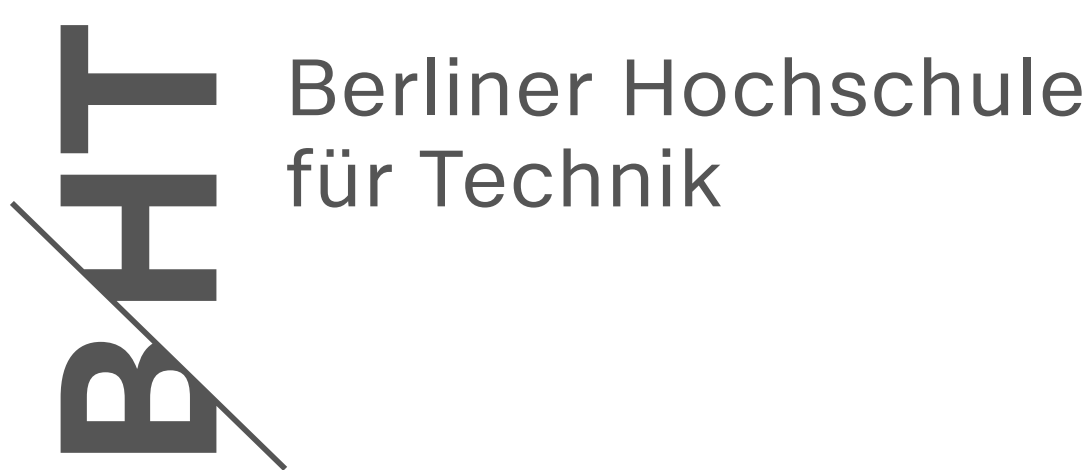




Virtual 3D-Reconstruction of Lost Places with Computer Vision

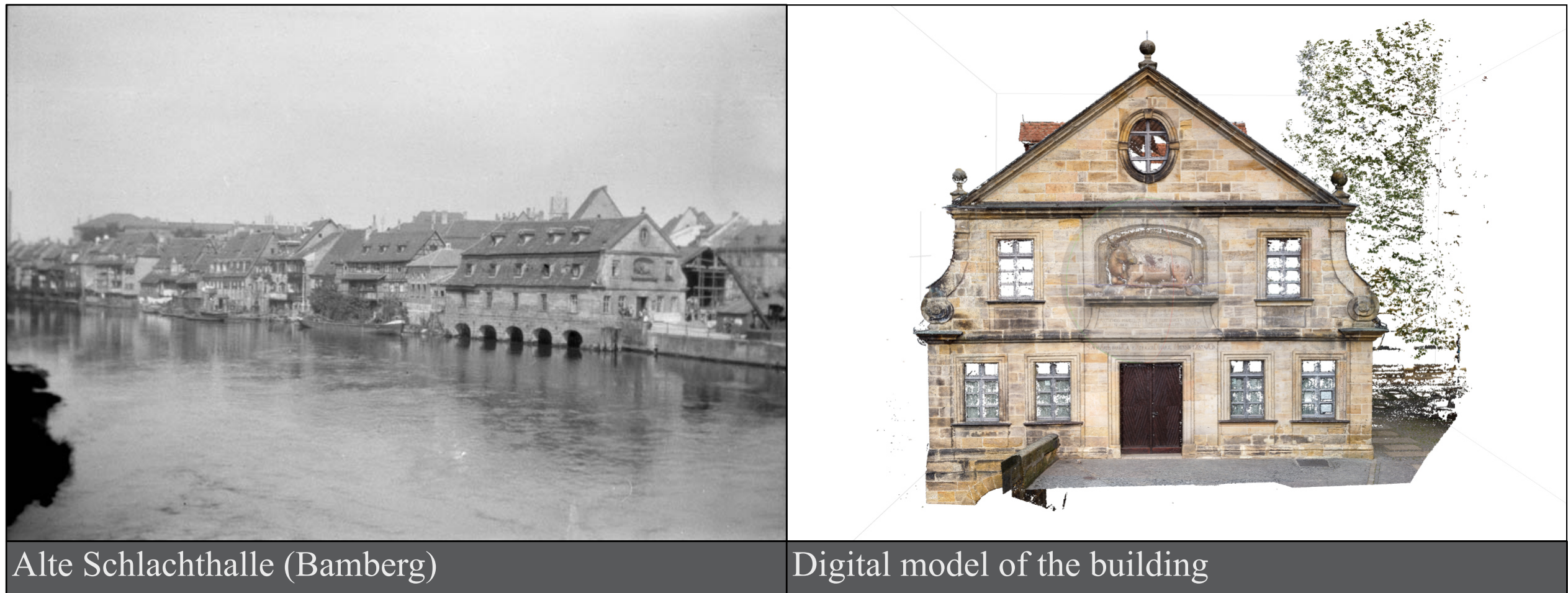


Introduction and Motivation

Germany is home to numerous *lost places* – sites of historical significance that no longer exist or have fundamentally changed. This includes, among other things, the loss of Jewish cultural sites that were once vibrant centers of social life until 1933. While *Stolpersteine* today commemorate deported and murdered Jewish citizens, a comprehensive understanding of daily life during that time is lacking. Recent surveys have shown that, particularly among youths and young adults from countries such as the Netherlands, knowledge about the Shoah is minimal to non-existent (Kühn, 2023).

The digital preservation of historical sites offers a promising alternative to costly restorations. Successful examples such as the VR applications for the *Sachsenhausen concentration camp*, *Vincent van Gogh's study*, or the *Anne Frank House* demonstrate how immersive technologies can make lost spaces once again experienced. In contrast to these still extant locations, fully disappeared sites present particular challenges.

This research addresses the question of which historical documents and procedures can be used for automated or semi-automated reconstruction of lost places. The focus is on the development of 3D models of former Jewish cultural sites, which are to be embedded in a geographical context and made experienceable through virtual reality. Of particular interest is the use of historical imagery for generating three-dimensional models that bring the erstwhile life at these locations back to life.



Using manual methods, Kirschke & Wolff (2018) have already virtually reconstructed the *Langenstein-Zwieberge concentration camp* in the form of a 3D application (without VR application) in Blender based on historical documents and current aerial photographs. The authors noted in their conclusion that further development using photogrammetric methods would be a research interest.

Research Questions

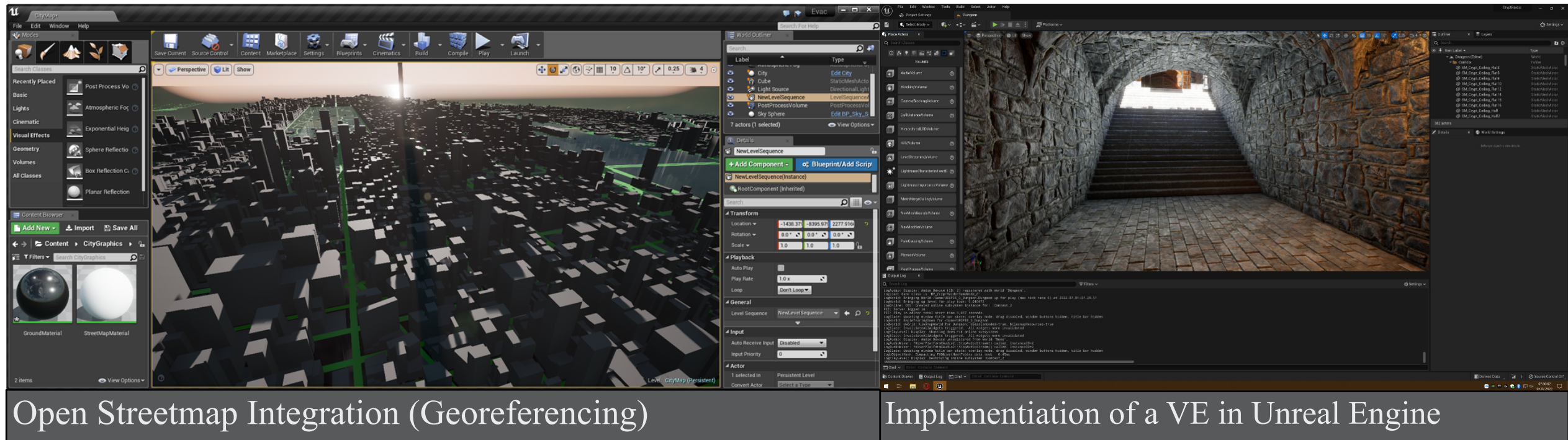
The following research questions are the focus of this study:

- *Question 1:* What requirements must historical source material (images, photography, and video) come across for a virtual reconstruction to be carried out?
- *Question 2:* What methods and processes can be applied for a virtual reconstruction of building objects based on historical documents?
- *Question 3:* Can virtual reconstructions using historical maps and current maps be (semi-)automatically georeferenced and integrated into a VR application with a geographic reference?

Classification to GIS

Game engines have seen increased popularity in recent years because they make recurring development concepts for 3D applications more accessible. Unity and Unreal dominate the market due to the numerous documentation available and their user-friendly licensing structure (Jungheer & Schlarb, 2022). Consequently, game engines are not exclusively used for the development of video games, but also for interactive visualizations in the fields of architecture, medicine, and mechanical engineering. Geovisualizations, which represent objects in a georeferenced space, are made possible through extensions like ArcGIS Maps or Cesium; however, they already require georeferenced 3D models (Atzl et al., 2023).

3D reconstructions must be precise in their object properties and should conform to historical documents. This includes not only the building components within a local coordinate system but also the upcoming georeferencing of the entire building model. In this way, further utilization of the models for applications such as digital twins is enabled.



Data and Methodology

To find objects for the work of reconstruction, the initial step requires the identification of archival sources. Cities and municipalities collect regional materials from this perspective, including photographs, video footage, sketches, construction documents, and blueprints. The work consequently takes place in collaboration with the city and state archives of the respective region (Berlin and Bamberg).

In the second step, suitable search criteria for the images must be established, particularly those that support the geometry and relevant perspectives for photogrammetry. Ideally, image data should provide a high resolution, a clear focus on the object, and a sufficient image angle (Remondino & El-Hakim, 2006).

To extract spatial information from historical photographs, particularly those from the period of 1900 to 1950, methods of computer vision are applied. The key techniques include photogrammetry, the use of machine learning, and 3D reconstruction with its shape-from-X approach (Szeliski, 2022).



Photogrammetry is a method that creates three-dimensional models from two or more images of the same scene taken from different perspectives. This technique is used to accurately depict objects and landscapes in their spatial form by analyzing the geometric relationships between image points (Eidg. Forschungsanstalt WSL (Hrsg.), 2023). Such an approach can be applied in historical photographs to reconstruct spatial information and geographical features.

Moreover, machine learning in the context of computer vision offers powerful tools for pattern recognition and classification. By using algorithms that learn from large datasets, historical images can be processed to identify recurring features or objects. This method requires, on one hand, a comprehensive research, but can successfully be used for the detection of structural elements in images (Kessler & Gómez, 2020).

Findings

The archival research has already revealed objects to which potential material for a virtual construction is attached. Among the collection of building objects is the *Alte Fleischhalle* from Bamberg, as well as potentially the *Willy Aron House* on Luipoldstraße. Both buildings still exist and are used as references. In Berlin, there is the *Beuth House*, which today belongs to the Berliner Hochschule für Technik. This building still exists as well, though structural changes were made during the post-war period. Two buildings that have been lost are the *Palast-Hotel* at Potsdamer Platz and the *Reich Ministry of Justice* in Wilhelmstraße. For these buildings, pictorial material is available in the local municipal archives.

The example of the *Alte Fleischhalle* was completely recorded from the outside with a drone and transformed into a 3D model using photogrammetry. This study contributed to gaining insights into the requirements for image material and better understanding the process of photogrammetry concerning building reconstructions. With this knowledge, the image requirements for archival research were revised.

This building model was also used for a study on the georeferencing of 3D models and integration into game engines. It was determined how geographic reference data from the original drone images behaved up to integration into a virtual environment. Currently, it is not possible to ensure a simple transfer of this information since the data exchange formats for 3D models and game engines generally use a Cartesian coordinate system. The use of reference systems is also limited and only possible through third-party software.

The integration into a virtual environment was tested and made available as a VR application. Users were able to provide feedback at public events and were observed regarding their usage interaction.

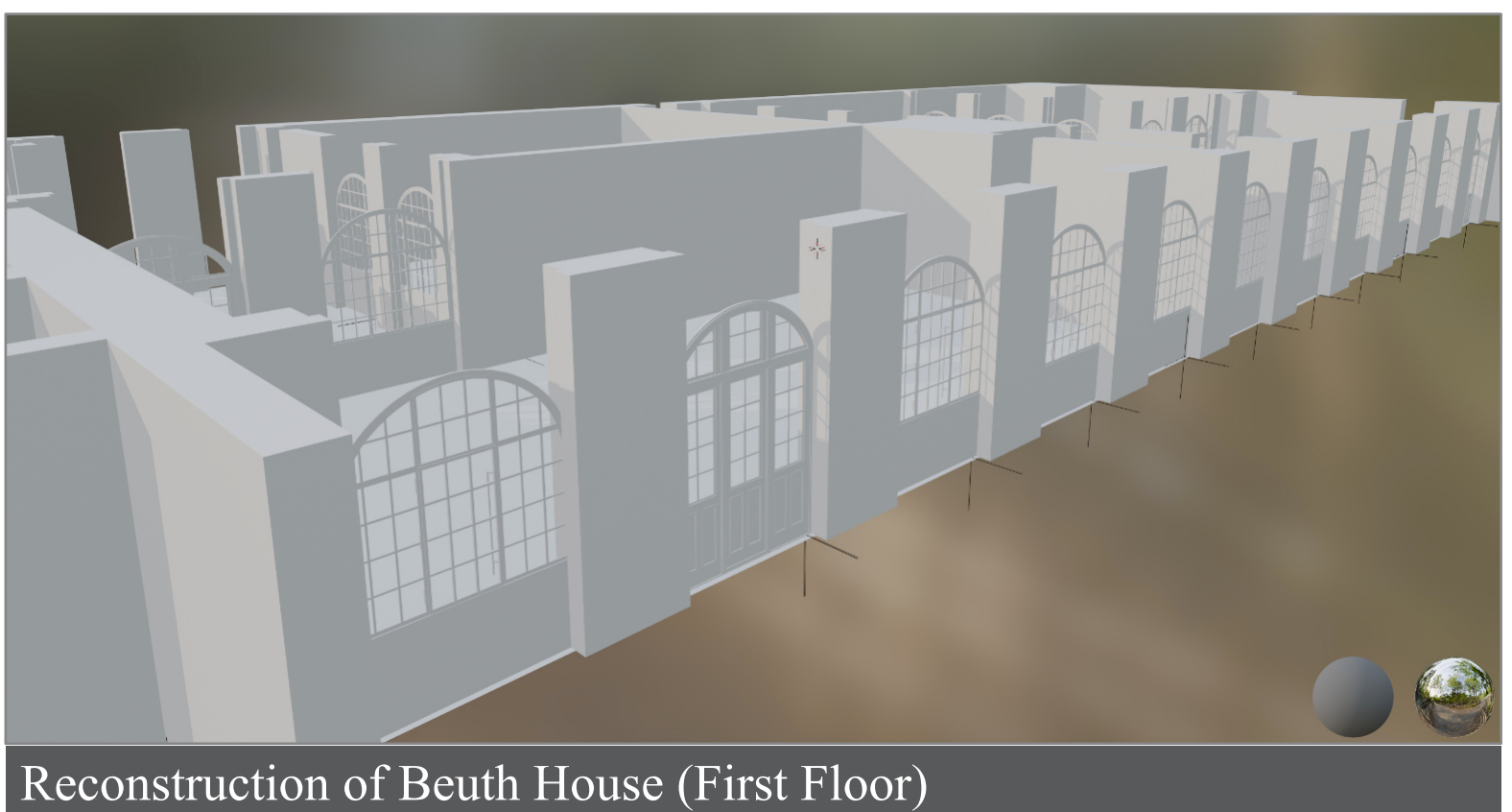
Historical image material must not only depict suitable geometries and perspectives for automated reconstruction but must also possess additional image properties, such as as high a resolution as possible, low contrast, no noise, or color, etc. Recently, AI-based models have been able to improve image data regarding the aforementioned parameters. It was investigated which already established AI models and parameters could enhance historical recordings to use them successfully for photogrammetric methods.

Currently, based on archival research, work has begun on producing 3D models. These are used as references for further steps in order to compare reconstructed results.

Challenges and Discussion Topics

The greatest challenge lies in the extraction of spatial information from historical images. Identifying and (further) developing suitable methods for this purpose, particularly with the goal of automated 3D reconstruction, is not trivial. Especially, the source material exhibits enormous differences depending on the object and photography technique, which does not necessarily make the results comparable.

The integration of additional multimedia content into a virtual environment can enhance immersion. An assessment or evaluation of which media and in what manner they can be integrated into a virtual environment is still pending.



Reconstruction of Beuth House (First Floor)

Geodata from the period (1900-1950) is not necessarily embedded in the historical image material. Manual post-processing is still required. An automated approach is not yet known.

Geovisualization in an immersive virtual environment is possible but only achievable through indirect means. In geography, the format CityGML is common, which combines 3D information and geoinformation (reference system).

However, this format is not supported by game engines, except indirectly through mapping software. There can also be errors in the transformation process.

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