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# Semantic segmentation of historical thematic maps from WWII

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**Abstract:**

Cities affected by the destructive effects of the Second World War had to undertake a revision of their building stock between 1939 and 1949. City administrations, specialised authorities, associations, companies and private individuals created a wealth of maps that made material and non-material assessments of the buildings or provided information on changes to technical infrastructures, demolition and stabilisation needs or rubble displacement and building material extraction. Such thematic maps emerged in accelerated procedures and specifically in preparation for decisions to demolish or rebuild after the war and today they are visual sources of the transformation intentions of the time (Enss & Knauer, 2022). As one of the most heavily bomb-damaged cities in Germany, with its historic city centre almost entirely destroyed, Nuremberg provides an excellent example for exploring the use of thematic maps as media for the urban transformation of postwar cities. This can be achieved by converting features depicted in historical maps into geospatial data that is subsequently analysed with a GIS (Ludwing & Alvanides, 2023).

The project UrbanMetaMapping (UMM) brings together maps from the war/postwar period, by converting urban features depicted in these maps into geospatial data that can be further analysed within a spatio-temporal analytical framework (Xydas et al., 2022). This contribution presents a method for capturing spatial information from historical thematic maps for the German city of Nuremberg from the 1940s, mindful of the various challenges of semantic segmentation in historical thematic maps in the context of the Nuremberg case study. The methodology employed is based on a Deep Convolutional Neural Network (DCNN) utilizing the U-Net architecture (Heitzler & Hurni, 2020). The network is trained in a supervised manner to perform image-to-image semantic segmentation, where the input consists of segmented patches extracted from the original historical map, and the output comprises the corresponding pixel-level semantic segmentation classes indicating the historical value of buildings. For this purpose, manually digitized building footprints and their associate semantic classes are used as ground truth for training purposes. To optimize model performance, multiple patch-sampling strategies are explored, varying in their spatial coverage to ensure a diverse and representative training dataset.

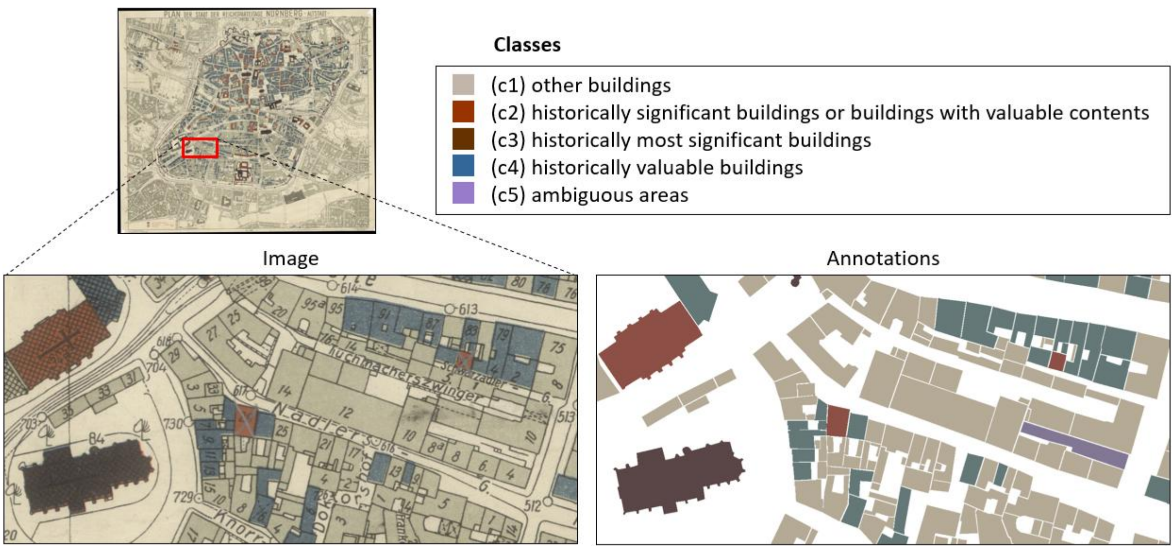


Figure 1. Upper: thematic map of Nurnberg 1942 [StadtAN_A4_X_210] with historical buildings class annotation. Lower: section of original map (left) and its ground truth thematic annotation (right).

Furthermore, extensive data augmentation techniques, including geometric transformations (rotation, flipping, scaling), are applied to enhance the model's generalization capabilities and robustness against noise and distortions present in historical maps. These noise factors include textual annotations, street demarcations, and a diverse array of graphical symbology, which pose significant challenges for automated feature extraction (Kesidis et al., 2019). The trained U-Net model demonstrates high efficacy in pixel-level semantic segmentation, as evidenced by comprehensive evaluation metrics such as Global Accuracy, Mean Intersection over Union (IoU) and Mean Boundary F1 Score. The high-resolution segmentation capabilities of the model affirm the suitability of deep learning architectures for historical map analysis, enabling the precise identification and classification of geospatial features such as building geometries from historical cartographic sources. Our findings validate the applicability of deep learning-based semantic segmentation techniques in the domain of historical cartography, offering a scalable solution for the automated digitization and vectorization of spatial information from archival maps. The integration of such methodologies paves the way for advanced geospatial analytics, supporting historical urban studies, land-use evolution analysis, and heritage conservation efforts.

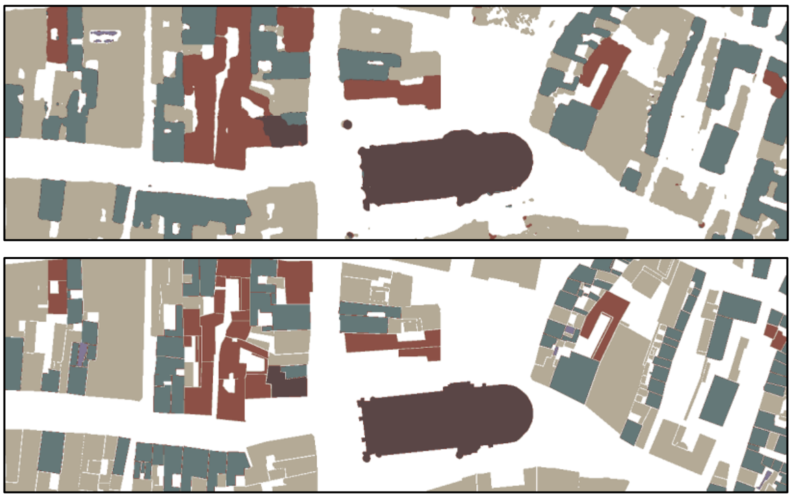

Figure 2. Upper: semantic segmentation results. Lower: corresponding ground truth annotation [StadtAN_A4_X_210].

An interesting prospect of this method is its extension to larger datasets and to different geographical areas. The same clustering process can be applied to other historical maps of cities that were devastated during World War II, helping to systematically record and analyze the effects of bombing on urban structures. In addition, the methodology could be adapted for the study of modern disasters, such as the detection of damage from natural disasters (earthquakes, floods, fires) using geospatial data and aerial photographs. Finally, the use of machine learning techniques, combined with geospatial data analysis, opens up new possibilities for the automated interpretation of historical cartographic evidence. The methodology presented here can form the basis for more advanced analysis systems, which will incorporate other techniques, e.g. deep learning, for even more accurate identification and categorisation of features on historical maps.

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Monument Value Level Map (Nürnberg, "Altstadt") [StadtAN_A4_X_210] https://online-service2.nuernberg.de/stadtarchiv/objekt_start.fau?prj=verzeichnungen&dm=Archivalien&ref=147475

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