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Supplemental data

Materials and Methods

Due to their complexity, building stocks are generally subdivided into different levels of analysis. The building stock of Zurich was analysed on three different levels, defined by different approaches, methods and data sources:

Level 1: City of Zurich

Level 2: Districts and quarters of Zurich

Level 3: Individual buildings

Figure 1 Plan of the city of Zurich in 1504 (Keller & Hegi, 1829) and in 1824 (Keller & Scheuermann, 1824). The city develops gradually within the town wall until their demolition after 1832. See also (Dändliker, 1908) – former figure 1

In this work, the focus is on the City of Zurich. Level 1 comprises the whole stock (55'000 buildings in 2010) and its development since 1832, i.e. all buildings that have existed or still exist inside the spatial limit of the commune of Zurich in 2010. The communal territory has been extended in the years of 1893 and 1934 by the integration of suburban communes. A special historical analysis concerned the development since the 14th century (source j) with maps from 1504 and 1824 (Keller plan, Figure 1).

Building stocks can be described by a simple use-age-size matrix. Table 1 shows in a condensed way the quantitative structure of the stock in 2010. There are four use classes (single family, multiple family, domestic with other use and non-domestic buildings).

Function	Average Age (year)	0-1920	1921-1950	1951-1980	1981-2010	Number of Buildings	Number	GF	Volume	Footprint
single family	72	2%	13%	2%	1%	9694	18%	5%	5%	7%
multiple family	65	6%	12%	11%	4%	17720	33%	33%	33%	32%
residential with other use	64	8%	7%	12%	8%	18810	35%	42%	41%	44%
non-domestic building	97	7%	4%	2%	2%	7724	14%	20%	21%	17%
whole stock	71	22%	36%	27%	15%	53948	100%	100%	100%	100%

Table 1 Composition of the stock in 2010 by four use and four age classes with average age of buildings, number of buildings, gross floor area, volume and footprint (in % of total)

There are slow increases and decreases for the number new constructions and demolitions. Around the year 2000, the number of demolitions exceeds the number of new constructions for the first time within the period between 1931 and 2010 (Figure 2).

Figure 2 Number of new constructed buildings (black line) and demolitions (red line) per year 1931 – 2010 (10 year sliding average) – former figure 13

Figure 3 and Figure 4 shows the evolution of the population (source h and j) and the number of buildings for the central, historic district. The number of buildings stays constant over 4 centuries (even if there is a slow and constant densification). The population increase from 1810 on (beginning of the industrialisation) clearly precedes the increase of buildings, which reaches a maximum around 1910. The decrease of population and number of domestic buildings after 1920 go parallel. This is more due to a change in the classification than to demolitions. From 1950 on the population, living in the city, remains constant and then decreases and the non-domestic building uses increase. There is an important and on-going densification of non-domestic buildings by adding floors (roof and additional basements.)

Figure 3 growth of the domestic stock (number of buildings in orange, left axis), non-domestic buildings (grey) and population (number of persons in blue, right axis) 1410-2010 of the historic center of the City of Zurich (Altstadt – District 1) – former figure 5

Figure 4 growth of the domestic stock (number of buildings in orange, right axis) and population (number of persons in blue, left axis) 1830-2010 in the City of Zurich – former figure 6

Figure 5 and Figure 6 show the complementary development of the historic core, the city with the communal limits and the agglomeration.

Figure 5 growth of the population 1410-2010 of the whole City of Zurich (light) and of the historic district of Zurich (dark) – former figure 7

Figure 6 growth of the population 1850-2000 in the agglomeration of the City of Zurich with its 5 suburb belts – former figure 8

Figure 7 growth of the domestic stock (number of buildings) 1860 to 2000 in the agglomeration of the City of Zurich with its 5 suburb belts – former figure 9

The growth of the agglomeration that became dominant from 1950 on does not have a clear limit yet (physical or institutional, Figure 7 and Figure 8). There is a growing importance of the public transport system on the agglomeration. Today the region is composed of 101 communes (Statistik Stadt Zürich, 2001), p.30.

Figure 8 Communes of the agglomeration of the region of Zurich — former figure 10

Figure 9 shows the volume of buildings related to type of building and size of building (2010). This representation, which has been suggested by Statistik Stadt Zürich (Mischler, 2005) for the year 2004 and was adapted for the year 2010. The horizontal axes indicate the building size (volume, logarithmic scale) and the vertical axes shows the total volume contribution of the different types. The one family buildings are small even if there is long tail of large villas. The difference between domestic and exclusively non-domestic buildings is considerable (*Figure 10*). The exclusively non-domestic buildings are in average much bigger than domestic buildings. This difference has to be kept in mind when arguing on the level of the whole stock. When comparing buildings stocks these differences must be taken into consideration.

Figure 9 Volume (m^3) per Use Category and Size (logarithmic scale) in the City of Zurich in 2010 – former figure 11

Figure 10 Average volume of use categories in m^3 - former figure 12

Material description

Available data on level 1 for the whole city and on level 2 for the current districts and former surrounding municipalities (Table 2).

	Old City								New districts added in 1893								New districts added in 1934												
	Number of residential buildings		Number of apartments per building		Number of new constructed residential buildings		Number of new constructed residential apartments		Number of demolished residential buildings		Number of demolished residential apartments with construction period or year		Number of demolished residential buildings with construction period or year			Number of residential buildings		Number of apartments per building		New constructed residential buildings		Number of new constructed residential apartments		Demolished residential buildings		Number of demolished residential apartments with construction period or year		Number of demolished residential buildings with construction period or year	
Years																													
1410, 1500, 1769, 1832, 1862	g, j																												
1860, 1870, 1880, 1888, 1900	h																h												
1901-1933			e	f																									
1910, 1920, 1930	h																h												
1934-2010	d		d	d	d												d		d	d	d								
1955-2010						c																					c		
1981-2010	a	a	a	a	b	b	b		a	a	a	a	b	b	b		a	a	a	a	b	b	b	b	b	b	b	b	b

Table 2 Data sources for the reconstitution of the building stock of the City of Zurich – new table

The different sources and their exploitation

[a] Depository of the building stock in the year 2010 contain information about 55 000 buildings. Each building has his own building number, coordinates and address. The database of Statistik Zürich contains about 50 fields per building. These attributes are geometrical, year of construction, ownership, and number of apartments, insurance value, energy system ECT. This depository serves also to link information from other sources to a specific building record. (Dataset of Statistik Stadt Zürich)

[b] Information concerning ca. 6000 buildings that were demolished between 1980 and 2010. It contains similar attributes (a) in particular the year of construction and the year of demolition. (Dataset of Statistik Stadt Zürich)

[c] Number of demolished apartments since 1955 for the following periods: before 1893, 1894-1920, 1921-1930, 1931-1940, 1941-1950, 1951-1960, 1961-1970, 1971-1980, 1981-1990, 1991-2000, 2000-2010 (Tabelle T_9.2.28 – abgebrochene Wohnungen nach Bauperiode, 1955-2011 – Statistisches Jahrbuch der Stadt Zürich 2013)

[d] Number of domestic buildings built or demolished each year since 1930).

(Tabelle T_9.2.40 – Gebäudebestand – nach Gebäudeart und Versicherungswert 1934-2011 – Statistisches Jahrbuch der Stadt Zürich 2013)

[e] Number of buildings built per year since 1901 (Tabelle T_9.2.23 1901-2011 – Statistisches Jahrbuch der Stadt Zürich 2013)

[f] Number of apartments built per year since 1901.

(Table T_9.2.25 – Neu erstellte Wohnungen – nach Zimmerzahl, 1901-2011 – Statistisches Jahrbuch der Stadt Zürich 2013)

[g] Number of apartments in existing domestic buildings for the years 1896-1905, only for the commune of Zurich without the later integrated communes – (Wolff, 1908)

[h] Number of existing domestic buildings and population for the years 1860, 1870, 1880, 1888, 1900, 1910 und 1920 (for the commune of Zurich and the later integrated communes, using census data)

[j] Comparative tables of buildings of the tax registers of the commune Zurich of XIV and XV century (Corrodi-Sulzer, 1939)

Statistical yearbook for the years 1905-2010 (Statistisches Jahrbuch der Stadt Zürich):
<https://www.stadt-zuerich.ch/prd/de/index/statistik/publikationen-angebote/publikationen/Jahrbuch.html> (15.07.2015)

Census in Switzerland for 1860-2010 (Volkszählungen der Schweiz):
<http://www.bfs.admin.ch/bfs/portal/de/index/150/03.html> (15.07.2015)

Processing of material

Number of new constructed buildings in time c:

$$b_{c,c}, \text{ known for } c \in [1901..2010] \text{ from source } e$$

Number of buildings standing in year t of construction year c (Table 3):

$$b_{c,t}$$

$$c \in [1832; 2010] \text{ with } t \geq c \left(\begin{array}{l} \text{known for } t \in [1980; 2010] \text{ for} \\ \text{individual buildings from source } a \text{ and } b \end{array} \right)$$

	1832-1866	1867	1868-2010
1832-1901			
1902		$b_{1867,1902}$	
1903-2010			

Table 3 Example for number of standing buildings of construction year 1867 in year 1902 – new table

Number of demolished buildings of construction year c in year t :

$$d_{c,t}$$

$$d_{c,t} = b_{c,t-1} - b_{c,t}$$

$$d_{c,t} = 0 \text{ für } t \leq c + 20 \text{ für } t \leq 1954$$

Number of apartments built in year c :

$$a_c, \text{ known for } c \in [1901; 2010] \text{ from source } f$$

Number of demolished apartments in year t from construction year c :

$$q_{c,t} \text{ known from source } c$$

Number of apartments for buildings in construction year c :

$$\frac{a_c}{b_{c,c}} \text{ known from source } g$$

1981-2010:

The basis for the reconstitution is the state of the stock in the year 2010 (source a), i.e. how many buildings provide from the different years of construction $b_{c,2010}$. The data from 1981 to 2009 (source b), contains demolition information $d_{c,1981-2009}$. This allows to determine and to validate the development for 1980 to 2009, $b_{c,1980-2009}$.

1955-1980:

The number of new apartments a_c see (f) in annex 2 and new domestic buildings $b_{c,c}$ see (e) since 1901 is known. The average number of apartments per building for 1863-1892, 1893-1900 and 1901-1906 is known (source g, p.17).

For the calculation of $b_{c,1955-1980}$ the demolition numbers $d_{c,1955-1980}$ were required. The number of demolished buildings within these periods was estimated on the basis of their distribution in the reference stock of 1980. The reconstitution of the data was realised on the basis of 8 periods of new construction 1832-1892, 1893-1920, 1921-1930, 1931-1940, 1941-1950, 1951-1970, 1971-1980 (source c).

For each period starting in time s and ending in time e the number of demolished buildings from this period was distributed by ratio of the number of standing buildings in the year after $(t+1)$ per number of all standing buildings in the year after $(t+1)$ of the construction period. This means the calculation was started for 1980 and went annually backwards in time.

For each $t \in [1980..1955]$

For $c \in [1832..1892]$ with $s = 1832$ and $e = 1892$

For $c \in [1893..1920]$ with $s = 1893$ and $e = 1920$

For $c \in [1921..1930]$ with $s = 1921$ and $e = 1930$

For $c \in [1931..1940]$ with $s = 1931$ and $e = 1940$

For $c \in [1941..1950]$ with $s = 1941$ and $e = 1950$

For $c \in [1951..1960]$ with $s = 1951$ and $e = 1960$

For $c \in [1961..1970]$ with $s = 1961$ and $e = 1970$

For $c \in [1971..1980]$ with $s = 1971$ and $e = 1980$

$$d_{c,t} = \frac{b_{c,t+1}}{\sum_{c=s}^e b_{c,t+1}} * \sum_{c=s}^e d_{c,t}$$

The number of demolished buildings in the construction periods were calculated by using the known number of demolished apartments $q_{c,t}$ (source c) and the ratio of apartments per building per construction period (source e and f or g).

$$\sum_{c=s}^e d_{c,t} = \sum_{c=s}^e q_{c,t} * \frac{\sum_{c=s}^e b_{c,c}}{\sum_{c=s}^e a_c}$$

For the construction period from 1893 to 1920, the ratio of apartments per building per construction period came from to different sources. The ratio was known for 1893 to 1900 (source g) and for 1901 to 1920 (source e and f) separately and was calculated for the whole period by transforming with the known number of constructed buildings in 1893 to 1900.

$$\frac{\sum_{c=s}^e b_{c,c}}{\sum_{c=s}^e a_c} = \frac{\sum_{c=s}^e b_{c,c}}{\left(\frac{\sum_{c=s}^{1900} a_c}{\sum_{c=s}^{1900} b_{c,c}} \right) * \sum_{c=s}^{1900} b_{c,c} + \sum_{c=1901}^{1920} a_c} \quad \text{only for } c \in [1893..1920]$$

1832-1900:

For the period 1832 to 1900, the number of standing buildings per construction year was calculated by reducing the number from the year before by the demolition rate r (source g).

$$b_{c,t} = b_{c,t-1} * (1 - r) \quad \text{with } r \in [0.1\%; 0.15\%]$$

For each $t \in [1832..1900]$

The constructed number of buildings per year is the difference between number of standing buildings in time t and the number of buildings without the new constructions in time t.

$$b_{c,c} = \sum_{c \leq t} b_{c,t} - \sum_{c \leq t-1} b_{c,t}$$

The number of standing buildings in time t was calculated year by year separated in five constructions periods 1832-1860, 1860-1870, 1870-1880, 1880-1888, 1888-1900 with s as the starting year of the construction period and e as the end year of the construction period. For the years s and e the number of standing buildings was known (source h).

*For $t \in [1832..1860]$ and for $c \in [1832..1860]$ with $s = 1832$ and $e = 1860$
 For $t \in [1861..1870]$ and for $c \in [1832..1870]$ with $s = 1861$ and $e = 1870$
 For $t \in [1871..1880]$ and for $c \in [1832..1880]$ with $s = 1871$ and $e = 1880$
 For $t \in [1881..1888]$ and for $c \in [1832..1888]$ with $s = 1881$ and $e = 1888$
 For $t \in [1889..1900]$ and for $c \in [1832..1900]$ with $s = 1889$ and $e = 1900$*

The difference between the standing buildings in the last year of a period e and the starting year s is the increase of the number of buildings within the period. This increase is distributed on the years in between according the distribution of the standing buildings from the corresponding construction years s+1 to e-1 in the year 1955. The year 1955 is the oldest year with a calculable distribution of all construction years. The distributed increase per construction year is added to the number of standing buildings from the year before $b_{c,t-1}$.

$$\sum_{c \leq t} b_{c,t} = \left(\sum_{c \leq e} b_{c,e} - \sum_{c \leq s} b_{c,s} \right) * \frac{b_{t,1955}}{\sum_{c=s}^e b_{c,1955}} + \sum_{c \leq t-1} b_{c,t-1}$$

In the year 1769 there were 1189 buildings in the commune of Zurich (source g) and 1133 in the year 1832 (source g, p.6). Basing on the ratio in the year 1860 (source h) between the Old City and the surrounding and later incorporated communes, the number of standing buildings in the surrounding communes for 1832 was estimated. The total number of buildings in 1832 for the area of the current City of Zurich resulted in 1500 buildings.

1900-1930

Number of new buildings is known (source e)

$$b_{t,t}$$

For each $t \in [1900..1930]$

The number of standing buildings in t is calculated like in Step 2:

$$\sum_{c \leq t} b_{c,t}$$

Check if survivor rate r and calculation of standing buildings correspond with end of decade:

The ratio between the number of surviving buildings from the year before in time t and the number of standing buildings in the year before allow to calculate the demolition rate r .

$$\sum_{c \leq t-1} (b_{c,t-1} * (1 - r)) = \sum_{c \leq t} b_{c,t} - b_{c,c}$$

1931-1954

For the calculation of the number of standing buildings from construction year c in time t , the number of demolished buildings in time t (source d) is distributed. The distribution for each year t follows the number of all demolished buildings between 1931 and 1954 and the share of the demolished buildings in the same period for each construction year.

$$b_{c,t} = b_{c,t-1} - \sum_{c \leq t} d_{c,t} * \frac{b_{c,1930} - b_{c,1955}}{\sum_{c \leq 1930} b_{c,1930} - \sum_{c \leq t-1} b_{c,1955}}$$

For each $t \in [1931..1954]$

for $c \in [1832; 1930]$

for $c \in [1931; 1934]$ no demolitions in this time period

At this level of granularity, buildings were considered as persistent objects, which did not change during their life span. The number and kind of renovations were not taken into account due to missing historical data. Renovations have certainly an influence on the survival of a building. The fact to not consider renovations equals that all buildings are considered renovated identically during the whole observation period.

Non-residential buildings:

Sources a , d , e and f were also available for non-residential buildings. For 1900-1930 and 1931-1954, the same procedure was used. For the period 1955-1980, the procedure for 1931-1954 was used.

The resulting ratio between residential and non-residential buildings in 1900 was kept for the calculation of the non-residential buildings prior to 1900.

References

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