

Online Supplementary Material

Estimating the potential number of daily visitors in urban areas. Methodical evaluation of the points of interest of open data services using the example of transport mobility in Cologne

Supplementary material S-1: OSMOSIS scripts used for data extraction

The list of the OSMOSIS scripts below is used to query the relevant points of interest within the OSM-PBF file. The list is organized according to the respective OSM keys. The file path specified in the query is user-dependent and may vary from user to user.

For privacy reasons, the file paths shown have been shortened.

Queries for the relevant points of interest of the key “amenity”:

```
osmosis --read-pbf H:\koeln-regbez-latest_20230214.osm.pbf --node-key-value
keyValueList="amenity.bar,amenity.biergarten,amenity.cafe,amenity.fast_food
,amenity.food_court,amenity.ice_cream,amenity.pub,amenity.restaurant,amenit
y.library,amenity.toy_library,amenity.car_rental,amenity.car_wash,amenity.v
ehicle_inspection,amenity.fuel,amenity.bank,amenity.clinic,amenity.dentist,
amenity.doctors,amenity.hospital,amenity.nursing_home,amenity.pharmacy,amen
ity.veterinary,amenity.arts_centre,amenity.casino,amenity.cinema,amenity.co
mmunity_centre,amenity.conference_centre,amenity.events_venue,amenity.exhib
ition_centre,amenity.gambling,amenity.love_hotel,amenity.music_venue,amenit
y.nightclub,amenity.planetarium,amenity.stripclub,amenity.theatre,amenity.p
ost_office,amenity.crematorium,amenity.dive_centre,amenity.funeral_hall,ame
nity.grave_yard,amenity.internet_cafe,amenity.marketplace,amenity.monastery
,amenity.place_of_mourning,amenity.place_of_worship,amenity.public_bath" --
write-xml H:\Geofabrik_OSM_20230214\Amenity02.osm.pbf
```

Queries for the relevant points of interest of the key “building”:

```
osmosis --read-pbf H:\koeln-regbez-latest_20230214.osm.pbf --node-key-value
keyValueList="building.hotel,building.kiosk,building.retail,building.superm
arket,building.cathedral,building.chapel,building.church,building.kingdom_h
all,building.monastery,building.mosque,building.presbytery,building.religio
us,building.shrine,building.synagogue,building.temple,building.stadium,buil
ding.castle,building.ruins" --write-xml
H:\Geofabrik_OSM_20230214\Building01.osm.pbf
```

Queries for the relevant points of interest of the key “historic”:

```
osmosis --read-pbf H:\koeln-regbez-latest_20230214.osm.pbf --node-key-value
keyValueList="historic.castle,historic.church,historic.city_gate,historic.c
```

```
itywalls,historic.memorial" --write-xml
H:\Geofrabrik_OSM_20230214\Historic01.osm.pbf
```

Queries for the relevant points of interest of the key “leisure”:

```
osmosis --read-pbf H:\Geofrabrik_OSM_20230214\koeln-regbez-
latest_20230214.osm.pbf --node-key-value
keyValueList="leisure.adult_gaming_centre,leisure.amusement_arcade,leisure.
bandstand,leisure.bathing_place,leisure.beach_resort,leisure.bowling_alley,
leisure.dance,leisure.disc_golf_course,leisure.escape_game,leisure.fitness_
centre,leisure.garden,leisure.golf_course,leisure.ice_rink,leisure.miniatur
e_golf,leisure.nature_reserve,leisure.park,leisure.pitch,leisure.resort,lei
sure.sauna,leisure.sports_centre,leisure.sports_hall,leisure.stadium,leisur
e.swimming_pool,leisure.tanning_salon,leisure.track,leisure.trampoline_park
,leisure.water_park" --write-xml
H:\Geofrabrik_OSM_20230214\Leisure01.osm.pbf
```

Queries for the relevant points of interest of the key “shop”:

```
osmosis --read-pbf H:\Geofrabrik_OSM_20230214\koeln-regbez-
latest_20230214.osm.pbf --node-key-value
keyValueList="shop.alcohol,shop.bakery,shop.beverages,shop.brewing_supplies
,shop.butcher,shop.cheese,shop.chocolate,shop.coffee,shop.confectionery,sho
p.convenience,shop.deli,shop.dairy,shop.farm,shop.frozen_food,shop.greengro
cer,shop.health_food,shop.ice_cream,shop.pasta,shop.pastry,shop.seafood,sho
p.spices,shop.tea,shop.wine,shop.water,shop.department_store,shop.general,s
hop.kiosk,shop.supermarket,shop.wholesale,shop.baby_goods,shop.bag,shop.bou
tique,shop.clothes,shop.fabric,shop.fashion,shop.fashion_accessories,shop.j
ewelry,shop.leather,shop.sewing,shop.shoes,shop.tailor,shop.watches,shop.wo
ol,shop.charity,shop.second_hand,shop.variety_store,shop.beauty,shop.chemis
t,shop.cosmetics,shop.erotic,shop.hairdresser,shop.hairdresser_supply,shop.
hearing_aids,shop.herbalist,shop.massage,shop.medical_supply,shop.nutrition
_supplements,shop.optician,shop.perfumery,shop.tattoo,shop.agrarian,shop.ap
pliance,shop.bathroom_furnishing,shop.doityourself,shop.electrical,shop.ene
rgy,shop.fireplace,shop.florist,shop.garden_centre,shop.garden_furniture,sh
op.gas,shop.glaziery,shop.groundskeeping,shop.hardware,shop.houseware,shop.
locksmith,shop.paint,shop.trade,shop.antiques,shop.bed,shop.candles,shop.ca
rpet,shop.curtain,shop.doors,shop.flooring,shop.furniture,shop.household_li
nen,shop.interior_decoration,shop.kitchen,shop.lighting,shop.tiles,shop.win
dow_blind,shop.computer,shop.electronics,shop.hifi,shop.mobile_phone,shop.r
adiotechnics,shop.telecommunication,shop.vacuum_cleaner,shop.atv,shop.bicyc
le,shop.boat,shop.car,shop.car_repair,shop.car_parts,shop.caravan,shop.fuel
,shop.fishing,shop.golf,shop.hunting,shop.jetski,shop.military_surplus,shop
.motorcycle,shop.outdoor,shop.scuba_diving,shop.ski,shop.snowmobile,shop.sp
orts,shop.swimming_pool,shop.trailer,shop.tyres,shop.art,shop.camera,shop.c
ollector,shop.craft,shop.frame,shop.games,shop.model,shop.music,shop.musica
l_instrument,shop.photo,shop.trophy,shop.video,shop.video_games,shop.anime,
shop.books,shop.gift,shop.lottery,shop.newsagent,shop.stationery,shop.bookm
aker,shop.copyshop,shop.dry_cleaning,shop.e-
cigarette,shop.funeral_directors,shop.insurance,shop.laundry,shop.outpost,s
hop.party,shop.pest_control,shop.pet,shop.pet_grooming,shop.pyrotechnics,sh
op.religion,shop.tobacco,shop.toys,shop.travel_agency,shop.weapons" --
write-xml H:\Geofrabrik_OSM_20230214\Shop01.osm.pbf
```

Queries for the relevant points of interest of the key “tourism”:

```
osmosis --read-pbf H:\Geofabrik_OSM_20230214\koeln-regbez-  
latest_20230214.osm.pbf --node-key-value  
keyValueList="tourism.aquarium,tourism.attraction,tourism.camp_pitch,touris  
m.camp_site,tourism.caravan_site,tourism.chalet,tourism.gallery,tourism.gue  
st_house,tourism.hostel,tourism.hotel,tourism.information,tourism.motel,tou  
rism.museum,tourism.theme_park,tourism.zoo" --write-xml  
H:\Geofabrik_OSM_20230214\Tourism01.osm.pbf
```

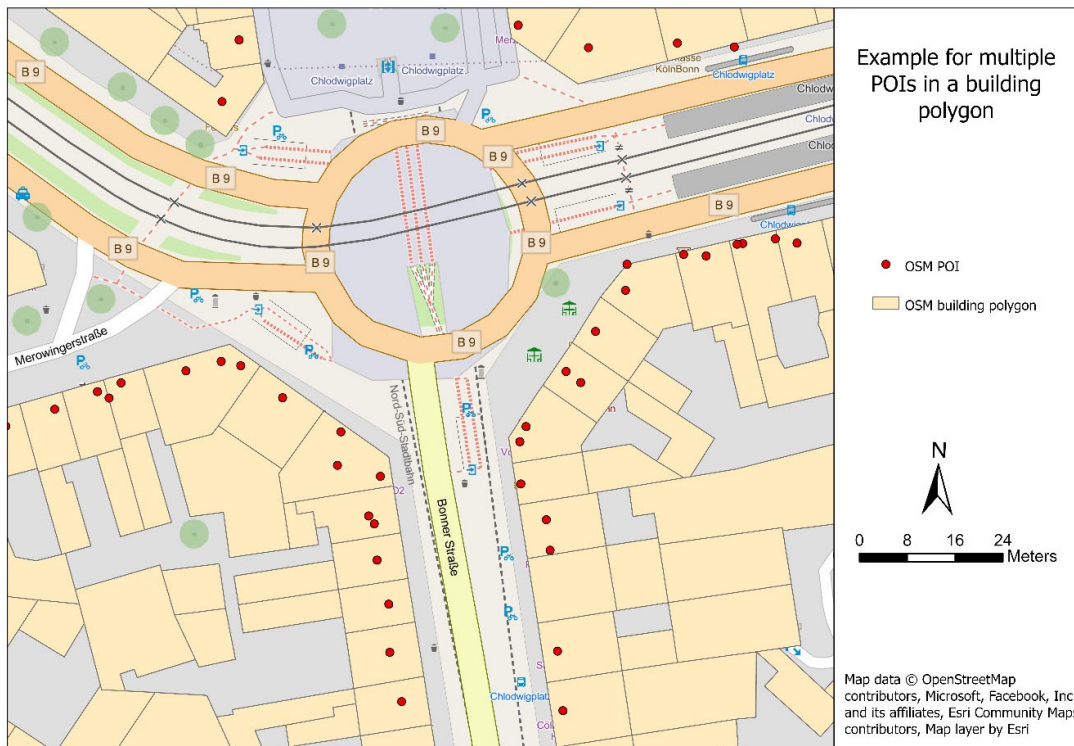
List of other OSM categories that were not included or named within the OSM Wiki:

beauty_shop, bicycle_shop, bookshop, car_dealership, computer_shop, furniture_shop,
gift_shop, graveyard, jeweller, market_place, mobile_phone_shop, outdoor_shop,
public_building, shoe_shop, sports_shop, tourist_info

Supplementary material S-2: Maps about the edited datasets to explain the processing of the POI data

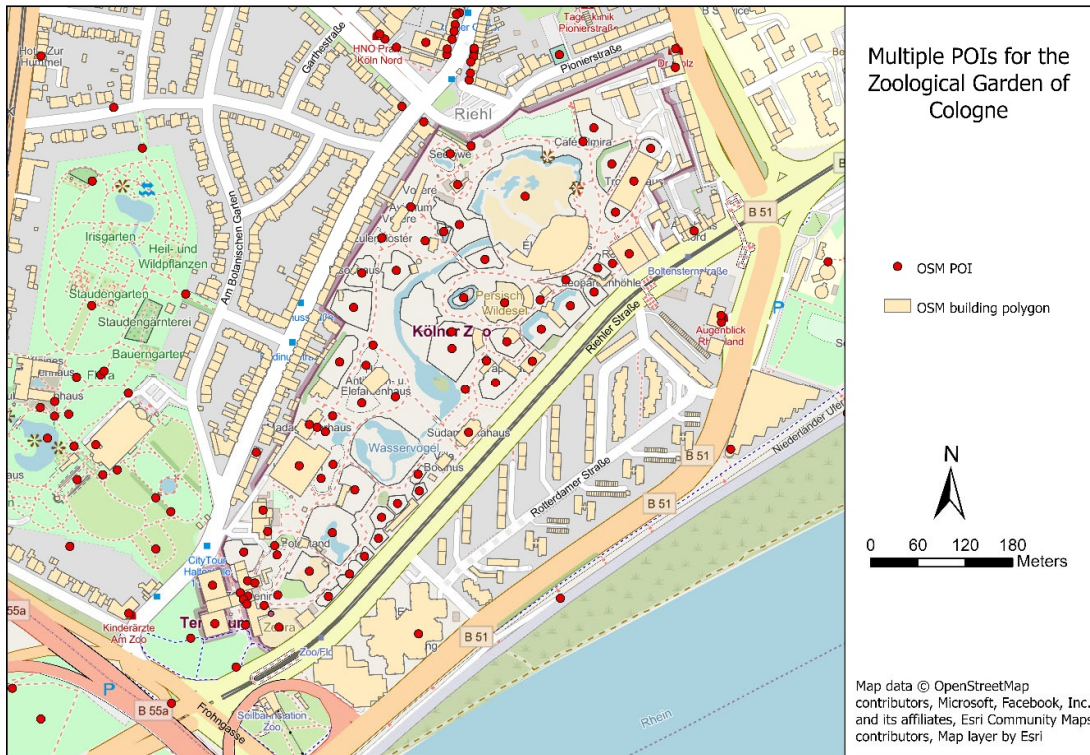
The processing described in the main publication is illustrated in the following detailed maps. The polygons and points of interest of the OSM dataset used are shown in each case. In addition, a brief explanation is provided for each map.

Figure S2-1: Example for multiple points of interest in a building polygon



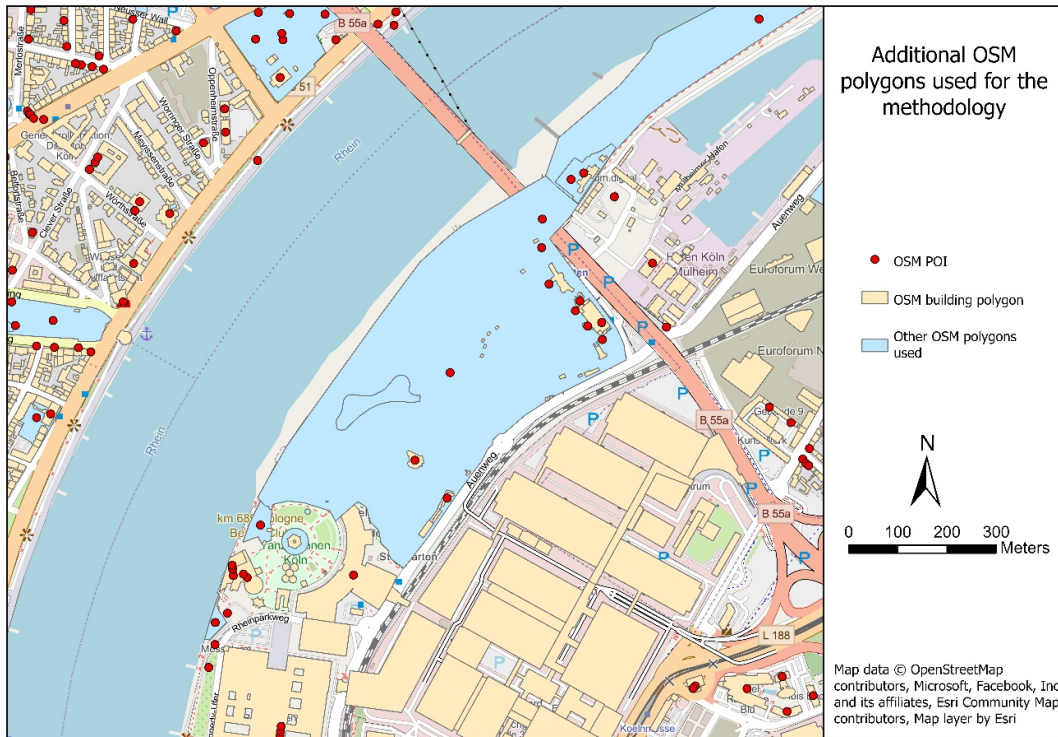
The first map (Figure S2-1) shows an example of how, in some cases, several points of interest are located within a building polygon. A spatial intersection was used to determine how many points of interest are located within a building polygon. The area was then divided proportionally. Without this approach, allocated areas would be considered multiple times. Therefore, a proportional distribution based on the number of points of interest per building polygon was decided upon.

Figure S2-2: Multiple points of interest for the Zoological Garden of Cologne



In a similar way, for the Zoological Garden of Cologne, the POI points had to be cleaned up as individual animal enclosures are marked in the zoo (Figure S2-2). This detailed information is not required for the analysis as only the information “zoo” is needed, so all additional points of interest were removed. Another correction involved private swimming pools that had been incorrectly mapped as public swimming pools in OSM. These were removed manually based on aerial images from the final dataset; individual cases are not displayed in order to protect privacy.

Figure S2-3: Additional OSM used for the methodology



To exemplify another example, the polygon for Cologne's Rheinpark is shown, in the centre of Figure S2-3. Accordingly, in addition to polygons representing buildings, polygons representing, for example, a public park were also considered. As with building polygons, an estimate of the number of visitors was made based on the area of these polygons. The values according to Bosserhoff (2022) were also used for parks in order to perform the calculation.

Supplementary material S-3: Tabular overview of the values used according to Bosserhoff (2022) per point of interest

Table S3-1 shows five examples of OSM points of interest with the respective estimated value assigned by Bosserhoff (2022). The respective OSM key and value pairs are listed. In addition, the respective journey purpose is named (as listed in Table 1 of the main article). In addition, the German term named after Bosserhoff (2022), which is assigned to the respective point of interest, is listed as well. This is followed by the designated reference areas used for conversion. Reference surface types are listed, with the German abbreviation which is used by Bosserhoff (2022): Gross floor area (BGF), operational floor space I (GFL), operational floor space II (GGF) and retail space (VKF). The next columns show the respective minimum and maximum conversion values for the estimated number of visitors to a point of interest. The last column refers to the specific location within Bosserhoff's (2022) dataset where the respective value can be found. A complete overview of all estimated values according to Bosserhoff (2022) can be found in the Ver_Bau dataset, which must be purchased.

Table S3-1: Tabular overview of the values used according to Bosserhoff (2022) per point of interest

OSM-Key	OSM-Value	Purpose of journey category (see Table 1)	Designation according to Bosserhoff (2022)	Area reference according to Bosserhoff (2022)	Estimated value minimum	Estimated value maximum	Reference to Bosserhoff (2022)
amenity	pharmacy	Medical facilities incl. pharmacies	Apotheken	Customers per m ² VKF	5	-	Hotlink under Bosserhoff 2022 Tab. Einzelhandel D/46
leisure	fitness_centre	Sports grounds and green spaces	Fitness-Center	Customers per m ² BGF	15	50	Hotlink under Bosserhoff 2022 Tab. Freizeit D/13
shop	cheese	Daily requirements	Nahrungs- und Genussmittel	Customers per m ² VKF	1.5	-	Hotlink under Bosserhoff 2022 Tab. Einzelhandel D/46

shop	supermarket	Daily requirements	Supermarkt oder anhand von Geschäftsnamen/passender Wert in Abgleich zur Fläche	Customers per m ² VKF	0.8	1.55	Hotlink unter Bosserhoff 2022 Tab. Einzelhandel D/46
tourism	museum	Cultural education	Museen	Visitors per 100 m ² BGF	10	30	Hotlink unter Bosserhoff 2022 Tab. Freizeit D/13

Supplementary material S-4: Provisional method for determining the daily number of visitors to points of interest of key gastronomy

With regard to the category gastronomy, no reference values are provided by Bosserhoff (2022), except for flow curves (see flow curve under Bosserhoff 2022, Table “Flow Curve – Commercial Customers, Restaurants”). Flow curves represent the temporal distribution of source traffic (departing trips) and destination traffic (arriving trips) of passenger cars over the course of a working day. Consequently, they do not provide precise numerical data concerning the number of persons present. For this reason, additional research was conducted to identify comparable reference values.

With respect to gastronomic establishments that, based on their categorization and designation within the OSM database, could be attributed to system catering (classified in OSM as “fast food”), assumptions were derived from published sources. The German Association for System Catering (Bundesverband der Systemgastronomie, BdS) served as the principal reference.¹ On this basis, it was determined that branches of the fast-food chain McDonald’s may serve up to approximately 1,000 customers per day², Burger King up to 500 customers per day³ and Kentucky Fried Chicken (KFC) up to 350 customers per day.⁴ These figures were estimated primarily from nationwide daily customer volumes and the total number of outlets. The resulting approximations were subsequently assigned to the respective points of interest within the Excel dataset. Despite extensive research efforts, no more specific reference values for snack bars could be identified.

For the estimation of visitor numbers to other types of gastronomic establishments, no suitable reference values could be identified. An attempt to obtain relevant data from the German Hotel and Restaurant Association (DEHOGA) was likewise unsuccessful.

In response to this issue, an approximation approach was developed to allow for a more differentiated estimation of visitor numbers. To establish a basic estimate of the potential capacity of a gastronomic establishment, the measured floor area of the respective point of

¹ <https://www.bundesverband-systemgastronomie.de/> (02.12.2025).

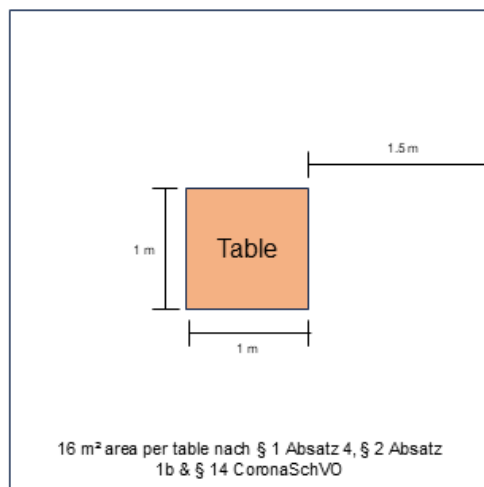
² <https://www.bundesverband-systemgastronomie.de/mitgliedschaft/mitglieder/mcdonald-s.html> (02.12.2025), <https://www.tagesschau.de/wirtschaft/unternehmen/gastronomie-systemgastronomie-umsatz-starbucks-100.html> (02.12.2025).

³ <https://www.bundesverband-systemgastronomie.de/mitgliedschaft/mitglieder/burger-king.html> (02.12.2025).

⁴ <https://www.bundesverband-systemgastronomie.de/mitgliedschaft/mitglieder/kfc.html> (02.12.2025), <https://de.statista.com/statistik/daten/studie/172244/umfrage/haeufigkeit-besuch-bei-kentucky-fried-chicken/> (02.12.2025).

interest was used as the foundation. It was first assumed that, in general, a table accommodating, for instance, four guests in a restaurant measures approximately $1\text{ m} \times 1\text{ m}$, thus occupying 1 m^2 of space (see Figure S4-1). As seated guests themselves require additional space and adequate distance must be maintained between adjacent tables, this supplementary area had to be determined. For this purpose, reference was made to the Corona Protection Ordinance of the federal state of North Rhine-Westphalia.⁵ According to §1 para 4, §2 para 1b and §14 CoronaSchVO, a minimum distance of 1.5 m between individual tables in gastronomic establishments was mandated during the COVID-19 pandemic. Under these regulations, a table seating four persons would occupy approximately 16 m^2 of floor space.

Figure S4-1: Schematic representation of the area estimation



This restriction resulted in a capacity reduction of about 40% compared to pre-pandemic conditions, as reported in several press releases citing the German Hotel and Restaurant Association (DEHOGA).⁶ Accordingly, after adjusting for this reduction, the average area per table would amount to approximately 9 m^2 rather than 16 m^2 . This assumption appears plausible, as data published by the Federal Statistical Office of Germany (Statistisches

⁵ Verordnung zum Schutz vor Neuinfizierungen mit dem Coronavirus SARS-CoV-2 (Coronaschutzverordnung – CoronaSchVO) vom 5. März 2021.

⁶ <https://www.ruhm Nachrichten.de/regionales/nrw-sonderweg-bei-den-corona-regeln-gastwirte-sind-sauer-ueber-eine-abstandsregel-w1637160-2000241348/> (02.12.2025); <https://www.wn.de/nrw/nrw-kippt-strenge-coronaregel-fur-gastronomie-1051536> (02.12.2025).

Bundesamt) on the monthly revenue trends in the hospitality sector indicate that by summer 2022, the industry had regained the pre-crisis level observed in summer 2019.⁷

As a result, no adjustment was made to account for a potentially higher utilization rate in terms of capacity since the end of the COVID-19 pandemic. Based on the estimated value of 9 m² per table, the number of tables within a gastronomic point of interest can be approximated using its calculated floor area. Consequently, the maximum number of guests that can be present simultaneously in the establishment can be estimated, assuming optimal occupancy of four persons per table. To refine this estimate, the turnover rate of these potential guest seats needed to be determined as well. Using the flow curves provided by Bosserhoff (2022), it was found that, as a rule, peak periods occur around lunchtime and in the evening hours, each lasting approximately two hours (a total of four hours), during which the highest levels of incoming and outgoing guest traffic can be expected (see flow curve in Bosserhoff 2022, Table Flow Curve – Commercial Customers, Restaurants). According to data from the Statista Research Department (2009), the average dwelling time in restaurants ranges between one and two hours in 54% of cases.⁸ Accordingly, it can be assumed that each table is occupied once per hour, resulting in four guest turnovers during peak operating hours. A numerical example illustrating this calculation method is provided as follows. For example, the spatial intersection with a building polygon determines an area of 200 m². Based on the assumption presented, approximately 22 tables can be expected. This means that a total of 88 guests can be at the point of interest at the same time. This number is multiplied by the four peak hours mentioned, resulting in a total of 352 guests.

An estimation outside the identified peak periods could not be conducted due to the limited availability of reference data. Nevertheless, the calculated value is assumed to represent the total visitor volume over the entire opening period. With regard to the calculated area based on building polygons, it is further assumed that this area also includes outdoor spaces or multiple floors, such that no deductions were made for storage areas or kitchen space. This estimation method was applied to the following POI categories: “bar”, “biergarten”, “café”, “pub” and “restaurant”.

⁷ <https://de.statista.com/statistik/daten/studie/1182138/umfrage/monatlicher-umsatz-der-gastronomie-in-deutschland/> (02.12.2025).

⁸ <https://de.statista.com/statistik/daten/studie/36244/umfrage/durchschnittliche-verweildauer-in-der-gastronomie-2008/> (02.12.2025).

Hospitals

With regard to hospitals, an initial attempt was made to identify comparable reference values to those used in Bosserhoff (2022), such as patients per square metre of gross floor area (GFA). However, this literature search did not yield any suitable data. Consequently, the analysis relied on the quality reports published by each hospital, which federal law requires be released at regular intervals (AOK-BV 2023). These reports document the annual number of outpatients treated at each hospital. To derive an estimate of the potential number of outpatients per day, the reported annual number was divided by 365 days. Inpatient cases were not considered, as hospital stays vary considerably in duration and thus do not allow for a meaningful daily conversion of incoming patients. Within the selected POI dataset for the City of Cologne, a total of 22 hospitals were identified. For each hospital, the most recent available quality report was reviewed. For example, Kliniken Köln – Krankenhaus Köln-Holweide reported 62,614 outpatient cases (Kliniken Köln 2022: 31), corresponding to approximately 170 potential outpatient visits per day. This procedure was repeated for all hospitals.

General Practitioners, Specialists and Dentists

For points of interest categorized in the OSM database as general practitioners (OSM tag “doctors”), specialists (typically “clinic”) or dentists (“dentist”), reference values for average daily patient numbers were derived from Rieser (2014) and Lamers (2020). According to Rieser (2014: 29), general practitioners in Germany treat an average of 52 patients per day, while specialists treat around 38 patients per day. Lamers (2020: 252) further notes that in highly frequented general practices, patient numbers may reach up to 100 per day. Since no reliable correspondence between these figures and the respective floor area could be established, particularly concerning the higher value reported by Lamers (2020: 252), only the values provided by Rieser (2014: 29) were adopted. Accordingly, general practitioners were assigned a rounded value of 50 patients per day, and specialists and dentists were assigned an adjusted value of 40 patients per day. No specific reference value for dentists could be determined; therefore, the value used for specialists was applied analogously. As in the case of hospitals, this estimation represents an area-independent approach to assessing potential daily traffic volumes. It should be noted that this method does not account for larger group

practices, home visits by general practitioners or other special cases, due to the standardized nature of the reference values applied.

Veterinarians

For veterinary practices, reference values were derived from a publication by the Veterinary Professional Portal operated by Royal Canin, based on data from the department Practice Management – Finance by Baralon, Blättner, Mercader et al. (2021). The authors indicate that veterinary practices typically handle between 10 and 12 or 12 and 15 patients per working day. In this thesis, a reference value of 10 patients per day was assigned to small veterinary practices with a building area of less than 100 m². To represent larger veterinary practices and clinics, the previously applied reference value for medical specialists – 40 patients per day according to Rieser (2014: 29) – was used to ensure comparability across similar facility scales. A threshold of 100 m² was chosen, as the total of 34 veterinary facilities identified in the POI dataset could be divided into approximately two equal groups based on this criterion.

Petrol Stations

For petrol stations, a reference value provided by the Association for Convenience & Fuel Retailing (NACS) was used.⁹ Thus, petrol stations with larger retail areas offering groceries and other goods record an average of 1,100 customers per day. This figure includes not only individuals refuelling their vehicles but also those visiting solely to purchase goods such as beverages. Accordingly, the value of 1,100 persons per day was adopted. It should be noted, however, that this figure refers to the U.S. market, as no equivalent value could be identified for German-speaking countries.

Banks

For banks (tagged as “bank” in OSM), data from the Statista Research Department (2022) indicate that in Germany, a bank branch served on average 2,142 customers in 2018.¹⁰ To estimate how frequently customers visit a branch per day, a publication by Deutsche Bank (2019) was consulted, which reports that 70% of the German population visit their local

⁹ <https://www.convenience.org/Research/Convenience-Store-Fast-Facts-and-Stats/FactSheets/Convenience> (02.12.2025).

¹⁰ <https://www.statista.com/statistics/944084/average-number-of-customers-per-bank-branch-in-europe-by-country/> (02.12.2025).

branch at least once per month.¹¹ Based on these figures, it can be approximated that around 50 persons per day visit an average bank branch. This value was assigned to all corresponding points of interest. It must be noted that this estimate does not distinguish between customers visiting the branch itself and those only using automated teller machines (ATMs). Due to data limitations, a more detailed differentiation could not be made.

Kiosks and Postal Shops

With regard to kiosks and postal shops, Bosserhoff (2022) provides values for estimating potential visitor numbers (see Bosserhoff 2022, Table Retail D/46). However, determining the actual floor area for these points of interest proved problematic. This issue was first observed during the initial screening of points of interest. In numerous cases, the calculated area appeared excessively large, resulting in unrealistically high visitor estimates. Consequently, research was conducted to determine average retail floor areas for kiosks and postal shops. These two categories were analysed together, as parcel service providers frequently operate parcel collection points within kiosks or lottery outlets. The Lekkerland Group (2021) served as the primary data source, given its extensive role in supplying and managing kiosks throughout Germany.¹² Thus, kiosks are typically classified as small establishments with an area of up to 30 m². While no explicit upper limit is stated, an establishment is generally considered large from about 80 m². Accordingly, all kiosks for which an area significantly exceeding 8 m² had been assigned were reassessed using an adjusted value of 90 m², as Lekkerland does not define a strict threshold.

Bakeries and Butcher Shops

A similar issue arose with points of interest classified as bakeries (“bakery” in OSM) or butcher shops (“butcher” in OSM). Although floor areas had been assigned, the resulting calculations again produced unrealistically large values. Consequently, additional research was conducted to identify reference values for the typical floor area of bakeries, since Bosserhoff (2022) provides conversion factors for retail uses (see Bosserhoff 2022, Table Retail D/46). Potential size values were sought in retail and urban centre development

¹¹ https://www.dbresearch.com/PROD/RPS_EN-PROD/Who_still_visits_a_bank_branch_in_Germany%3F/RPS_EN_DOC_VIEW.calias?rwnode=PROD000000000497075&ProdCollection=PROD000000000499222 (02.12.2025).

¹² <https://www.lekkerland.de/magazin/kiosk-eroeffnen/kiosk-eroeffnen-kosten/#:~:text=Bei%20einem%20mittleren%20Kiosk%20mit,Kosten%20in%20H%C3%B6he%20von%20ca> (02.12.2025).

concepts published by municipalities. However, documents such as the City of Cologne's Retail Concept (Stadt Köln 2010) and the City of Aachen's Retail Concept (Stadt Aachen 2015) did not include explicit area data. While, for instance, the Aachen report (Stadt Aachen 2015: 5) specifies the total sales area for bakeries and butcher shops combined, it does not list the number of establishments, making any derivation of per-store areas impossible. Therefore, the approach was again based on the values reported by Lekkerland (2021), under the assumption that kiosks with parcel services are comparable in size to bakeries and butcher shops. Similar thresholds to those applied for kiosks and postal outlets were therefore adopted. For bakeries, the threshold was reduced to 100 m², acknowledging that some include additional café areas. For butcher shops, a limit of 60 m² was applied, following Lekkerland (2021).

Points of interest without assigned area

During the calculation of potential visitor numbers, it became apparent that not every point of interest had been assigned a corresponding floor area polygon through the spatial intersection process. In such cases, the Excel cell intended to display the calculated value instead returned “#N/A” or 0. This issue likely occurred when a point of interest was located slightly outside a building polygon or point-of-interest area, possibly due to digitization inaccuracies. To address this issue, an additional Spatial Join operation was performed in ArcGIS Pro for the affected points of interest. In contrast to the initial approach, the “Within” condition was replaced by the “Closest” condition. This adjustment enabled the software to determine the nearest building polygon or, as a secondary option, the nearest point-of-interest area, based on Euclidean distance.

The assumptions and solution approaches described up to this point can be associated with the downward arrow from Phase 5 to Phase 4 of the workflow (as illustrated in Figure 2 in the main article). After multiple iterations of adjustments and strategies for addressing missing values, a final plausibility check of all calculated values was conducted. For this purpose, the Excel table containing the computed visitor numbers was sorted in ascending order. Initially, cases exhibiting clearly excessive or unrealistic values were examined. For reference, the previously mentioned point of interest of the RheinEnergieStadion in Köln-Müngersdorf was assumed to have the highest potential visitor volume, estimated at 50,000 persons. During this step, 420 cases were reviewed and values deemed unrealistic were adjusted. Reasons for these

discrepancies included, for example, instances in the Cologne city centre where the assigned floor area did not correspond to the point of interest, leading to erroneous allocations and consequently overestimated visitor numbers. Additionally, errors in the application of conversion factors that had generated incorrect values were corrected. A similar procedure was applied to cases where the calculated visitor numbers were underestimated, such as a REWE supermarket, for which the initial value of 20 persons was found to be unrealistically low and subsequently adjusted. Following the manual adjustment of clear outliers, the values previously calculated in Excel were transferred to ArcGIS Pro. The Excel table was imported into the GIS using the “Excel to Table” function. Finally, through the OSM ID associated with each point of interest, the computed values were joined to the corresponding points of interest via a Table Join.

With regard to hotels and other accommodation facilities, no reference values could be found in the Ver_Bau tool (Bosserhoff 2022) or determined through research. As a result, an approximation was also developed for this purpose in order to be able to specify more individual values for each hotel.

To this end, all points of interest with the values “hotel”, “hostel”, “guest_house” and “chalet” were first transferred to a separate Excel table. The selected points of interest, a total of 358, were then assigned a random value using the Excel function “RAND”. This allowed the Excel table to be sorted in ascending order based on the random numerical value, so that a random sample could be taken from the first 31 entries (Table S4-1). As part of this sample, the number of rooms for each hotel and hostel was determined through internet research. The sample with the number of rooms and the source reference is presented in the table above. The determined number of rooms was divided by the specific building area. The median of the results of this calculation is 7.60. With the help of this value, the number of rooms per hotel could be estimated in the next step, based on the determined area per point of interest. The estimated number of rooms could then be used to determine the number of people. Hotels usually have predominantly double rooms. For this reason, it is assumed at this point that approximately 80% of hotel rooms are double and the remaining 20% are single rooms or shared rooms. For simplicity’s sake, we assume that the 20% are single rooms. Based on the estimated number of rooms, we can now determine the number of people staying per room and thus calculate the total number of people per hotel.

Table S4-1: Tabular overview of the hotel sample

Name of the hotel in the OSM database	Number of rooms determined	Estimated number visitors in single rooms	Estimated number visitors in double rooms	Estimated number of visitors	Sources
Hyatt Regency	306	61	490	551	Hyatt Regency o. J.
Tagungs- und Gästehaus St. Georg	31	6	50	56	DPSG-Köln o. J.
Hotel Eden am Hof	77	15	124	139	Eden Hotel o. J.
A&O Köln Hauptbahnhof	39	8	62	70	a&o Hostels Köln Hauptbahnhof, o. J.
NH Köln – City	217	43	348	391	nh-Hotel o. J.
Hotel Skada Köln	31	6	50	56	Hotel Skada City Cölln o. J.
Ibis Hotel Köln Messe	180	36	288	324	All accor o. J.
Savoy Hotel	151	30	242	272	Savoy o. J.
Casa Colonia	16	3	26	29	Hotel Casa Colonia o. J.
Hotel Uhu	35	7	56	63	Hotel Uhu o. J.
Dorint Hotel	145	29	232	261	Essential by Dorint o. J.
Insel Hotel	42	8	68	76	Insel Hotel o. J.
Hotel Lorien	55	11	88	99	Hotel Lorien o. J.
Hotel Berg	30	6	48	54	Hotel Berg o. J.
Hotel Brandenburger Hof	29	6	46	52	Hotel Brandenburger Hof o. J.
Hotel Boulevard	26	5	42	47	Hotel Boulevard o. J.
Leonardo Hotel	165	33	264	297	Leonardo Hotel o. J.
Hotel Germania	23	5	36	41	Hotel Germania o. J.
Hotel Haus Röttgen	18	4	28	32	Hotel Haus Röttgen o. J.
Hotel Gertrudenhof	22	4	36	40	Hotel Gertrudenhof o. J.
Hotel Domspitzen	30	6	48	54	Hotel Domspitzen o. J.
Hotel Freiheit	30	6	48	54	Hotel Freiheit o. J.
Dorint An der Messe	312	62	500	562	Dorint Hotel & Resorts o. J.
Hotel Sion	25	5	40	45	Hotel Sion o. J.
Stadthotel am Römerturm	107	21	172	193	Stadthotel am Römerturm o. J.
Hotel Der Löwenbräu	18	4	28	32	Löwenbräu Köln o. J.
Maritim Hotel	454	91	726	817	Maritim Hotel o. J.
Excelsior Hotel Ernst	134	27	214	241	Excelsior Hotel Ernst o. J.
Hotel Chelsea	39	8	62	70	Hotel Chelsea o. J.
A&O Köln Dom	41	8	66	74	a&o Hostels Köln Dom o. J.
Adina Hotel Cologne	171	34	274	308	Adina o. J.

Source of samples (Table S4-1):

a&o Hostels Köln Dom, o. J. a&o Hostels Köln Dom.

[https://www.aohostels.com/de/koeln/koeln-](https://www.aohostels.com/de/koeln/koeln-dom/?cnagn=a%26o%20k%C3%B6ln%20dom&gad=1&gclid=CjwKCAjw4ZWkZhA4EiwAVJXwqdRy4smnWJ_OAFdI_Su1crZ5PHA6vGatq5zscSck1DdY3OrLdiRGOxoC3gYQAvD_BwE)

[dom/?cnagn=a%26o%20k%C3%B6ln%20dom&gad=1&gclid=CjwKCAjw4ZWkZhA4EiwAVJXwqdRy4smnWJ_OAFdI_Su1crZ5PHA6vGatq5zscSck1DdY3OrLdiRGOxoC3gYQAvD_BwE](https://www.aohostels.com/de/koeln/koeln-dom/?cnagn=a%26o%20k%C3%B6ln%20dom&gad=1&gclid=CjwKCAjw4ZWkZhA4EiwAVJXwqdRy4smnWJ_OAFdI_Su1crZ5PHA6vGatq5zscSck1DdY3OrLdiRGOxoC3gYQAvD_BwE) (20.04.2023).

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