Dasymetric Mapping for Detailed Population Distribution in Salzburg City

Course: Analysis and Modelling

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1.0 INTRODUCTION

Accurate population data is crucial for urban planning (cortinovis & Geneletti, 2019), environmental protection (Hu et al., 2021; Li et al., 2021), yet conventional census data is often limited by coarse spatial resolution. Demographic data is traditionally gathered through national censuses, which are typically conducted at intervals of 5 to 10 years or more. These datasets are usually aggregated at broad administrative levels, such as countries, cities, counties (Neal et al., 2022; Nilsen et al., 2021), which leads to data with coarse spatial resolution and limited temporal accuracy. Dasymetric mapping, a spatial disaggregation technique, which is often attributed to John K.wright (1936), offers a method to refine this data using ancillary variables. According to European Environment Agency (EEA), In Austria where demographic analysis supports infrastructure development, environmental planning, and public service delivery, high resolution population data is increasingly necessary.

Traditional methods like areal weighting distribute population uniformly across administrative units, often ignoring actual settlement patterns. In contrast, dasymetric mapping integrates spatially explicit data such as land use, impervious surface data, or building footprint to enhance population distribution models, several recent studies (Baynes et al., 2022; Jitt-Aer et al., 2022) have shown that dasymetric mapping provides improved granularity and accuracy in population estimates.

Among dasymetric mapping techniques, the limiting variables methods stand out by only allocating population to spatial units that meet a predefined criterion, such as residential buildings. This approach minimizes overestimation in uninhabited areas like industrial zones or parks. Applications have ranged from regional planning (Chen et al., 2020) to disaster risk analysis (Kandwal et al., 2023), demonstrating the versatility and robustness of this method.

However, despite its potential, dasymetric mapping using limiting variables methods remains underutilized in Salzburg city. While some efforts have been made at national and municipal levels, comprehensive methodological studies and implementation using up to date building footprints data are lacking.

This research aims to create a high-resolution dasymetric population map of Salzburg city using the limiting variable method. By incorporating building footprint, heights from DSM and DEM data, and validating against district-level population at the building level with greater accuracy. The final output will be a detailed map showing population distribution across the city.

2.0 METHODOLOGY

This research adopts a spatial analysis grounded in dasymetric mapping, with a specific emphasis on the limiting variables method. This technique enables the redistribution of coarse population data to a finer spatial resolution by restricting allocation only to areas that meet defined criteria. In this case, residential building footprints.

2.1 Data collection

Population data were sourced from the Stadt Salzburg municipal datasets, typically aggregated at the district level. Ancillary datasets used to refine spatial allocation include:

- Building Footprints from OpenStreetMap (OSM), clipped to the Salzburg city administrative boundary.
- Building height data, derived by calculating the difference between Digital Surface Model (DSM) and Digital Elevation Model (DEM), obtained from data.gv.at.
  These datasets from the basis for identifying and categorizing residential structures which act as the limiting variables in the redistribution process.

2.2 Data Preparation and Harmonization

To ensure spatial consistency, all datasets were:

- Reprojected to a common coordinate reference system
- Cleaned for geometric and attribute inconsistencies
- Filtered to isolate residential buildings (e.g., apartments, dormitories, detached homes)
  Non-residential structures such as commercial centers, churches, and public buildings were excluded to maintain redistribution accuracy. Population data were then joined to corresponding district boundaries in the preparation for redistribution.

2.3 Redistribution Process

The redistribution of population from districts level census data to individual buildings was conducted using a volume-weighted dasymetric mapping approach. This method accounts for both the horizontal footprint and vertical capacity of residential structures to more accurately allocate population.

Building Height Calculation

To determine the height of each residential building:

- The raster calculator tool in ArcGIS was used to subtract the Digital Surface Model (DSM) from the Digital Elevation Model (DEM):

$$\text{Height} = \text{DSM} - \text{DEM}$$

- The Zonal Statistics to Table tool was then applied using the building footprint polygons as zones. This extracted the mean height of each building from the raster result.

Taller buildings typically have more floors and can house more people, making building height a crucial factor for accurate population estimation.

Building Footprint Area Calculation

Each residential building's area was calculated using the calculate Geometry function:

- A new field, Area-M2 was created to store the area in square meters.

The footprint area provides an indication of the physical base size of the building, which directly affects total usable space.

Building Volume Calculations

A new field (Volume) was computed using the formula:

$$\text{Volume} = \text{Area}_{m2} * \text{Height}$$

This volume represents the total usable space in the building, serving as a proxy for how many people it can accommodate. Larger and taller buildings are expected to house more residents.

Districts-Level Volume Summation

To determine the total volume available in each district, buildings were grouped by District-ID, and the volume field was summed using the statistics tool. This created a lookup table with:

- District_ID
- Total_District_Volume

This step enables proportional allocation of population based on each building's share of the district's total volume.

Population Allocation

Population was allocated to each building using the following formula

$$\text{Building\_Population} = (\text{Volume}_i / \text{Total\_Volume}_{\text{District}}) * \text{Pop}_{\text{District}}$$

Where:

- Volume_i is the individual building
- Total_volume_district is the sum of all buildings in the same district
- Pop_District is the official census population of the district

This ensures a fair and proportional distribution of residents based on the building's capacity.

Population Density

Population density was calculated by dividing the estimated population of each building by its footprint area in square meters:

Population Density = Building Population Building Area (m^2)

This approach highlights spatial variations in residential intensity, correcting the bias of large structures appearing overrepresented due to size rather than true occupancy levels

Validation

After allocation, a validation check was performed:

- For each district, the sum of building-level population estimates was calculated
- These totals were compared to the original district population values from the census

This validation confirms that the disaggregated data remains consistent with official statistics, ensuring both accuracy and reliability of the model.

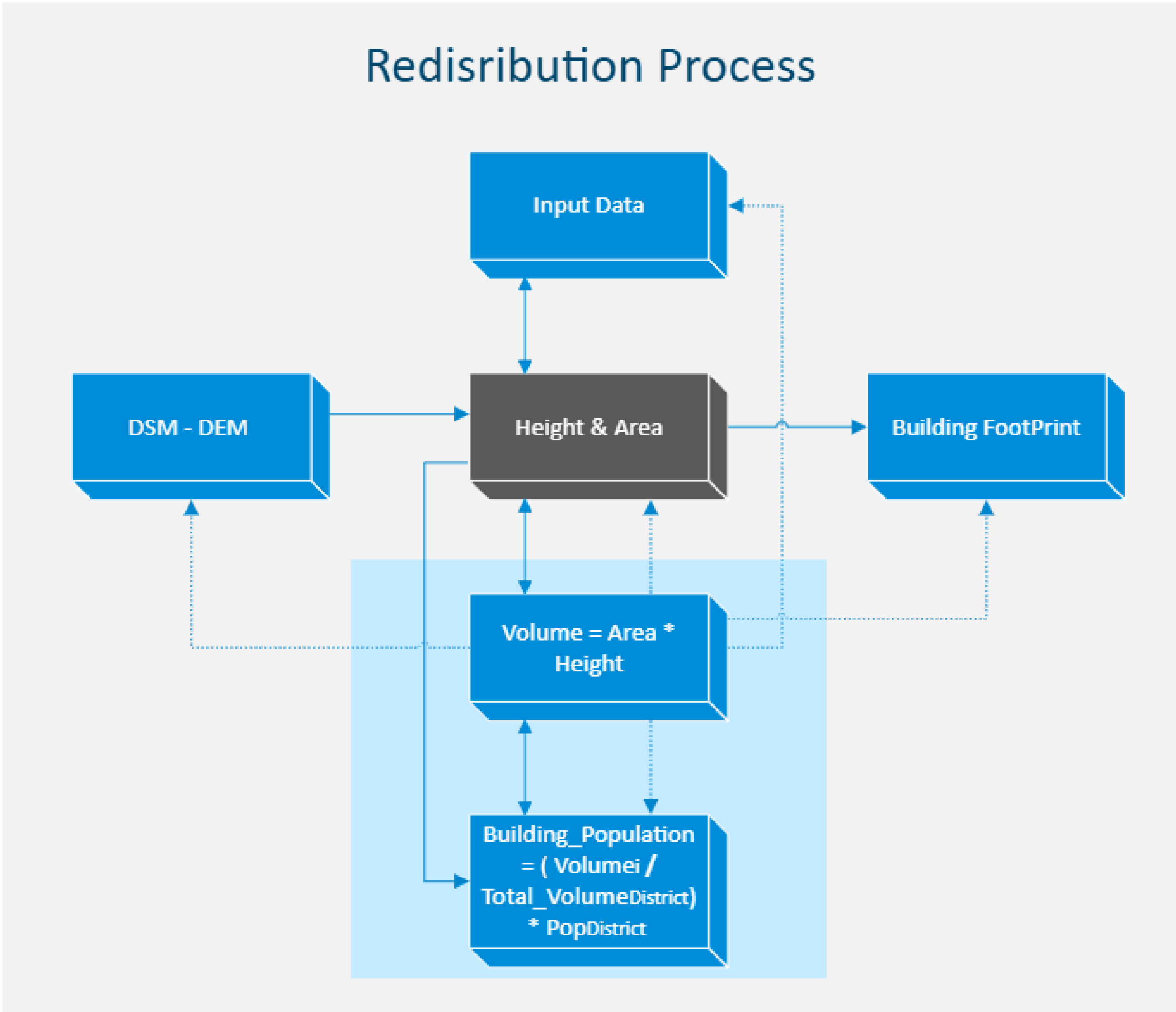

Fig 2.0: Population Redistribution Process

3.0 RESULTS

3.1 Overview of Input Data

To begin the analysis, district-level population data for Salzburg were combined with spatial datasets on residential buildings. Population figures were sourced from official municipal records, providing totals for each district in the city. Residential building footprints were extracted from

OpenStreetMap and filtered to include only relevant structures, such as detached houses, apartment blocks, and dormitories.

The elevation data, specifically the Digital Surface Model (DSM) and Digital Elevation Model (DEM), were used to estimate the height of each building. After cleaning and clipping the data to the city boundary, the dataset included approximately 10,337 residential buildings across 32 districts. These datasets formed the basis for building-level population estimation in the next steps.

District_Name	Population	No of Residential Buildings	Avg. Building Height	Avg. Building Area
Taxham	4899	470	-9.742587	0.000128
Hellbrunn	380	8	-2.001007	0.000203
Thumegg/Gnesis	2787	206	-7.777382	0.000239
Schallmoos	10669	295	-10.866768	0.000326
Gnigl/Langweid	6649	900	-7.840333	0.000151
Parsch-West/Aigen	6774	513	-8.513461	0.000287
Liefering-Nord	6613	969	-6.685045	0.000157
Maxglan/Nurere Riedenburg	8670	254	-8.661525	0.000362
Josefiau / Alphenstrase-Ost	5577	571	-8.763026	0.000191
Maxglan	6181	504	-7.58592	0.000228
M2nchberg/Inneres Nonntal	1117	98	-10.707664	0.000192
Ausseres Nonntal/ Freisaal	5140	372	-12.33283	0.000238
Sam/Kasern	3597	394	-8.167352	0.000162
Hernau/Alphenstrasse	1878	291	-9.1818.15	0.000153
Neustadt	3439	140	-15.535834	0.000414
Itzling	7706	398	-9.560605	0.000299
Leopoidskron/Moos	8520	412	-6.957574	0.000204
Lehen-Nord	8499	214	-13.147695	0.000432
Elisabeth-Vorstadt	7108	228	-13.920011	0.000335
Parsch-Ost/Aigen	5968	352	-8.206842	0.000233

Gaisberg	144	7	-7.158121	0.000298
Liefering-Ost	6496	586	-8.463299	0.000203
Lehen-Sud	8718	175	-13.147695	0.000492
Maxglan/Flughafen	5085	89	-7.824137	0.000345
Itzling-West/Hagenau	2451	180	-9.003481	0.000225
Alstadt/M IIn	2391	309	-15.108859	0.000276
Kapuzinerberg/Steinviertel	516	53	-11.359124	0.000232
Aigen/Gas	6766	408	-7.266195	0.000211
Liefering-West	2757	400	-7.451278	0.000172
Aiglhof/Innere Riedenburg	6435	228	-10.115634	
Rechte Altstadt/Andrnviertel	2184	202	-15.057281	0.000302
Kleingmain/Morzig	2315	111	-6.692395	0.000257

Table 1: Summary of input data per district, including population, number of residential buildings, average height, and average footprint area.

3.2 Building Height and Area Characteristics

To estimate building height, the DSM was subtracted from the DEM using the raster calculator in ArcGIS. This gave the above-ground height of structures. Then, using the zonal statistics tool, the average height for each building footprint was calculated.

In parallel, the footprint area of each residential building was measured in square meters using the "Calculate Geometry" function. The results revealed clear patterns: buildings in the central districts of Salzburg tend to be taller but have a smaller footprint, suggesting vertical development. In contrast, buildings in suburban districts are usually shorter but spread out over larger areas.

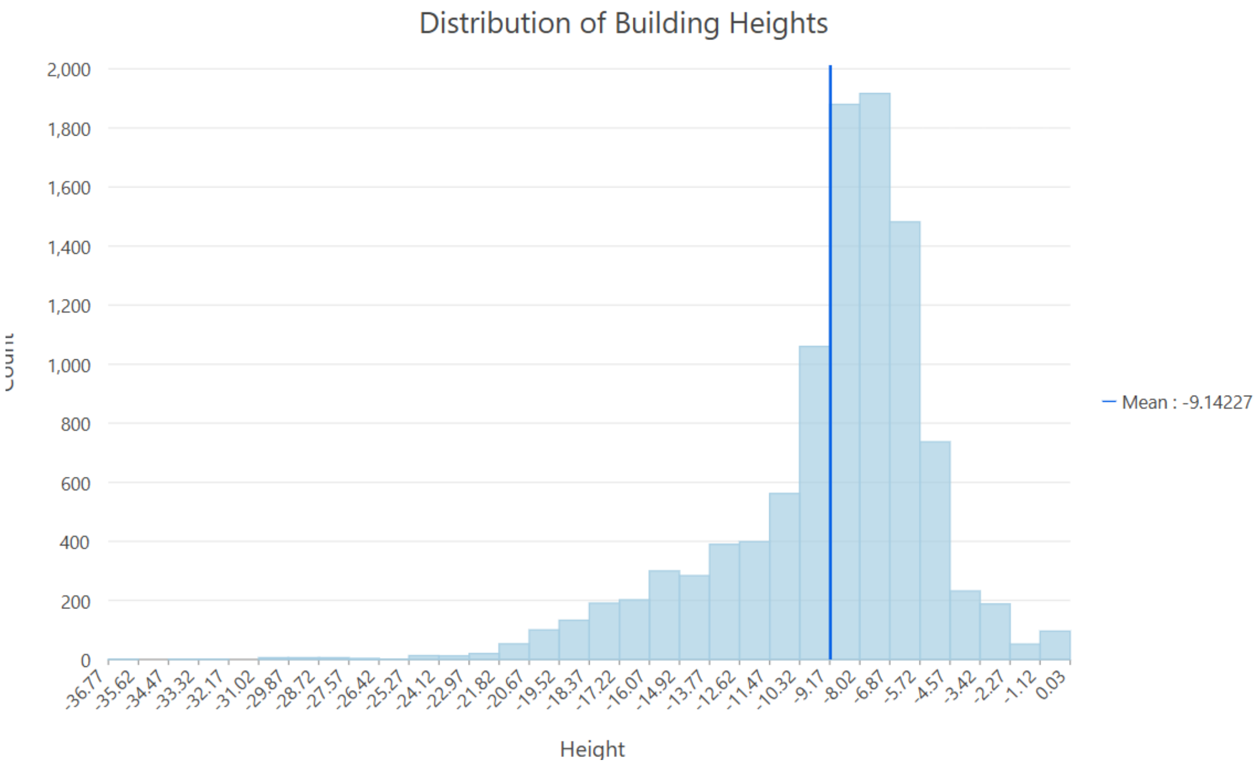

Fig 3.1: Histogram showing the distribution of building heights across Salzburg

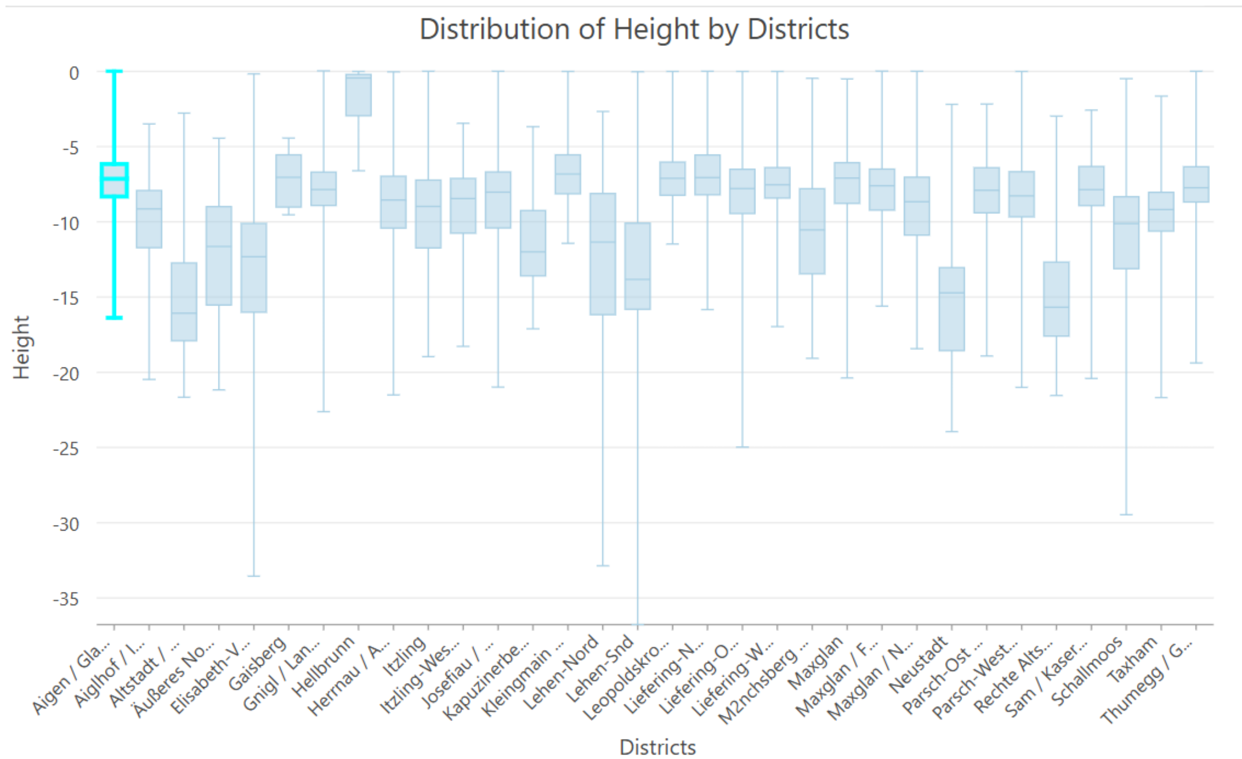

Fig 2.3: Boxplot comparing building heights by district

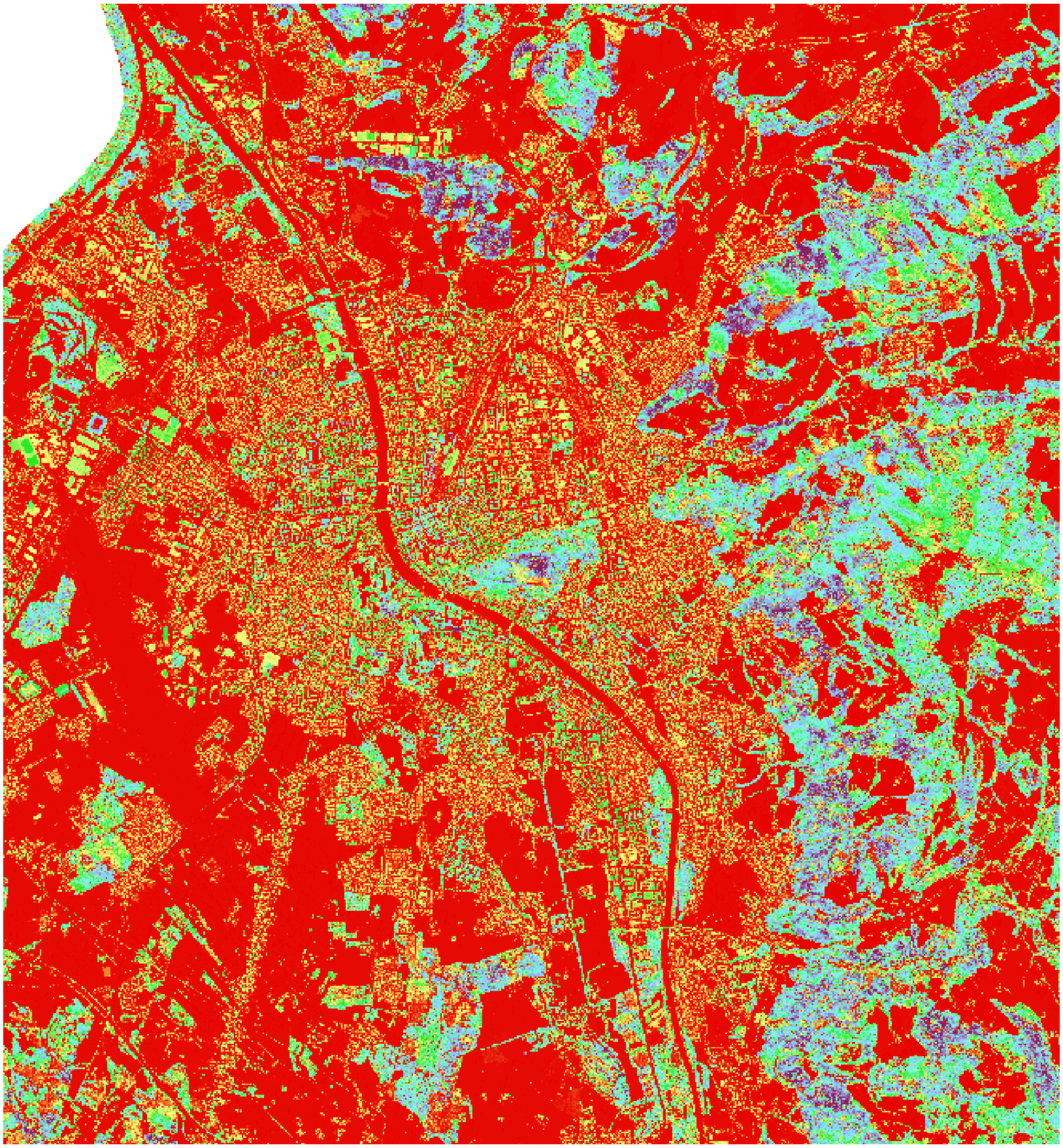

Fig 3.3: Building heights throughout the city (Derived from DEM-DSM)

3.3 Building Volume and Residential Capacity

Once height and area known, the volume of each residential building was calculated by multiplying its footprint area by its estimated height. This volume represents an approximation of each building's usable space and serves as a proxy for how many people it might realistically accommodate.

When the volumes were grouped by district, there were notable differences. For example, central areas had a higher total volume due to the presence of taller apartment complexes, while outer districts had fewer but wider and lower buildings. These results provided the necessary inputs for the next phase: allocating population based on building capacity.

District_Name	Frequency	Building_Volume
Taxham	470	-0.671662
Hellbrunn	8	-003702
Thumeg/Gneis	206	-0.420447
Schallmoos	295	-1.120612
Gnigl/Langweid	900	-1.110241
Parsch-West/Aigen	513	-1.438574
Leifering-Nord	969	-1.114734
Maxglan/Nurere Riedenburg	254	-0.844015
Josefiau/Alphentrase-ost	571	-0.555701
Maxglan	504	-1.022716
M2nchsberg/Inneres Nonntal	98	-0.202652
Ausseres Nonntal	372	-1.13792
Sam/Kasern	394	-0.555701
Hernau/Alpentrasse-west	291	-0.453272
Neustadt	140	-0.968884
Itzling	398	-1.313061
Leopoldskron/Moos	412	-0.575886
Lehen-Nord	214	-1.478984
Elisabeth-Vorstadt	288	-1.478984
Parsch-Ost/Aigen	352	-0.739934
Gaisberg	7	-0.015994
Liefering-Ost	586	-1.1407
Lehen Sud	175	-1.220882
Maxglan/Flughafen	89	-0.2564
Itzling-West/Hegenau	180	-0.413121
Alstadt/M IIn	309	-1.295036
Kapuzinerberg/Steinivertel	53	-0.45687
Aigen/Glas	408	-0.639861
Liefering-West	400	-0.541997
Aighof/Innere Riedenburg	228	-0.740827
Rechte Altstadt/Andrnviertel	202	-0.94783
Kleingmain/Morzg	111	-0.199302

Table 2: Summary of total building volume per district

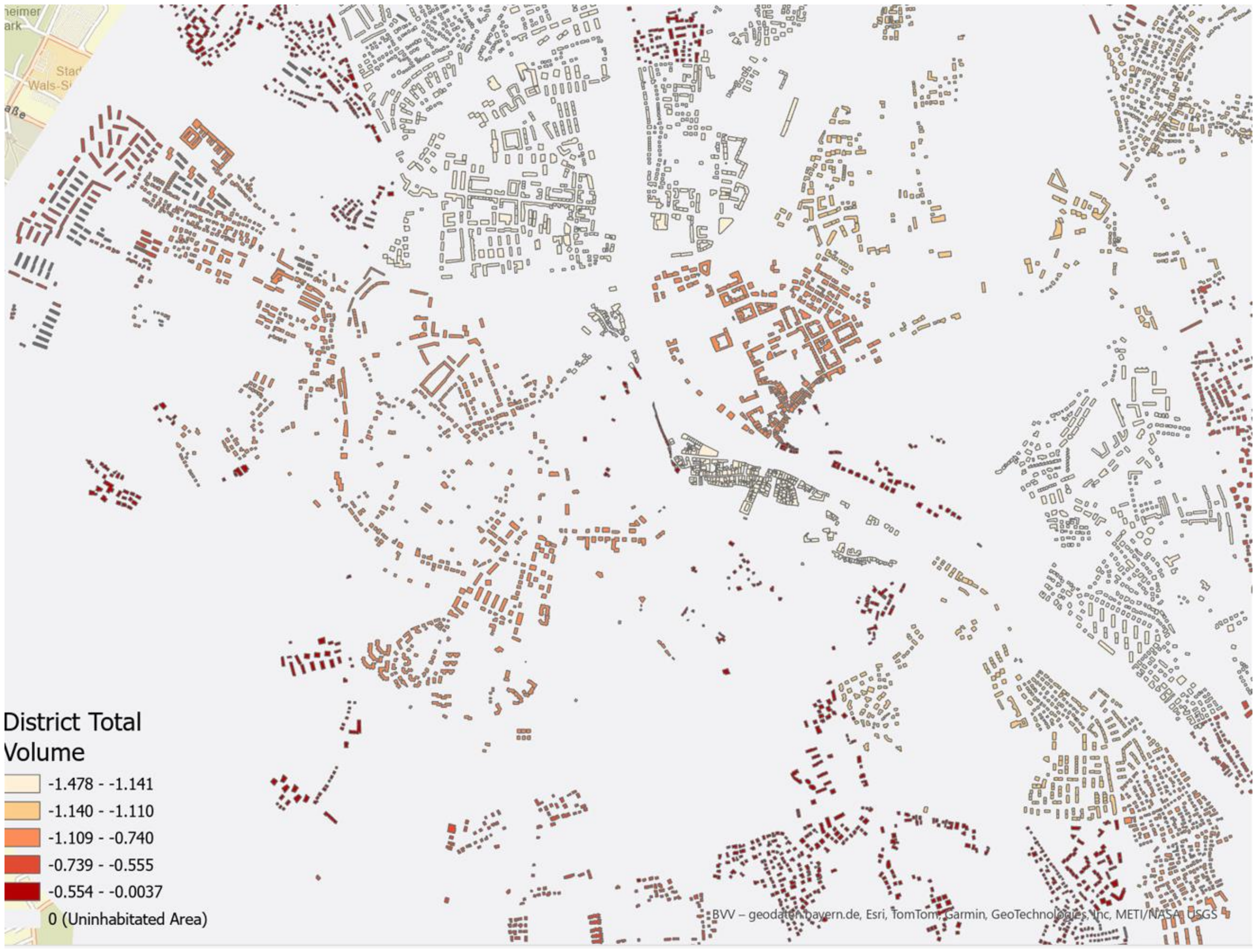

Fig 3.4: Map Visualization Building volume

3.4 Population Allocation Results

Using the calculated building volumes, population was redistributed from the districts level to each individual residential building. The principle behind this step was simple: larger and taller buildings generally hold more people, so they received a larger share of the total district population. The formula applied ensured that the proportion of population allocated to a building matched its share of the district's total residential volume.

This method resulted in a highly detailed population map for Salzburg, revealing how people are spread across the city not just by district, but by building it showed, for instance, that many residents are concentrated in tall apartment buildings in the city center, while suburban homes host fewer people but occupy more land.

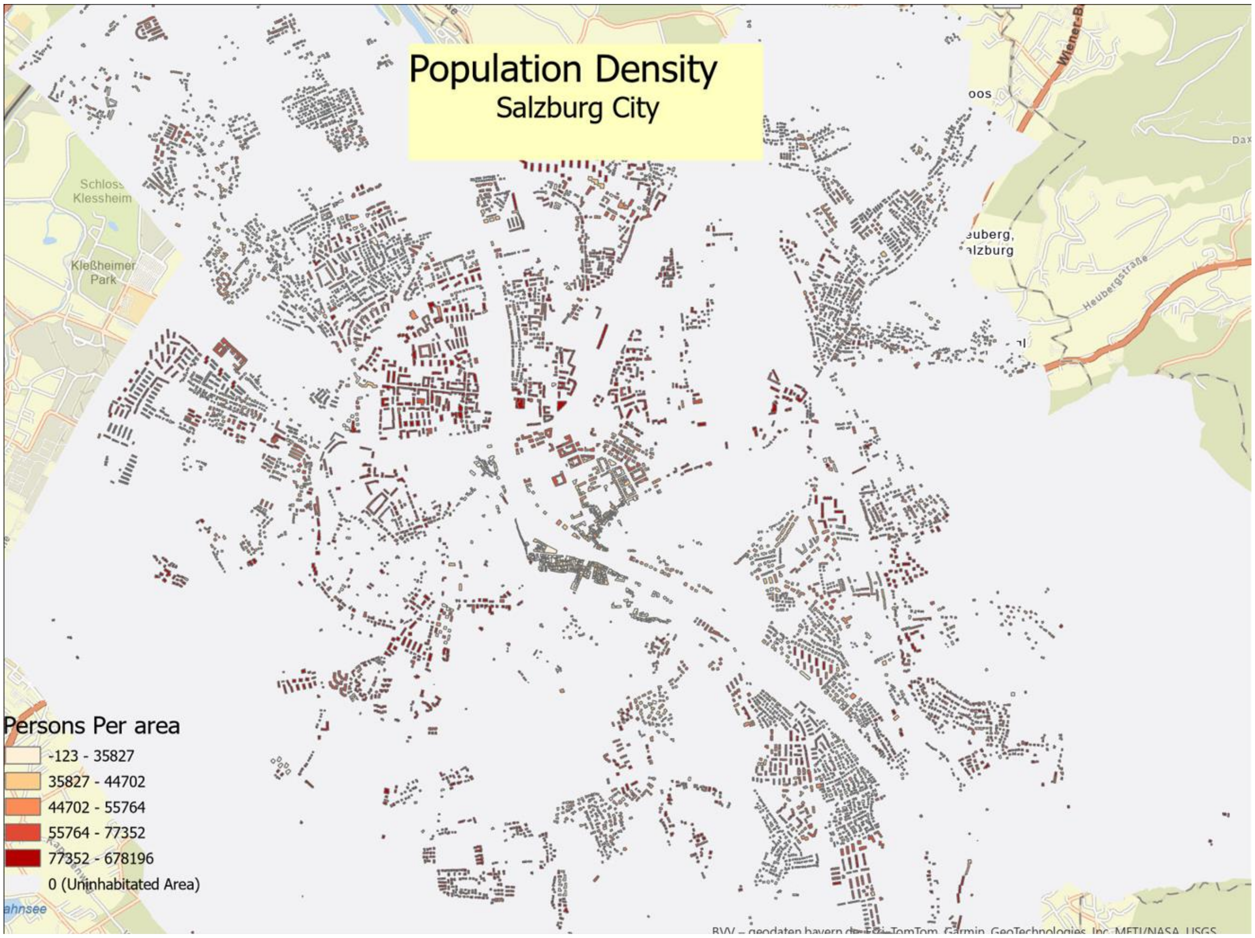

Fig 3.5: Final dasymetric Population map of Salzburg city

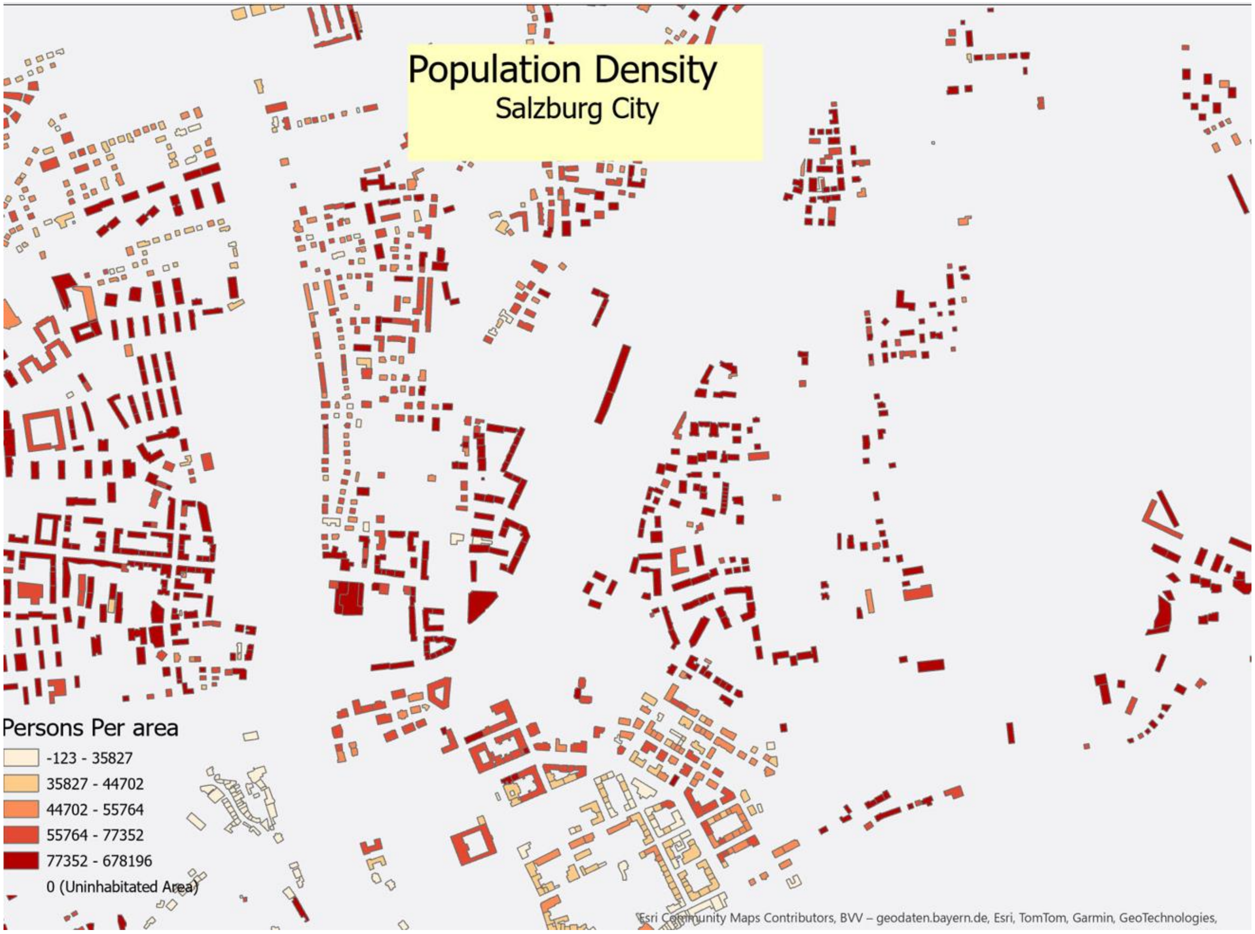

Fig 3.5: Zoomed-in map of some district showing building level-population distribution

3.4 Validation of Population Distribution

To check the accuracy of the redistribution, the total population across all buildings in each district was summed up and compared to the original census figures. The results showed a nearly perfect match, confirming that the population had been allocated correctly. Any minor discrepancies were due to rounding and were adjusted automatically during the calculation process.

4.0 CONCLUSION

This study set out to create a detailed map of how people are distributed across Salzburg city by using a technique called dasymetric mapping. Instead of relying solely on broad census data, which typically tells us how many people live in a district, but not where exactly they were able to redistribute that information down to the level of individual buildings.

By combining data from multiple sources, including footprints from OpenStreetMap and building heights calculated from DSM and DEM elevation models, the study estimated the physical volume of each residential building. This volume (essentially a combination of floor area and number of floors) was used as a realistic indicator of how many people a building could accommodate.

The results showed clear patterns; taller apartments buildings in the city, center housed more people, while suburban areas with single-family homes had fewer residents spread over a larger area. Importantly, the model was validated against the original census data, and the total population per district remained consistent, confirming that the redistribution was statistically accurate.

This volume-based approach offers a much more accurate picture of where people actually live compared to older methods that assume population is evenly spread. The resulting building-level population map can be incredibly useful for city planning, emergency response, and even environmental modeling.

While this study focused on Salzburg, the method can easily be applied to other cities with similar data availability. Future work could include additional variables like building use, household size, or real occupancy data to refine the estimate even further.

In short, this project demonstrates that when spatial data is used creatively, we can gain a much easier, clearer, and more practical understanding of how people are distributed within our cities.

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