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The Viennese Building Stock from 1920 to 2018: a Prototype Model

Ferdinand Reimer, Ulrich Kral

(DI Ferdinand Reimer, Technische Universität Wien, Karlsplatz 13, 1040 Wien, ferdinand.reimer@tuwien.ac.at)
(Dr. Ulrich Kral, Technische Universität Wien, Karlsplatz 13, 1040 Wien, ulrich.kral@tuwien.ac.at)

1 ABSTRACT

Historical urban archives and todays geospatial data provide rich information about the development of settlements. The goal of our study is to show the historical development of the building stock in the city of Vienna. We developed a spatial-temporal model and tested its application on the Viennese 18th district. Four steps were carried out. First, we made a 3D reconstruction of the building stock of 1920. We digitalized historical city maps and manually converted them into vector data. The building heights originate from a historical building registry and the construction period from a historical thematic map. Second, we used the existing building stock model for 2018 from the city government and attributed the construction period to each building. To get the best quality data on the construction periods, we merged three different spatial datasets from the city of Vienna. Third, we developed an algorithm to compare the building stock of 1920 and 2018. The comparative analysis produced thematic maps with demolished and newly constructed buildings. Fourth, we used these bottom-up results and developed an optimization model to determine the construction and demolition rates over time. We found that the total built area increased from 0,8 to 1,1 Mio m^2. About 0.02 Mio m^2 have been demolished and replaced with about 0.03 Mio m^2. About 0.02 Mio m^3 have been newly constructed without prior demolition. The annual demolition rate (demolished built area over total built area) ranges between 0.1 and 0.3% p.a. The annual construction rate (constructed built area over total built area) steadily declines from 1.3% p.a. in 1920 to 0.3% p.a. in 2018. In the future, we will extend the geographical scope of the analysis to the entire city. At the end of the project, the datasets will be available under a creative common license and can be used for applications in the field of urban history and cultural heritage research.

Keywords: geographical, spatial, building stock, development, trends

2 INTRODUCTION

2.1 State-of-the art modelling approaches

Settlements, its buildings and infrastructure, change their physical apperance over space and time. Urban archives are viable information pools to recontruct historic urban patterns, and present GIS-based building stock models provide accurate physical building paramters (location, built area and volume). Despite other purposes, researchers use the historical tracking of settlement data to estimate the material flows and stocks associated with buildings and infrastructure. The latest overview on material stock and flow models for the built environment is given by Lanau et al. (2019). The review shows three distinctive approaches for dynamic modelling of the housing stock. First, using statistics with physical building paramters over time (e.g. Aksözen et al. 2017, B. Müller 2006). Second, using GIS-based building stock models to estimate building stock paramters of today, and using statistics and backwards calculation to estimate physical paramter of the past (e.g. Džubur and Laner 2018, Lederer et al. 2019). Third, using GIS-based building stock models at different points in time to analyse spatio-temporal changes. For instance, Tanikawa and Hashimoto (2009) analyzed the changes of Salford in Manchester, UK, from 1849 to 2004. Another example is given by Kleemann et al. (2016), who used a change detection methodology based on areal images to identify demolished buildings between 2013 and 2014. This third approach is addressed in this conference paper.

2.2 Aim and structure of the paper

The aim of this conference paper is to characterize the spatio-temporal development of the building stock in Vienna. We established a modelling approach (section 3.1), defined the system boundries in time and space (section 3.2), collected and digitalized raw data (section 3.3), established a city map of 1920 and 2018 (section 3.4, 3.5), made a spatio-temporal comparsion of the buildings between 1920 and 2018 (section 3.6) and finally estimated the development of the built area per building (section3.7). The results are presented in section 4.

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It is noted that collecting and digitalizing historical data are very time consuming. For this reason, we developed a protoype that limits the geographical scope to a relatively small area in the city of Vienna (section 2.2.1). The development of the protopye enabled us to develop an effective and effizent way for collecting and processing relevant data. In the future, we will use the same modelling approach and extend the geographical scope to the entire city.

3 MATERIALS AND METHODS

3.1 Modelling approach

The goal of our study is to identify spatio-temporal changes in the Viennese building stock between 1920 and 2018. Basically, we compare city maps of two different points in time, which enables the identification of buildings that have been demolished, replaced and constructed. To run the analysis, we developed a modelling approach as given in in Fig. 2. First, we defined the system boundaries in space and time. Second, we were looking for historical raw data in archives. As most of the data are available in analog format only, we converted them into a machine readable-format. Third, we linked the digital raw data and established a city of map 1920 by mapping all buildings in a geographical information system (GIS) and added the attributes, built area, volume and construction period. Fourth, we compiled datasets from the city government and established a city map for 2018, including the attributes volume and construction period for each building. Fifth, we used the spatial and temporal dimensions of each building (location, built area, construction period) and compared the 1920 and 2018 city maps. This allows identification of buildings that have been demolished and newly constructed. Sixth and last, we used the bottom-up data and estimated the annual rates of demolished and constructed buildings.

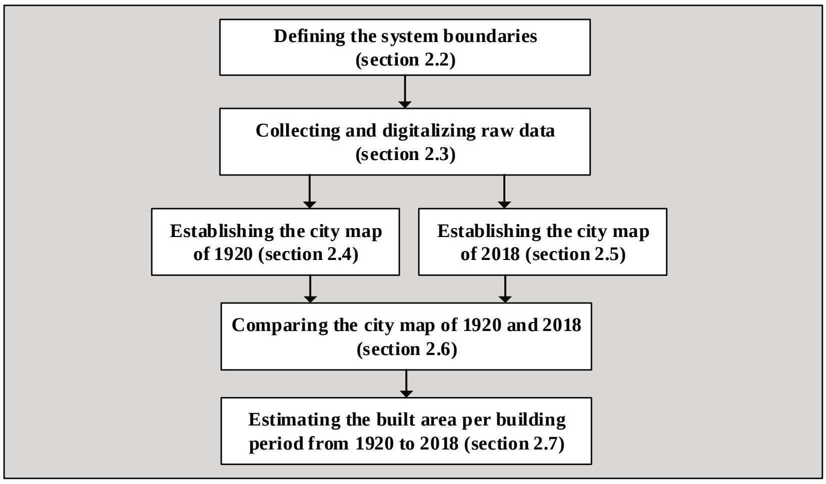

Fig. 1: Overview of the modelling approach. Each task corresponds with one of the subsequent sections in this paper.

3.2 Defining the system boundaries

3.2.1 Geographical scope

We developed the prototype for the cadastral communities 1501 (Gersthof), 1514 (Währing) und 1515 (Weinhaus), which are largly located in the 18th district in the city of Vienna, Austria (Fig. 2). The selection of this case study area has three reasons. First, the urban development of the area is well documented by Eigler (1990). This gives us the opportunity to put the development of the building stock in urban planning perspective. Second, we as study authors know the 18th district very well. To know the way around the place helps to interpret, process and validate building data. Third, a vector-based map was available including all buildings in the study area at the year 1920. The map was produced by Friedrich Hauer, deliverd to the Wiener Stadt- und Landesarchiv and published in the "Historischer Atlas von Wien (Wiener Stadt- und Landesarchiv 2015).

3.2.2 Temporal scope

We analysed the development of the bulding stock from 1920 to 2018. We started with 1920, because it marks a turning point in the demographic and political development and the building culture and urban design. In a demographic perspective, the population peaked in 1920 at about 2 Mio inhabitants. This was the highest number in the city's history. From a political perspective, the Austrian-Hungarian monarchy (1867-1918) ended and the the first republic started (1918-1938). Furthermore, the urban design and architectural culture changed drastically. In 1918, the so-called founder period (in German: Gründerzeit) ended and therewith the building block structure and the representative building culture of the empire. Between 1923 and 1934, the socio-democrats implemented a social housing program and constructured close to 70'000 apartments, which gave home to about 10% of the total population (Stadt Wien 2019a).

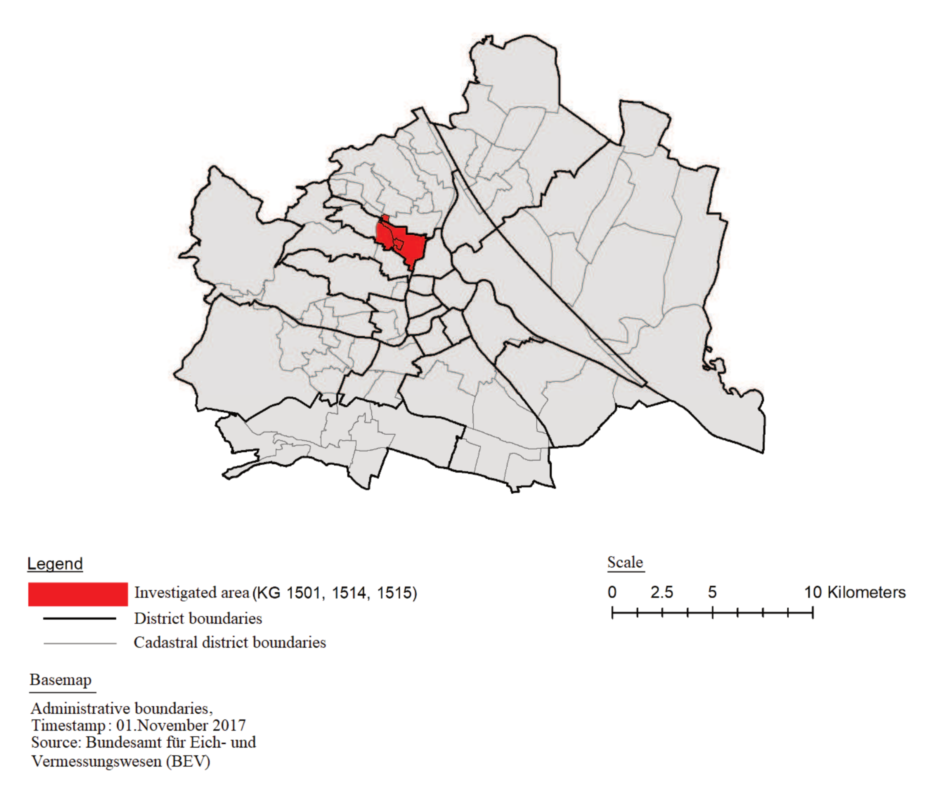

Fig. 2: Area under investigation (red colored), located in the city of Vienna, Austria.

3.3 Collecting and digitalizing raw data

Tab. 1 provides an overview on the raw data and indicates wheater the raw data source is available in a machine-readable format, or not. Latter ones were converted into machine-readable formats as followed:

- Building Cadastre of Vienna: For the analogue scan of the Building Cadastre of 1928 (Salzberg 1928) we used the optical character recognition feature of the "ABBYY FineReader" software. We then applied an algorithm written in Python to identify misplaced characters using "regular expressions", an encoding standard for text patterns. If extracted information such as a building address deviated from a given text pattern, the algorithm applied corrective procedures. In other cases where needed to manually review and correct the output.
- City map 1975: A geoferenced raster image of the 18th district of Vienna, imaging the buildings in 1975. We vectorized the dataset and created building polygons.
- Building age map: To convert the thematic information of the building age map 1920 (Wiener Stadt- und Landesarchiv 2015) into machine-readable format, we used a machine-learning algorithm called "Maximum Likelihood Classification". This algorithm is integrated in the geo-information systems software ArcGIS. It classifies the colours in a raster data set into predefined categories. The resulting categories of our application corresponded to the thematic colour encoding in the map, thus making the thematic information digitally available.
- Building property documents: We randomly selected 39 buildings, which were present in 1920, and acquired the original construction plans for building permission (Stadt Wien 2018). For each building, we measured the number of floors, the eave height, and the built area, and formulated a linear regression with the eave height as response variable and the number of floors and the built areas as explanatory variables.

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Title	Content	Format	Machine-readable	Reference
Building Cadastre of Vienna, 1928	A directory released in 1928, listing all buildings per address. For most buildings, the following details are given: number of floors, area, year of construction, number of flats, number of commercial units, buyer, rental income.	PDF	No	Salzberg (1928)
Basemap 1920	A 2D map with geoferenced building polygons in the 18th Viennese district in 1920.	DWG	Yes	Hauer (2018)
City map 1975	A 2D map in the form of raster data, showing the buildings of the 18th district in 1975	JPG	No	Stadt Wien (2019b)
Building age map 1920	A thematic map showing the construction period for the buildings in Vienna in the year 1920.	JPG	No	Wiener Stadt- und Landesarchiv (2015)
Historic Fire Brigade Map	A city map from 1933, made for the fire brigade, showing street names and the individual buildings including their address number.	TIFF	No	BEV (2018b)
Property cadastre	Georeferenced property polygons of the 18th district.	SHP	Yes	BEV (2018c)
	Data table of the properties in the 18th district. Includes cadastral district, property code, address, postal code, street code, geographic coordinates	CSV	Yes	BEV (2018a)
Adress Service Vienna	Identification of an address according to given geographic coordinates, and identification of the geographic coordinates of a given address.	JSON	Yes	Stadt Wien (2018b)
Building property documents	Documents that include all legal information about a building and a history of legal proceedings concerning the building.	Paper	No	Stadt Wien (2018e)
Area-multi-purpose map	Georeferenced building polygons of Vienna, recorded through annual overflights, where 1/3 of Vienna is covered in each year.	WFS	Yes	Stadt Wien (2018d)
Construction period and Building Typologies	Georeferenced building polygons with the period of construction for a limited set of buildings (about 60'000) in Vienna and the inventory date.	SHP	Yes	Stadt Wien (2018c)
Urban Inventory	Georeferenced building polygons containing inventory data such as construction type, construction period, use, number of floors, given space below ground, and date of inventory.	SHP	Yes	Stadt Wien (2018f)
Adress, building and apartment register	The database registers each building and attributes a wide range of building specific data, as for instance, geographical location, construction period, date of inventory.	XLS	Yes	Stadt Wien (2018a)

Tab. 1: Raw data sources

After we collected and processed all data for the map of 1920, we combined the data into a single comprehensive data set. The resulting data set is a shape file containing the buildings of 1920 in a vector graphics format, with data attached to each shape. The relevant data resulting for each building is the a) location and built area, b) building volume and c) year or period of construction.

- Location and built area: The basemap of 1920 includes the polygons of the buildings in 1920, without georeferencing (Hauer 2018). By comparing the district boundary and the outlines of the blocks formed by building clusters in the map of 1920 with a map of today, we gave the correct geographical location to each building as well as its correct scale. We added the built area by using the integrated function “calculate area” in ArcGIS, which calculates the respective area of a polygon that has been geographicaly located, as can be seen in Fig. 1.

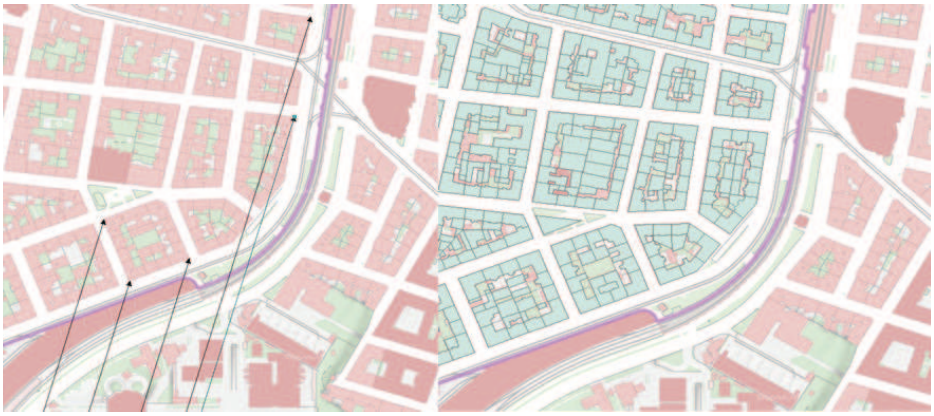

Fig. 3: Geographic adjustment of the basemap 1920

- Building volume: In order to calculate the volume of each building, we used the number of floors to estimate its height. We took this information from the building directory of 1928 (Salzberg 1928), which we had previously digitized. To identify each building in the directory on the map of 1920, we needed the address each building had in 1928. We acquired the address of 2018 for each building by using the Viennese reverse geocoding service (Stadt Wien 2018b). To know whether an address has changed since 1928, we compared building addresses of 2018 with the addresses in the directory of 1928. Adresses of 1920 that didn't match with 2018 adresses were manually corrected. The final result are two addresses attached to each building, one for 1928 and one for 2018.

To validate each address of the buildings in 1928, we used the map of the fire brigade from 1933 (BEV 2018b), where every building unit has an address label.

After we attached the address to each building in the map of 1920, we added the number of floors as an attribute, as well as the eave height (see section 2.3). We then multiplied the height estimate with the ground area covered to calculate an estimate for the buildings' volume.

- Year or construction period. To receive the period of construction for each building in 1920, we extracted the relevant data from the building age map 1920 (Wiener Stadt- und Landesarchiv 2015), which we had previously digitized. To combine the colour-encoded data of construction periods with the vector graphics in the map of 1920, we fitted the raster data set showing construction periods in 1920 to the 1920 vector data set and applied the function "tabulate area" in the software ArcGIS.

The "tabulate area" function aggregates the data from a raster data set within the confines of individual polygons in a vector data set. The result is visible in Fig. 4. We used a statistic of the raster data each vector shape covers, and determined the respective construction period for each building.

Fig. 4: Basemap of 1920 (Hauer 2018) combined with the construction period data from the building age map of 1920 (Wiener Stadt- und Landesarchiv 2015)

3.4 Establishing the city map of 2018

For the city map of 2018, we used the area-multi-purpose map (Stadt Wien 2018d), which includes the geoferenced building polygons and attributed the built area, the building volume and the year or period of construction.

- Location and built area: The area-multi-purpose map (Stadt Wien 2018d) already contains the correct geographical location of each building. We used the "calculate area" function in ArcGIS to add the built area.
- Building volume: The area-multi-purpose map (Stadt Wien 2018d) includes the attributes "O_KOTE", the height of the highest point of the building in meters above sea level, and "HOEHE_DGM", the height of the buildings ground floor center point above sea level. By subtracting "O_KOTE" from "HOEHE_DGM" in ArcGIS, we added the height of the building. We then multiplied the built area with its calculated height to receive the volume of the building.
- Year or construction period: For the building age of 2018, we had three datasets available: the "Construction period and Building Typologies" (Stadt Wien 2018c), the Urban Inventory (Stadt Wien 2018f) and the "Adress, building and apartment register" (Stadt Wien 2018a). All datasets contained the year of inventorization. For inventory years until 2000 we have chosen the

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construction period with the latest update. For the years starting from 2001 we have chosen the building age information from “Adress, building and apartment register” (Stadt Wien 2018a), because this data source was most precise. We then transferred the preselected building age information to the area-multi-purpose map.

3.5 Comparing the city map of 1920 and 2018

We made a spatio-temporal comparison of the buildings between 1920 and 2018. To assign each building its inter-temporal counterpart, we connected every building shape of 1920 to the building shape of 2018, and vice-versa. The criteria for the connection was the grade of spatial overlapping. With respect to the temporal dimension, we compared the construction period of the buildings in 1920 and in 2018 in relation to each other. Based on the comparison, we applied the scheme in Fig. 5 and defined the status of the buildings in 2018.

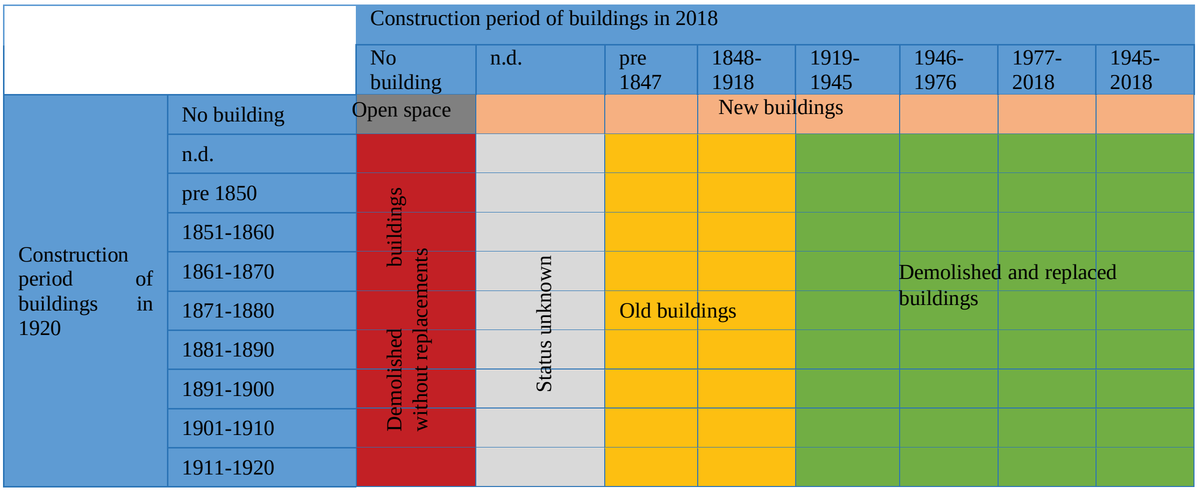

Fig. 5: Scheme for identifying the building status. Notes: n.d. = not defined.

3.6 Estimating the built area per construction periods from 1920 to 2018

The basic idea is to use known data on the built area at specific points of time and to estimate the unknown continuous development of the built area from 1920 to 2018. After we have established and compared the city maps of 1920 and 2018 (section 2.4, 2.5, 2.6), we calculated a) the total built area of all buildings of 1920, 1975 and 2018, b) the built area of buildings constructed before 1920, at the time of 1945, 1975 and 2018, c) the share of the total built area per construction period in 2018. These datapoints are plotted with green colored boxes in Fig. 6.

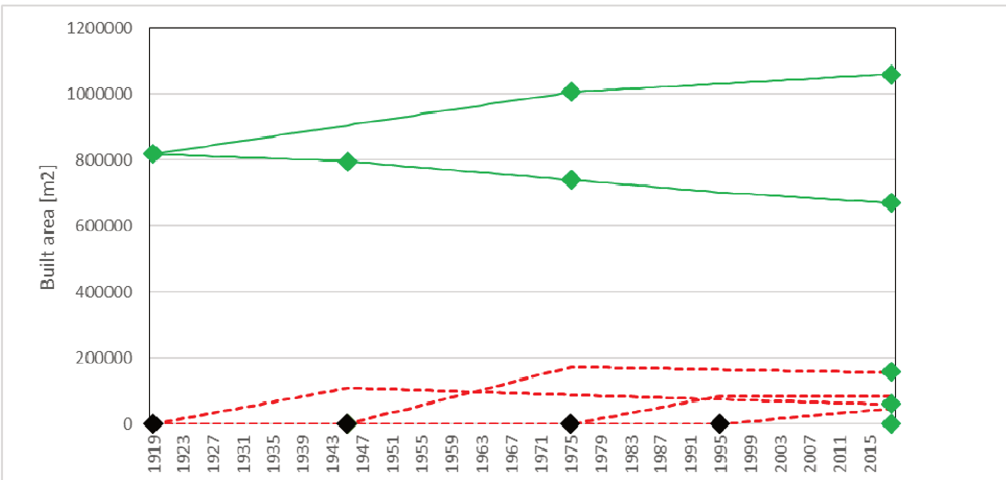

Fig. 6: Scheme for estimating the built area per construction period. The green colored datapoints orginate from the GIS analysis and act as input data for the model. The temporal developments of the built area per construction period (red dotted lines) are unknown.

To simply the analysis, we assumed a linear development of the built area between the known data points, a constant rate of new buildings within the construction period (e.g. 1945-1975), no demolitions within the construction period, and a constant rate of demolitions after the end of the construction period (e.g. after 1976).

Based on the known datapoints and the assumptions, we calculated the unknown peaks for the built area of each construction period (red dotted lines in Fig. 6). The peak is the end of each construction period and consideres that at each point of time, the sum of the build areas from the individual construction periods results the total built area.

4 RESULTS

4.1 Mapping demolished, replaced and new constructed buildings

Based on the comparision of the city maps of 1920 and 2018, as described in section 2.7, we produced a new spatial data set including georeferenced building polygons. The building polygons (location, built area) represents the situation 2018 and the attribute “building status”. The building status “old” stands for a building that remains unchanged between 1920 and 2018. The building status “demolished with replacement” shows the building polygon of 2018. It existed in 1920 and has been demolished and replaced between 1920 and 2018. A building with the status “new” did not exist in 1920 and has been newly constructed between 1920 and 2018. Apart from the building status, each the following attributes (if known) have been attached to the building polygons: “construction period”, “address”, “built area” and “volume”. Each attribute is given twice, one for the year 1920 and one for the year 2018.

From a spatial perspective, we found that former rural areas in the northwest and southwest of the case study area have been settled, included the construction of new buildings. This finding is line with Eigler (1990), who describes the extension of the city towards the Wienerwald. The replacement of old buildings by new one is scattered over the entire case study area.

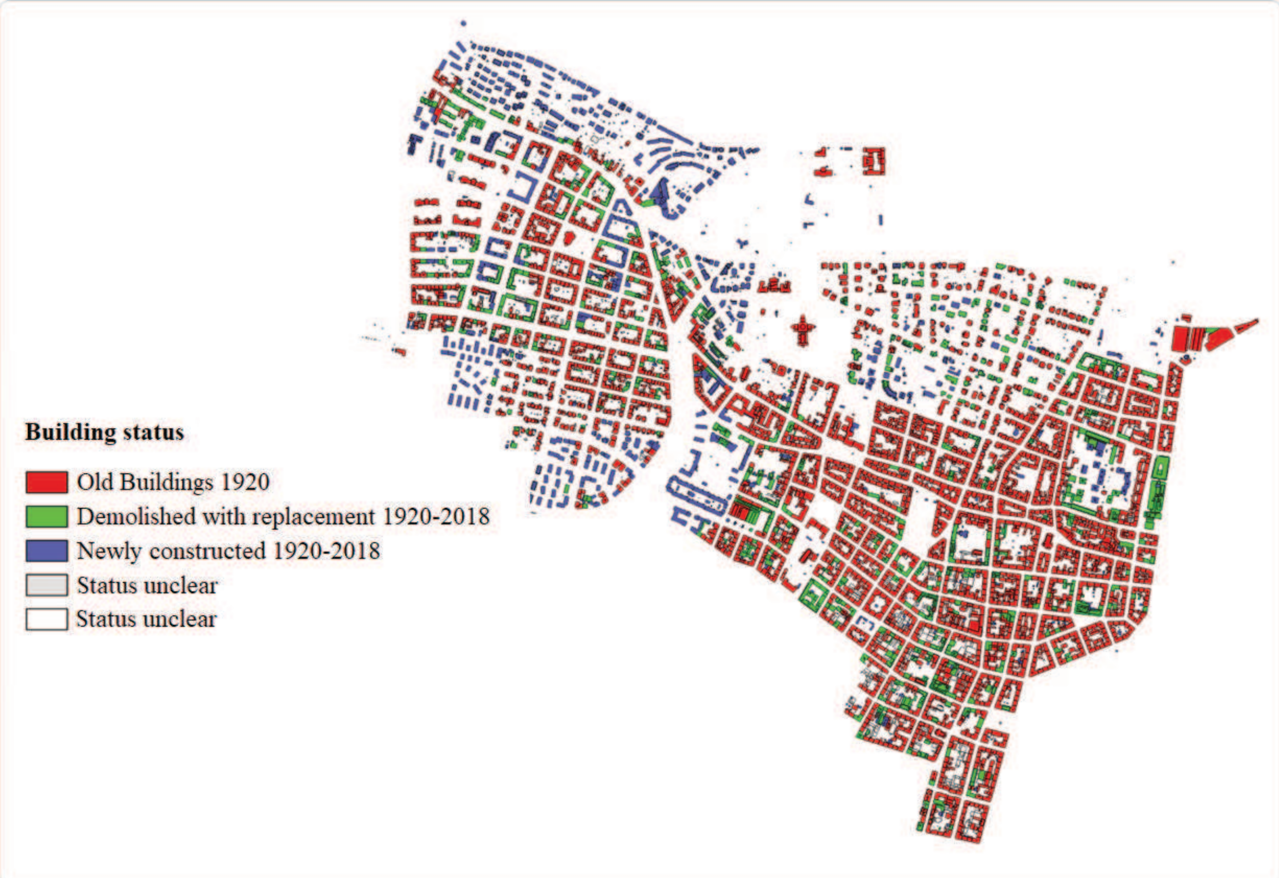

Fig. 7: Building stock of the year 2018.

4.2 Results for changes of built area between 1920 and 2018

Figure 4 shows a waterfall chart representing the total built area in 1920 and 2018 and the changes between 1920 and 2018. We summarized the built areas of the buildings in the city map 1920 and plotted the result

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(82 * 104 m^2), subtracted the demolitions from the building stock 1920 (18 * 104 m^2), added the replacements and extensions (25 * 104 m^2), added the new constructions (17 * 104 m^2) and resulted 106 * 104 m^2 in 2018.

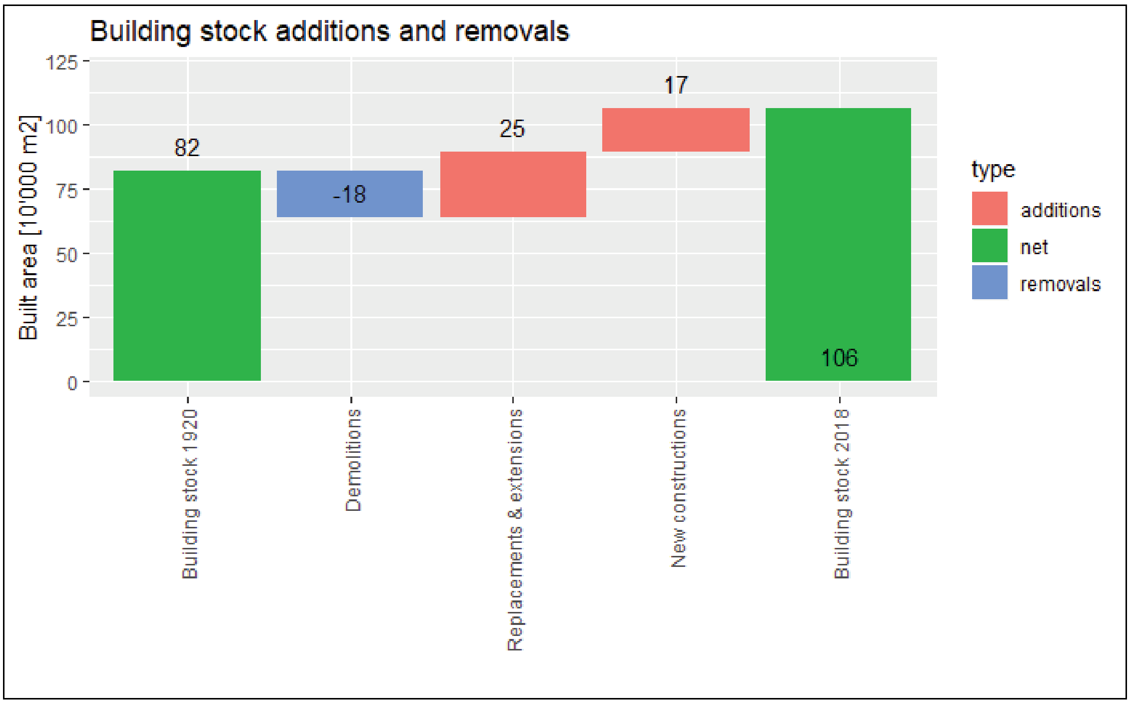

Fig. 8: Total built areas from 1920 to 2018 per building status.

4.3 Built areas per construction period from 1920 to 2018

Fig. 5 shows the development of the total built area between 1920 and 2018 per construction period. We found that the total built area increased from 0,82 million m^2 (mio m^2) to 1,06 mio m^2. The buildings, which have been constructed before 1920, dominate the building stock all over the time (red line). However, this cohort has lost about 27% of the built area between 1920 and 2018. The second largest built areas orginate from buildings constructed after second world war, between 1945 and 1975 (magenda line).

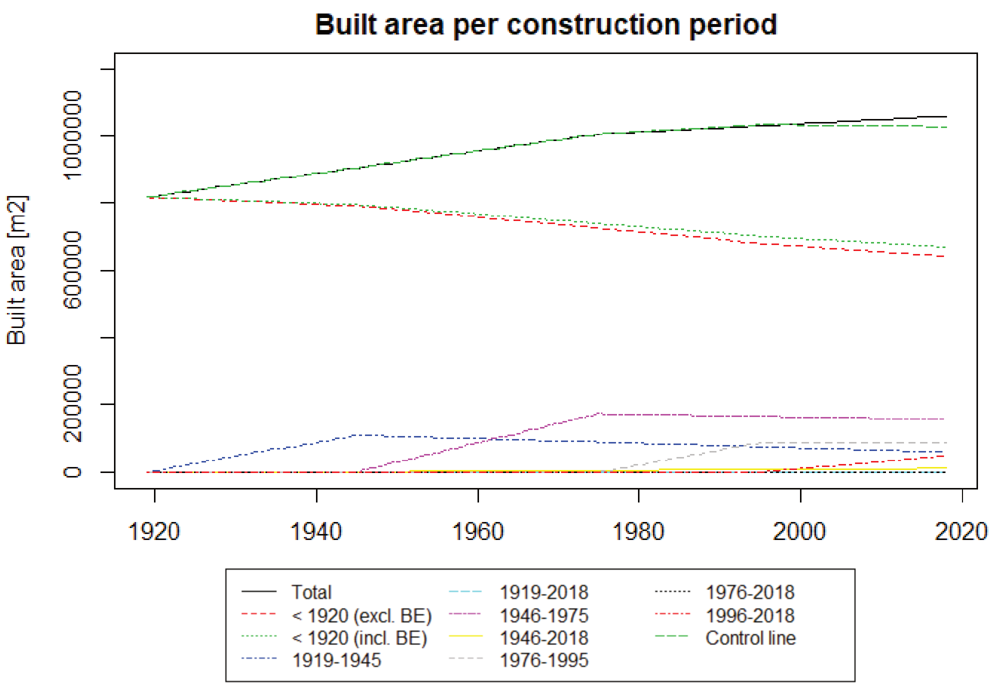

Fig. 9: Development of the building area from 1920 to 2018 per construction period. Notes: BE = Building Extensions.

4.4 Rates of annual built area additions and removals

Fig. 9 is the starting point to estimate the annual increase and decrease of the total built area in the case study region. The annual increase rate is the annual addition of the built area (due to replacements and new constructions) over the total built area at the start of the year. The annual decrease is the annual removal of the builts area (due to demolition) over the total built area the the beginning of the year.

We found that the addition of built area starts with 1.3% per anno (p.a.) in 1920 and steadly declines to 0.3% p.a. in 2018 (Fig. 10). The removal of built area is at 0.1% p.a. between 1920 and 1945 and steps up to 0.3% p.a from 1945 to 2018. Since mid of the 1990, the removals and additions are balanced.

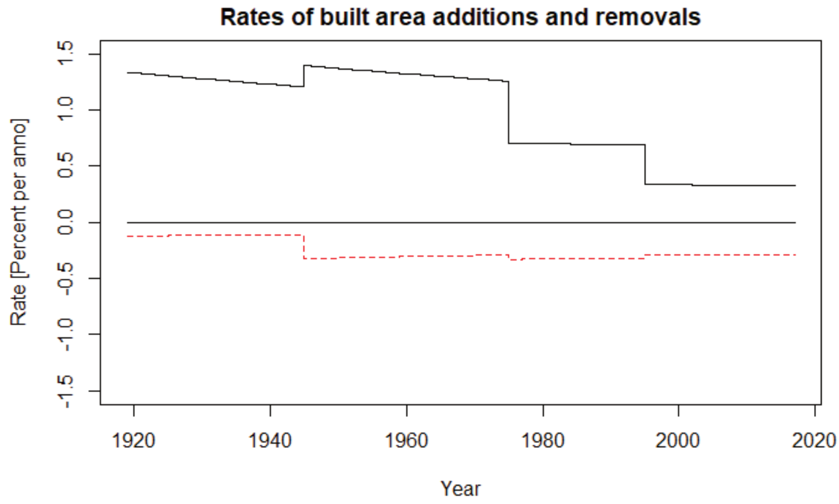

Fig. 10: Annual rates of added (black line) and removed built areas (red line).

5 CONCLUSION AND OUTLOOK

We developed a routine to analyse the spatio-temporal development of an building stock and applied the routine in a case study area in the city of Vienna for 1920 to 2018. The results include, on the one hand, new machine-readable datasets for the city of Vienna (e.g. building stock model for 1920, harmonized dataset for bulding periods in 2018). On the other hand, the linkage of the new datasets provides building-specific insights regarding demolitions, replacements and new constructions between 1920 and 2018. The computation of demoliation and construction rates over nearly 100 years goes beyond the existing body of knowledge in Viennas urban history research. Our project is still ongoing, and we plan to make the new datasets and results publicy available in a machine-readable format. We feel that the datasets can be used for applications in the field of urban history and cultural heritage research on the one hand, and waste and resource management on the other hand. As the results show long-term trends in urban planning, they can be a starting point to to develop future planning scenarios. Socio-economic factors may be embedded in the analysis, investigating correlation and causality with changes in the structure of the urban environment. Another use case of the data refer to waste and resource management, because the results of our study inform decion makers about construction and demolition activities. Our data can be linked with a material inventory of buildings, which reveals material consumption and waste generation in a long-term perspectictive. An analysis of historic urban changes with a projection into the future may help planning for capacities and location of recycling facilities and help formulate operational goals in relation to an expected trend of re-using and recycling construction and demolition waste.

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