The potential of implementing superblocks for multifunctional street use in cities

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Abstract

The Barcelona superblock has been proposed as a sustainable urban neighbourhood transformation strategy in cities. Superblock design reduces space assigned to cars to enable alternative uses for improving liveability and sustainability. Here, the potential for superblock transformation is systematically quantified and evaluated for cities with varying urban forms and densities. A superblock consists of nine (3 × 3) urban city blocks including interior and exterior streets. Miniblocks, consisting of four (2 × 2) blocks, are proposed as a less disruptive strategy to initiate urban transformation on which superblocks can build. A geospatial network-based approach is developed to find locations for introducing multifunctional streets. For possible site prioritization, the identified locations are evaluated concerning the potential disruption to traffic. The analysis reveals that the potential for super- and miniblocks, as well as their disruption effect, varies considerably across cities and is affected by the urban layout. For some cities, over 40% of the street network is potentially suitable for integrating super- or miniblock design, providing opportunities for city-scale transition towards more sustainable and liveable cities. A grid-like layout in cities is not a sufficient condition for high superblock potential and cities with irregular street layouts can show high transformation potential as well.

Main text

Pursuing sustainable urban design approaches in today’s cities is necessary as cities face manifold challenges due to climate change, urban heat, flooding and air or noise pollution. The COVID-19 pandemic intensified the discussion on how to transform cities and neighbourhoods to be more...
liveable, resilient and sustainable and has triggered the rethinking of public urban spaces. Unconventional concepts such as tactical urbanism, multifunctional streets or superblocks are being envisioned, where more space is assigned, for example, to urban greening, pedestrians or cycling zones. Encouraging walkable neighbourhoods by reducing car-based dependencies is envisioned to improve health and urban liveability. Superblocks (Superilles) were prominently proposed in Barcelona as an innovative and unconventional urban transformation strategy to create pedestrian centric neighbourhoods and have since become an integral part of Barcelona's climate commitment strategy to reduce transportation emissions and address urban heat islands. The Barcelona superblock forms an urban unit made up of nine (3x3) urban blocks with interior and exterior streets and is characterized by enabling a transformation of the interior streets for new shared urban uses (Figure 1a). In Barcelona, a speed limit of 10 or 20 km/h was applied to interior streets and they were altered so that superblocks cannot be crossed by car, thus preventing through traffic. Superblocks do not only redefine urban mobility by shifting the modal split towards public transportation, cycling or fostering walkability but have also the intention to improve urban green infrastructure and biodiversity by establishing urban corridors traversing the city. The long-term vision in Barcelona is to transform individual neighbourhoods and bring about transformation at the larger scale by repeated superblock implementation across the city. For such a superblock based urban regeneration strategy, an average increase in life expectancy of almost 200 days due to reduced urban heat, air and noise pollution levels was estimated in the case of implementing 503 superblocks across Barcelona.

Despite the promising potential benefits of the Barcelona superblock design, it has only received limited attention in research, even though cities are independently exploring how superblocks could be implemented and the European investment bank is financing urban regeneration with superblocks. A systematic quantification of the potential for superblock design across different cities is currently lacking. The potential for implementing superblocks given the street network topology for different urban morphologies is equally unclear. The principal aim here is to address this knowledge gap and to provide a first exploration of the potential of the superblock concept with help of automated geospatial analysis for different cities whilst considering impacts on urban mobility.
Considering mobility is essential, as typically banning traffic from one area in a city will affect the remaining parts of a street network and the implementation of superblocks is challenging in cases involving considerable disruption to traffic. In this work, a data-driven geospatial methodology for automatic detection of superblock potentials is developed and applied for a range of cities with various shapes and sizes. Additionally, the suitability of superblock potentials concerning traffic flow exposure is assessed with help of a network flow algorithm. Because urban morphology varies substantially across cities, the superblock concept first needs to be conceptually transferred to different urban morphologies.

**Barcelona superblock design in different cities**

Barcelona was extended in the 19th century following an urban development plan based on chamfered square urban blocks with a side length of around 113m². Some Barcelonan districts (e.g. Eixample) are characterised by a grid-like street network and therefore represent a perfect model for superblocks. Other parts of Barcelona have an irregular typology with urban blocks not following a grid plan. Urban blocks act as the fundamental spatial organisation of a city and can be described as the land area defined by the street network, whereby urban blocks vary in size and shape across the world. Exploring the Barcelona superblock strategy in different cities is promising, as many cities are facing similar challenges. Even though the urban morphology varies between cities, an often common element is the presence of dense urban structure surrounded by higher-order, exterior streets, such as the sikkak system in Arab countries or the hutongs in China. The spatial dimension of the area surrounded by the superblock can differ, and typologies have been proposed to characterise internal street layouts. However, there is no common use of the superblock terminology: In the case of the much larger and functionally different Chinese superblock, for example, removing gates and opening the interior streets is proposed (in contrast to the Barcelona model). In this work, the term superblock is used as intended for the Barcelona case and careful replication and contextualization is necessary. Cities may not always form large urban blocks or may show heterogeneous urban layouts. To address this, different superblock design elements are delineated from the Barcelona superblock concept with
which analogous street transformation strategies can be envisioned, most importantly the mini
superblock (miniblock) (Figure 1b). Miniblocks follow the same logic as superblocks, i.e. they include
exterior and interior streets, but are only made up of 2×2 or 1×2 urban blocks and form a lighter and
geometrically smaller version of a superblock. A superblock consists of four overlapping miniblocks. An
even greater reduction to a linear block could be conceived, where only a single street is bordered by
two blocks. Adaptations of the Barcelona superblock may however not provide the same functionality:
Ecosystem services of implemented alternative street use measures may not perform equally well for a
range of different criteria32. Whereas for example, one intention of the superblock is the creation of
multifunctional and independent neighbourhoods or foster walkability, this may be possible only to a
lesser degree with miniblocks: It may be more difficult to have key destinations for daily living within
the boundary of the miniblock to establish independent communities or the public street space
available for exercising, daily interchange, leisure and so on may be smaller12,28. However, including the
miniblock enables to broaden the analysis, as otherwise potentially only very few sites with urban
layouts identical to Barcelona are identified.

Geospatial modelling and network analysis

For each street, the suitability for superblock design is assessed based on urban characteristics and the
street network topology. The developed geospatial and network analysis for the identification of
super- and miniblocks relies on a graph-based representation of the street network, which is
downloaded and processed from OpenStreetMap, a commonly used volunteered geographic
information data source33.

Structural diversity and density are two key urban characteristics for evaluating the suitability
of superblocks34. Streets with low population density values are excluded from the analysis (Table 1), as
superblocks are typically proposed for high-density neighbourhoods. High-density areas are most
exposed to negative effects resulting from urban concentration and therefore alternative street use is
potentially most pressing15. Another rationale for focusing on high-density areas is that a high urban
concentration means that alternatives to car-based mobility are potentially more feasible. Information
related to structural diversity is difficult to obtain, as data such as working spaces are typically not freely available. To include non-residential areas in the analysis, the building footprint coverage is used to approximate overall imperviousness. If the building footprint coverage is below a threshold (Table 1), a street is considered unsuitable. This approach thereby follows the same hypothesis as in other studies\textsuperscript{19}: in case of currently high availability of sealed land and little urban green, the transformation of a street is more beneficial and of higher priority\textsuperscript{19,36}.

A range of network indicators have been proposed to describe urban form and street network layouts\textsuperscript{27,37}, which are used for identifying super- and miniblocks. The local edge connectivity measure and the node degree are found to be highly useful for analysing street network segments. The local edge connectivity measure describes the minimum number of edges that must be removed to disconnect a considered edge from a network. Edges with a local connectivity value of one are considered unsuitable and removed, as these are typically cul-de-sac or network elements, which do not follow the logic of superblocks. The degree of a node, i.e. the number of edges that are incident to a node, is used to locate street network nodes that could form part of super- or miniblocks. Furthermore, the lengths of the exterior (i.e. circumferencing streets) and interior streets are used for geometric characterization. A superblock typically contains a network cycle of four nodes with a degree value larger or equal than three. Miniblocks are identified with network nodes with a degree larger than or equal to three, where the encompassing exterior streets need to fulfil length criteria. For detecting exterior streets, a shortest-path algorithm is applied to determine the shortest route that connects all neighbours of the superblock nodes. Table 1 summarises all applied criteria for the identification of super- and miniblocks.

For analysing the street network typology and locating potential superblocks, spatial geometry scenario ($G_f$) are considered (see methods). Key geometric indicators of the Barcelona superblock (termed $v_0$) are varied with a geometric deviation factor $f$. A scenario $G_f$ includes indicator values $v$ in the range $\left[\frac{v_0}{1+f}, v_0 \times (1 + f)\right]$. The Barcelona superblock is considered to have an overall dimension of $400\text{m} \times 400\text{m}$ ($G_0$), whereby an additional uncertainty of $\pm 20\%$ of the dimension is assumed to consider
slightly different spatial dimensions. Resulting properties for a deviation where the minimum block width is half and the maximum block width twice the size of the Barcelona block \((G_1)\) are provided in Table 1, which are further used for the presented analysis. Urban configurations are up to this value here still considered as comparable in terms of urban characteristics such as walkability, urban streetscape or the reachability for urban mobility. The scenario parameter \(G_i\) allows easy adaptation to the search to fit a desired geometry. The sensitivity of \(G_i\) is shown in Figure 2, which reveals that the simulated total street length of super- or miniblocks increases for higher values. Such an increase in streets fulfilling the respective geometric criteria is to be expected with increasing geometric deviation. The detected street percentages however level off from a value of \(G_1\) onwards. The selected value of \(G_1\) used here includes a considerable geometric deviation to the Barcelona superblock. Therefore, the obtained simulation results reflect a generous estimate.

**Super- and miniblock potential**

The developed methodology is applied for a selection of smaller and larger cities (see methods). Figure 3 shows the processed street network and modelled street classification. The classified streets may provide multiple options for superblock implementation, particularly if the street network is grid-like and various options exist for placing the superblock. For the miniblock classification, urban configurations consisting of three or four blocks are combined (Figure 1). All simulated potential super- and miniblock options and street classification are available for download. Figure 4 summarises the statistics of the street network classification. The pedestrian street class includes living- and pedestrian streets as defined by OpenStreetMap and provides an estimation of already transformed streets to be car-free or where low-speed limits apply. These streets are not further analysed, as in these locations either urban transformation strategies (including superblocks) have already been applied or they require alternative strategies (e.g. historic town centres with a distinct urban form). When comparing the absolute length of the street types across the case studies (Figure 4a), several points need to be noted: First, the choice of the \(5 \times 5\) km case study area extent, which was centred on the city centre, determines which streets are considered and affects the street distribution. Second, the
local geography affects the overall length, as for example, large water bodies reduce the urban area and thus street length. Third, OpenStreetMap is user-generated, which means that the classification or completeness needs to be considered and may differ.

The relative classification results across the selected cities are compared in Figure 4b. The number of large streets is typically around 20–30%. The share of pedestrian streets is typically only a few percentages, except for some cities such as Barcelona. The street network that could potentially be considered for implementing superblocks ranges between a few percentages (e.g. Atlanta) to over 40% (e.g. Mexico City). The potential for miniblocks generally follows the same pattern and unless the city has a highly grid-like structure, miniblock potentials are detected more frequently. For some cities (e.g. London), the potential for transforming larger neighbourhoods as intended with superblocks is smaller: the street network fulfils the topological criteria fewer times and superblocks would oftentimes be too large or be intersected by primary, secondary or trunk streets. However, despite having a lower superblock potential, there is nonetheless potential for miniblock transformation with a combined potential of super- and miniblocks of approximately 12.7% of total street network length. The identified potential for superblocks in Figures 3–4 consequently is highest in cities having similar layouts to Barcelona, such as Madrid or Mexico City. However, even though some cities have a grid-like city structure (e.g. Atlanta), the simulated density (either population density or building coverage) is not sufficiently high for super- or miniblocks. The same holds for other cities such as Warsaw, where many buildings are surrounded by large green open spaces.

Identified super- and miniblock implementation opportunities serve as an upper limit estimation, as in the case of actual turning interior streets into multifunctional use other streets would need to serve as exterior streets. These streets would need to be removed as suitable candidates, thus reducing the potential following implementation, particularly for grid-like city layouts. As there are multiple options of implementing super- or miniblocks, all simulated options are here provided without proposing a concrete design.
Disruption simulation of urban mobility

To link superblock design to car-based urban mobility, the importance of each street concerning traffic flow is assessed. Detailed traffic flow simulation modelling approaches could be used for this analysis, which is however challenging to set up for a large number of cities. Alternatively, manifold studies have investigated the resilience or importance of a single network element for different network types, including the street network\textsuperscript{39}. Typically, the street hierarchy provides a first and important indication of its importance. Marshall\textsuperscript{27}, for example, describes the criteria continuity, connectivity and depth to build a street hierarchy. Even though street hierarchy typically is higher for larger streets, street size is not the only indicator of its importance: large streets may be less critical in the case where traffic could easily be rerouted. The availability of redundancy and alternative routes are thereby essential when evaluating the disruption due to the removal or reconfiguration of an individual street. Therefore, the importance of a street needs to be assessed with help of the street network with network indicators to differentiate street hierarchy or the criticality of a single street network element\textsuperscript{40,41}. For this study, available user-generated information on the street hierarchy is used for excluding large streets, which are not considered suitable for super- or miniblocks due to their critical importance for traffic. Additionally, the importance of each street is assessed with help of a network flow algorithm, the Edmonds-Karp algorithm, which is a flow-based algorithm and a special implementation of the Ford-Fulkerson algorithm. The algorithm has been applied in different research fields and for various network types, including traffic flow simulation\textsuperscript{42,43}, and is commonly used for analysing the resilience of networked infrastructure. The algorithm requires information on the flow capacity for each network edge, i.e. information on the maximum amount of flow that can pass through each edge. Different models have been proposed to estimate street flow capacities for changing conditions, which typically aim to identify critical quantities where traffic flow changes and traffic jams occur. Traffic flow depends on the street type, network layout, topography, user behaviour, weather et cetera.\textsuperscript{44}. For this study, the flow capacity for each street is set with help of the street classification and the number of lanes provided by OpenStreetMap, thus only considering relative flows. The number of lanes serves as a
proxy for network capacity, i.e. the simplifying assumption is made that capacity is directly linked to
the number of lanes. As lane information is not consistently available in OpenStreetMap, missing lanes
numbers are estimated with the street hierarchy. For all interior streets classified as potential super- or
miniblock locations, the street network disruption indicator (NDI) is calculated (see methods).

Figure 5 shows the absolute and relative street length of all super- and miniblocks, categorized
into a low, medium and high NDI class. The presented categorization enables the evaluation of the
modelled potentials in Figure 4 and can serve to identify the least disruptive sites. When comparing
the absolute street lengths, the same considerations need to be made as mentioned previously, i.e. the
relative street categorization allows better comparison between the case studies. The prevailing street
network typology of cities strongly affects how disruptive superblock interventions are, which is
revealed by the considerable variation in calculated NDI values: the streets falling into the lowest NDI
class, which is considered to have the least disruption effects, ranges between approximately 39–74%.
For Paris, Barcelona or Budapest, a higher percentage of the identified super- and miniblock sites have
higher NDI values. For cities having today already higher shares of pedestrian streets, the availability of
streets with low NDI values tends to be lower. The analysis reveals that across cities with high shares of
streets having low NDI values such as London, Cairo or Bangkok, there is high potential to transform
neighbourhoods with only limited impact on traffic flow. Other cities such as Paris or Berlin have less
favourable network topologies where the superblock implementation is comparatively more disruptive.
Identified super- or miniblock potentials in cities with more grid-like urban layouts are not necessarily
less disruptive, even if currently only very few pedestrian zones exist. For Mexico City, for example, a
high superblock potential was modelled, of which however sites are oftentimes considered as having a
considerable street network disruption effect.

In the case of implementing superblock design, the network flow changes and traffic would need
to be re-routed. Such a dynamic interplay was not considered here. Calculated NDI values therefore
only provide a first estimate on the current exposure of super- or miniblock sites to urban mobility,
thereby assuming that transforming streets with high traffic flow is potentially most disruptive.
Detailed studies would need to accompany concrete implementation plans including detailed traffic simulations that consider unique properties of streets and local constraints.

**Discussion**

This investigation provides a first estimate of super- and miniblock potentials across different cities and on how disruptive identified potential sites are concerning traffic flow. Superblock design crucially frees up urban space from car-based mobility by assigning novel uses to street spaces such as urban greening or pedestrian zones. This analysis offers insights on opportunities for cities to tackle several of the challenges they are increasingly faced with such as climate change, noise or air pollution, urbanization or limited availability of urban green space. The introduced geospatial data-driven methodology for the automatic detection of superblock design opportunities can be easily applied to different cities or geographical extents and the methodological assumptions changed to adapt the analysis. The approach could similarly be extended for other urban design strategies, which for example focus on transforming cul-de-sac streets. The share of the existing street network simulated to be suitable for implementing superblock design was found to range for some cities from a few percentages of the street network (e.g. Atlanta, London, Hong Kong) to a considerable share above a third of the street network for other cities (e.g. Mexico City, Madrid, Tokyo). Even if only few superblocks were identified, the transformation potential of streets is still notable when also considering miniblocks. Miniblocks are found where the urban layout complicates the implementation of a superblock but still offers opportunities for street transformation at smaller scales. Notably, a grid-like urban street layout does not automatically mean high implementation potential for superblocks, due for example a lack of dense and compact urban form. The validation of the modelled superblock opportunities is challenging, as local knowledge is required and the concrete implementation and street conversion potentials are highly disputed: The implementation depends not only on the personal vision for cities but also on the political will for urban transformation or on how future urban mobility will evolve, particularly related to autonomous vehicles, which is anticipated to result in a considerable change to urban form.
Substantial differences were not only found in the quantitative simulation of superblock design potentials but also concerning traffic flow disruption. The identified super- and miniblock locations can be prioritized with help of the calculated network disruption indicator. Urban transformation could be more challenging concerning traffic disruption for cities that have already considerably transformed streets and that have a high number of pedestrian streets. Implementing miniblocks may be a less disruptive strategy to start or further expand urban transformation. Because superblocks essentially consist of multiple miniblocks, miniblocks are an opportunity to initiate city transformations on which superblocks could build upon.17

The presented simulation results serve as a starting point for urban neighbourhood transformation by super- or miniblocks and provide crucial inputs to city planners, particularly for locating and prioritization of the most promising sites for alternative street use. This information is particularly relevant for the ongoing discourse surrounding densification, urban rewilding, or the transformation of parking spaces. When implementing superblock design, particularly improving alternative transportation modes is vital to enable inter-metropolitan commuting and changes to the urban street network may require amendments to the existing public transport system. Superblock design however goes beyond traffic calming measures and aims towards an integrated urban transformation strategy to improve urban sustainability at the city scale. Implementing superblocks must therefore not be done in isolation. The identified sites need to be further assessed and evaluated concerning opportunities to improve the connectivity of green infrastructure across a city with green axes, reduce pollution, integrate superblocks into public transport, how to best foster walkability or achieve optimal urban heat mitigation. To this end, further integrated modelling efforts are required. It is also necessary to account for a wider range of considerations including social change related to gentrification. Follow-up studies to the presented generic and data-driven approach for individual case study cities should integrate further local constraints in more detail.

The analysis reveals considerable potential for transforming urban streets with super- or miniblocks in high-density areas to improve urban liveability and reduce environmental stresses. The simulation results can serve as a basis for further exploration of sustainability impacts of different
superblock scenarios at city-scale in various cities. It however needs to be noted that superblock
design represents only one urban design strategy amongst different strategies to achieve more
sustainable neighbourhoods and cities.

Methods

Case-study selection: The case studies are chosen to include different cities around the globe, that
are commonly used for urban studies\textsuperscript{51}. From the 18 selected case study cities, 12 cities are part of the
C40 cities initiative, which aim to lead the way in urban sustainability. The selection ranges from large
cities strongly following a grid street plan (e.g. Mexico City or Tokyo) to smaller cities, which are not
dominated by a grid-like urban layout (e.g. Zürich). This selection is not exhaustive and comparatively
more European cities are analysed. Barcelona is considered to test the methodology for the city where
the superblock concept originates. The presented analysis can however be applied to further cities and
is merely constrained by data availability.

Street network data processing: The case study extent for each city is 25km\textsuperscript{2} for which the street
network is downloaded with help of the overpass API\textsuperscript{52} and represented as graphs with nodes and
edges. For the graph-based algorithms and geometric processing steps, the python-packages
NetworkX\textsuperscript{53} and Shapely\textsuperscript{54} are used. The downloaded raw data is processed in several steps to obtain
more accurate street length estimations: First, network nodes that are within a 15m distance to each
other are clustered to obtain a simplified network. This street network abstraction particularly reduces
the complexity of street intersections. Second, closed detached rings (loops) and isolated subgraphs
are removed from the street network as well as long (>300m) tunnels and streets intersecting
buildings. Further network cleaning is conceivable, depending on the case-study context, such as
removing elevated streets. Third, very small network edges not forming part of longer streets are
removed, as they typically represent driveways (see supplementary material Section 2). The street
network was not re-designed by extension. For example, the street network connectivity was not
increased by adding new streets, which could potentially help to design more super- or miniblocks.
Before searching for potential super- or miniblocks on the street network, the street network nodes are classified into higher and lower-level nodes. Whenever a node forms part of an intersection (i.e. degree ≥ 3), the node is classified as a higher-level node. A lower-level node forms part of a street (edge) between two higher-level nodes. Typically, the street between two higher-level nodes consists of multiple lower-level nodes and edges, as the streets are typically not perfectly straight. The lower level nodes are considered for calculating distances on the street network and creating the blocks. However, when checking for the network topology criteria to identify super- and miniblocks, only the higher-level street network is considered. This differentiation is necessary, as otherwise oftentimes super- and miniblocks would not be identified on the street network due to the lower-level nodes (see supplementary material Section 1).

**Street hierarchy:** The complexities surrounding superblock implementation are higher for streets that are essential to urban mobility. Contributors to OpenStreetMap can classify streets and assign different attribute labels to define a street network hierarchy. Based on the provided street hierarchy, the assumption is made that streets labelled as primary, secondary and trunk streets are not suitable for superblock design. Similarly, streets that form part of a trolleybus or tram route are excluded as potential superblock locations. For this analysis, all footways and private streets are ignored. Streets categorized as pedestrian or living streets are considered as streets that are already today not centred on car-based mobility and are ignored, as the focus here is on transforming streets that are currently focused around car-based mobility.

**Calculation of population density and building coverage:** To go beyond relying on street network characteristics for detecting superblock design, density values are calculated for the entire street network. For each network node, average density values are calculated considering a radius of 100m and then averaged per edge by averaging the density values from the starting and end node. Alternatively, the population density could be calculated based on buffering the street network edges. The population density calculation is based on population data provided by CIESIN\(^5\), which are population estimates based on satellite data and census data at a ~30m resolution. With help of OpenStreetMap building footprints, the building footprint coverage is calculated first for
every node on the street network considering the same radius of 100m. Second, the average building
coverage per edge is calculated based on averaging the value from the start and end node of each
edge.

**Detecting super- and miniblocks on the street network:** The street network forms the basis for
locating potential super- or miniblock candidates. Before searching potential candidates, the street
network is characterized concerning the street type, population density and building coverage as
outlined in the previous two paragraphs for narrowing down the search. Then, the street network is
first cleaned for cul-de-sac street elements and the degree of all street network nodes is calculated.
Second, all nodes with a degree ≥3 are filtered, as they could potentially be part of interior street
intersections of super- or miniblocks. From this reduced filtered street network, all network cycles are
identified, as they could potentially be an interior street loop of a superblock. Isolated nodes with
degree ≥3 not forming part of a network cycle or interior street loop of a superblock are further
evaluated as a potential minblock. Third, to find the exterior streets, all neighbouring nodes of the
considered node(s) are identified and a shortest-path algorithm is applied on the network, where the
considered nodes are removed, to connect all the neighbouring nodes. If no path is found, the street
network typology prevents the design of a mini- or superblock. For miniblocks, all neighbours of the
single node (single interior street intersection) are selected. Similarly, for superblocks, all neighbouring
nodes not forming part of the interior street loop are connected along the shortest path route to form
the superblock polygon. If no path is found, or the path crosses a bridge, the node is not further
considered. Finally, the geometric properties of the identified potential super- or miniblocks are
checked whether all the boundary conditions are fulfilled. In case a potential superblock does not fulfil
the boundary conditions, the conditions for fulfilling a miniblock are tested. Table 1 lists all conditions
and the geometric scenario calculation is outlined in the next method section.

**Geometric scenario calculation:** The geometry of the superblock is calculated based on the assumed
400m length of the Barcelona superblock ($l_{BCN}$) consisting of three individual blocks (i.e. block side
length $l_{block} = \frac{l_{BCN}}{3}$). When identifying super- (S) or miniblocks (M), the following boundary conditions
for the exterior street length \(l_{ext}\), interior street length \(l_{int}\) and the length of the interior street loop or ring \(l\) (for superblocks only) need to be fulfilled:

\[
I_{ext,max}^M = \left( 8 \times l_{\text{block}} \times z \times (1 + f) \right) \\
I_{ext,min}^M = \left( \frac{8 \times l_{\text{block}} \times z}{1 + f} \right) \\
I_{int,max}^M = \left( 4 \times l_{\text{block}} \times z \times (1 + f) \right) \\
I_{int,min}^M = \left( \frac{4 \times l_{\text{block}} \times z}{1 + f} \right) \\
I_{ext,max}^S = \left( 12 \times l_{\text{block}} \times z \times (1 + f) \right) \\
I_{ext,min}^S = \left( \frac{12 \times l_{\text{block}} \times z}{1 + f} \right) \\
r_{int,max}^S = \left( 4 \times l_{\text{block}} \times z \times (1 + f) \right) \\
r_{int,min}^S = \left( \frac{4 \times l_{\text{block}} \times z}{1 + f} \right)
\]

Whereby \(f\) denotes the deviation factor and \(z\) incorporates an uncertainty of ±20% of the Barcelona superblock and takes a value of 0.8 (min) or 1.2 (max). Example values for \(G_0\) and \(G_1\) are provided in Table 1.

**Street network disruption indicator (NDI):** The Edmonds-Karp algorithm is applied to assess the importance of each network edge concerning traffic flow across the street network. This approach is inspired by Lustenberger et al., who introduce artificial 'super' sinks/sources. Super sinks/sources enable to extend a network by adding a single node that feeds all the sources or drains all the sinks.

The following steps are performed to assess the street network edge criticality: In a first step, four supernodes are projected in each direction to the network and placed outside the street network extent. Then, 100 helper nodes are equally distributed along a straight axis on each side of the network extent. An auxiliary linking edge is established between each helper node and the supernode. An additional linking edge is next added between each helper node and the closest node on the street network. A visualization and a more detailed explanation of this step are provided in the supplementary material Section 3. In a second step, the Edmonds-Karp algorithm is run consecutively for each direction between opposing supersinks and supersources. The resulting flows of each...
simulation run are summed and averaged for each edge \((i)\) to obtain the average flow \(f_{i}^{avg}\) per edge.

The average edge flow is then normalized \(f_{i}^{norm}\) with the calculated maximum average flow value of the network:

\[
f_{i}^{norm} = \frac{f_{i}^{avg}}{\max(f_{j}^{avg})}
\]  

(Eq. 11)

To consider local as well as regional network impacts, these outlined steps are performed on a raster with a resolution of 2.5 km as well as for the entire case study area. The calculations on the raster provide local flows \(f_{i}^{norm}\) as outlined above. As the overall analysed city extent is 25 km\(^2\), local flows are thus calculated across four regional cells across the city. In addition to these local flows, the same calculation is performed once for the entire case study area using the 5×5 km as the input for the flow calculations in Eq. 11. This calculation using the entire street network reflects flows at a higher geographical level and is termed \(f_{i}^{norm}\). In a third step, the two calculations are equally weighted and combined to a single indicator to calculate the relative importance of each edge concerning traffic flow, and is termed network disruption indicator \((NDI)\):

\[
NDI_{i} = \frac{f_{i}^{norm} + f_{i}^{norm}}{2}
\]  

(Eq. 12)

Edges with high NDI values are edges that are critical to the street network, edges with low NDI values have a low disruption potential as they do not form part of a critical network element and alternative paths exist for rerouting traffic. Calculating the NDI provides an approximate indication of the street disruption of a network towards urban mobility. The NDI is further used to derive classes indicating the street network disruption (low, middle, high). As identical geographical extents have been selected across our case studies, the obtained NDI values are comparable.

**Supplementary Material**

Additional methodological explanations [LINK](#).

**Data Availability**
The classified streets including calculated NDI values and all simulated super- and miniblocks for the geometric scenario G₁ are available for download as shapefiles or GeoJSON files:

http://dx.doi.org/10.5281/zenodo.4562462

**Code availability**

The workflows and code used are available from the corresponding author upon reasonable request.

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**Author Contributions Statement**

The author confirms sole responsibility for the entire study.

**Competing Interests Statement**

The author declares no competing interests.
Table 1: Criteria used for identifying super- and miniblocks. The formulae for calculating the values are provided in the method section. G₀ represents a scenario with a geometric dimension of a superblock with an overall length of 400m, where a 20% uncertainty range is assumed to obtain the minimum and maximum values. The degree of a node indicates the number of neighbouring edges of a node on a graph. Building footprint coverage, street nodes and population density values are kept constant.

| Criteria                        | superblock | miniblock |
|---------------------------------|------------|----------|
|                                 | G₀         | G₁       | G₀       | G₁       |
| Interior street loop length     |            |          |          |          |
| minimum (m)                     | 427        | 213      | n/a      | n/a      |
| maximum (m)                     | 640        | 1,280    | n/a      | n/a      |
| Exterior street length          |            |          |          |          |
| minimum (m)                     | 1,280      | 640      | 853      | 427      |
| maximum (m)                     | 1,920      | 3,840    | 1,280    | 2,560    |
| Total number of interior street nodes | 4        | 4        | 1        | 1        |
| Minimum number of nodes with degree ≥ 4 | 3        | 3        | 0        | 0        |
| Minimum number of nodes with degree ≥ 3 | 1        | 1        | 1        | 1        |
| Minimum length of interior streets (m) | n/a      | n/a      | 427      | 213      |
| Maximum length of interior streets (m) | n/a      | n/a      | 640      | 1,280    |
| Minimum building footprint coverage (%) | 30       | 30       | 30       | 30       |
| Minimum population density (inhabitants * ha⁻¹) | 100      | 100      | 100      | 100      |
Figure 1: Superblock design (a) Schematic of the Barcelona superblock adopted from the urban mobility plan of Barcelona. Superblock design is characterized by exterior streets surrounding urban blocks and the transformation of interior street space. (b) The superblock design is further developed into similar urban configurations such as mini- or linear blocks.

Figure 2: The relative street network length classified as super- or miniblocks is modelled for different geometric deviation factor (f) values for each case study city. f indicates the geometric deviation to the Barcelona superblock. Whereas the analysis is sensitive to...
the parameter $f$, the classification levels off at $G_1$. Boxplots depict the full value range across all cities and the mean classification results are plotted as lines.

Figure 3: Modelled classification of the street network for selected cities. Potential super- or miniblock locations are coloured in green. The suitability for superblock design is evaluated based on density criteria, street network geometry and street network topology. The deviation of the modelled super- and miniblocks is minimum half and maximum twice the size of the Barcelona superblock width ($G_1$, Table 1). Different shadings in green result from overlapping blocks.
Figure 4: Comparison of the modelled absolute (left) and relative (right) street types for the case study cities. The calculations are for a 25km² extent for each city. Calculated super- and miniblock potentials represent upper limits.

Figure 5: Absolute (left) and relative (right) length of all street networks modelled as either super- or miniblocks. The streets are categorized based on the calculated network disruption indicator (see methods) into a low (≤5%), a middle (5–15%) and a high (>15%) network disruption category.
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