, potential users of the 4D Browser and expert interpreters of images, will be interviewed. They will be shown six digital images on a computer screen. The researcher will ask specific questions about each image, which the participant can answer verbally. After presenting images of five different 3D models a sixth image will be shown, encompassing all variants and allowing the participant to compare and to rate the visualizations. The interview will be recorded digitally for analysis afterwards. It is estimated that each participant will point out a favorite visualization and will give hints about how they perceive the depictions of the ruin. The results can serve as a basis for further discussion and to develop standards for visualizing non-extant buildings in 3D models, especially to visualize hypotheses.

5. OUTLOOK: THE AUGMENTED REALITY APP

An Augmented Reality (AR) application for mobile devices is another part of the Urban History 4D project and uses the same database as the 4D Browser. It presents visualizations as enrichment of the real world through virtual data, which can include 3D models, texts, pictures, film or audio data. The viewer is able to interactively capture visual and textual information about objects in their historical spatial reference system (Ridel et al., 2014). This offers an enhanced, contextualized experience to visitors and advanced working paradigms to researchers.

We combine 3D-printed models of architecture with historical photographs of these buildings to explore depicted city perspectives in AR installations (Niebling et al., 2017).

Historical textures for registered models of architecture are created by UV mapping vertices of the respective digital 3D model to the historical photographs. Using the photographic images as model textures allows the buildings to be 3D modeled at a low resolution, as details are provided by comparably high-resolution photos. Small variances that often occur during the lifetime of a historical building can then be approximated by the same coarse 3D model.

Figure 13. Handheld AR

We render the textured digital model on top of the video of the tracked physical model in a handheld and a HMD-based AR setup, discarding parts that are not contained in the photo selected by the user (Figure 13 and 14). The tablet or HoloLens device can be moved to view buildings from a different perspective than that of the photo, still allowing the user to perceive the historical appearance of the building depicted in the historical image (Niebling et al., 2018).
A small subset of historical photos in the Deutsche Fotothek repository are spatially oriented in the coordinate system of the underlying digital 3D model created by a previous SfM workflow, providing location, orientation, and field of view of the camera for each photo.

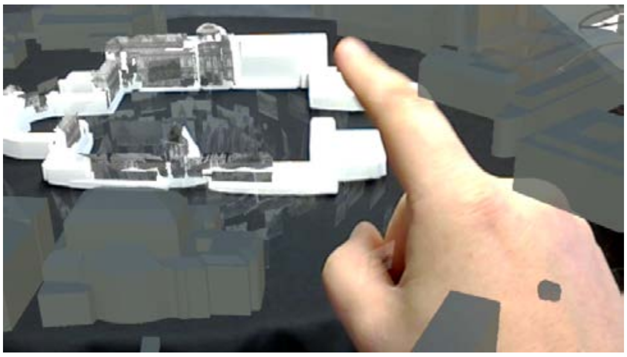

Figure 14. HMD-based AR using HoloLens

6. CONCLUSION

This paper provides an overview of the options for providing users with visual information connected to historical content. Two factors are important for us: (1) to provide sound, generalized information on appearances of buildings to ensure that users correctly interpret a 3D model and (2) to support scholarly investigation using quantitative visualization.
The novelty of using large numbers of images for quantitative visualizations needs to be further investigated. We need to question our trust in 3D models just as much as our ability to comprehend the models.

From these investigations further research questions arise: Are users able to derive relevant information from the visualizations? What is the added value for scientists of this data visualization? What are the subject-specific requirements for data visualization? How do scientists interact with the visualized data? Do different design options help to improve visualizations? Another issue for future investigations is the human perception of AR.

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