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Atmospheric dispersion and urban planning: An interdisciplinary approach to city modeling

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ABSTRACT

Geometry modeling is a common approach in pollutant dispersion studies. Block typology is a key element for representing geometries closer to real city environments. However, urban pollutant modeling studies and urban planning processes have different approaches regarding block typology and applied metrics. Therefore, the objective of this work is to compare urban block typologies and urban metrics used in literature studies with those found in real cities. The methodology combined a literature review with an empirical analysis of sample areas in selected cities. The results showed that more than 50 % of the studies applied idealized building arrays. Nonetheless, the idealized array tends to underestimate real densities, often misrepresenting urban planning indices. On the other hand, derived geometry reduces modeling complexity and increases the applicability of studies in urban planning. Based on our findings, we suggest an urban block parameterization derived from real urban areas (representative of the densest cities in Asia, Europe, and America). This study selects five block typologies derived from actual cities (single block, detached buildings, courtyard, inner courtyards, and row buildings) with estimated values of the floor area ratio (FAR) and surface coverage (SC) that, when combined, provide a more precise representation of density.

1. Introduction

In 2018, 55 % (approximately 4.2 billion) of the world population was living in cities, and this number is estimated to reach 68 % (approximately 6.7 billion) by 2050 (United Nations Department of Economic and Social Affairs, 2018). This growth can increase building density in urban areas (Tang and Wang, 2007). As building density increases, the airflow pattern can trap pollutants, resulting in their accumulation within the urban canopy. In general, compact urban areas frequently lead to higher pollutant concentrations, for both high (An et al., 2019; Yuan et al., 2019) and medium building densities (Buccolieri et al., 2015; Hang et al., 2015). In this context, urban planning can regulate city configurations and contribute to establishing a healthy urban environment. However, a gap remains between urban air quality studies and their application in urban planning (Badach et al., 2020; Cárdenas Rodríguez et al., 2016). It is possible to identify two key aspects restricting the use of air quality studies in urban planning: (*i*) the application of urban geometries that are often overly idealized or overly specific and (*ii*) air pollution dispersion studies adopt different metrics than those used in the urban planning process.

Air quality studies often model urban geometries using computational fluid dynamics (CFD). This technique offers advantageous features, such as its affordability, accuracy, reasonable response time, and comprehensive visualization (An et al., 2019; Blocken and Gualtieri, 2012; Buccolieri et al., 2015; Nebenzal et al., 2020). The quality of the results depends not only on using the appropriate equations to represent the phenomenon and employing suitable numerical strategies but also on the correct description of the urban geometry (Carpentieri and Robins, 2015a; Guo et al., 2017a; Peng et al., 2019; You et al., 2017). Therefore, the urban geometry must be carefully taken into consideration for the model to provide a realistic representation of the environment.

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Urban geometry is the result of a city's configuration, which combines its urban layout (urban blocks and streets; see Fig. 1) with its urban block typology (the arrangement of buildings on the urban block). In the literature, geometries are classified as real or generic. Real geometry represents an existing situation in a specific region. Simulating existing regions can indicate the most impactful characteristics of urban geometry (Shen et al., 2017; Yang, Shi et al., 2020). Also, simulating these regions provides guidelines for implementing the urban planning of a specific city (Kurppa et al., 2018; Yuan et al., 2019, 2014a). In this sense, simulating a real geometry assists with planning a specific region but hinders the ability to extrapolate the results for a general purpose. On the other hand, generic geometry reduces the complexity of CFD simulations, allowing for a broader application of the results (An et al., 2019; Carpentieri and Robins, 2015b; Yang, Shi, Zheng et al., 2019; Yang, Shi, Shi et al., 2019). Because generic geometry is a parameterized representation of urban configurations, it simplifies the complexity of real geometries.

Generic geometry can be divided into three types: idealized, simplified, and derived (Fig. 2). The idealized building array often uses the same dimensions for buildings' widths, lengths, and/or heights and the space between buildings (Chen et al., 2017; Hang et al., 2015; Lin et al., 2014). However, the idealized building array does not take the concept of the urban block into account; consequently, the dimensions of this component vary greatly from the urban reality. To use geometries that resemble real city environments, Merlier et al. (2019) and Ricci et al. (2017) simplified the geometry of an existing city block. Simplified geometry considers the urban block as a bluff body, i.e., it does not consider the buildings' arrangement (the block typology). Nonetheless, Guo et al. (2017a,2017b) and Ricci et al. (2017) found that block typology affects urban airflow, and simplified block typology often generates an overly idealized or unrealistic version of the city. More recently, some studies presented derived geometry as a new category, which simplifies the real configuration by using the predominant block typology of a specific region (Carpentieri and Robins, 2015a; Peng et al., 2019). Therefore, derived geometry represents a generic approach that is closer to what is seen in real cities.

Furthermore, it is significant that modeling studies use different metrics than those employed in the urban planning process. The majority of the literature applies the concept of packing density using the plan area density (λ_P) and the frontal area density (λ_F) to describe the building density (Hang et al., 2015; Ramponi et al., 2015; Shirzadi et al., 2018). However, these metrics differ from the usual urban planning indices. Some of the most common urban planning indices around the world include the floor area ratio (FAR), which correlates with the built density area, the surface coverage (SC), (surface coverage), which correlates with urban porosity, and building height (H). Only a few recent air quality studies focusing on urban planning apply indices such as FAR and SC (Cheshmehzangi and Butters, 2016; Peng et al., 2019). Although both modeling metrics and urban planning indices relate to surface coverage and built proportion, there is a key difference between them: the modeling metrics (λ_p and λ_f) consider the streets in the total area, while the urban indices (FAR and SC) exclude the streets in the total area (Fig. 3). Moreover, the metric λ_f correlates the built area with building height, while FAR represents the built volume.

Given the differences between modeling studies and urban planning, the main objectives of this work are (*i*) to discuss the treatment of urban block typologies and metrics in literature studies and those found in real cities; and (*ii*) to propose an urban block parameterization more similar to actual urban environments. To achieve these aims, a literature review of pollutant dispersion studies and an empirical analysis of real city morphologies were conducted. The findings support an urban block parameterization derived from real urban areas that brings modeling studies closer to the urban planning process.

2. Urban blocks and pollutant dispersion

The urban block has been a key element in the urban planning process for several decades. Nonetheless, pollutant dispersion modeling studies identify the urban block or "city block" as a novel generic configuration (Moonen et al., 2012). This configuration is simple enough to be generic yet complex enough to be relevant for urban planning (Moonen et al., 2012). Three main parameters describe urban block geometry: (*i*) shape, (*ii*) block typology, and (*iii*) the relation of built and unbuilt space. In this section, these parameters are classified, and their impact on pollutant dispersion is summarized.

Urban block shapes vary significantly from city to city or even from neighborhood to neighborhood. The block shape results from the city layout, which is determined by urban planning guidelines and urban characteristics, such as topography and the historical development of the region. Commonly, urban blocks are square or rectangular, but several regions present complex shapes with various angles and sinuosity. Each shape impacts pollutant dispersion differently. For example, given the same area and built volume, square blocks may promote a higher wind velocity at the pedestrian height than rectangular ones (Gan & Chen, 2016).

Furthermore, the buildings' arrangement contributes to a variety of block typologies, each with different spacing between buildings. The buildings' arrangement may improve ventilation between the buildings or produce regions of airflow stagnation. For instance, configurations such as closed blocks (single block) and row buildings are unfavorable to natural ventilation (Guo et al., 2017a,2017b). Moreover, in the courtyard typology, the inner patio area remains clean, indicating that traffic-related pollutants are not easily transported into these inner areas (Gronemeier and Sühring, 2019; Kurppa et al., 2018). Consequently, the specific block typology can affect the pollutant concentration pattern within the block and in the neighboring streets. Several studies emphasize that block typology is one of the most important factors for pollutant dispersion in the urban environment (An et al., 2019; Yang,

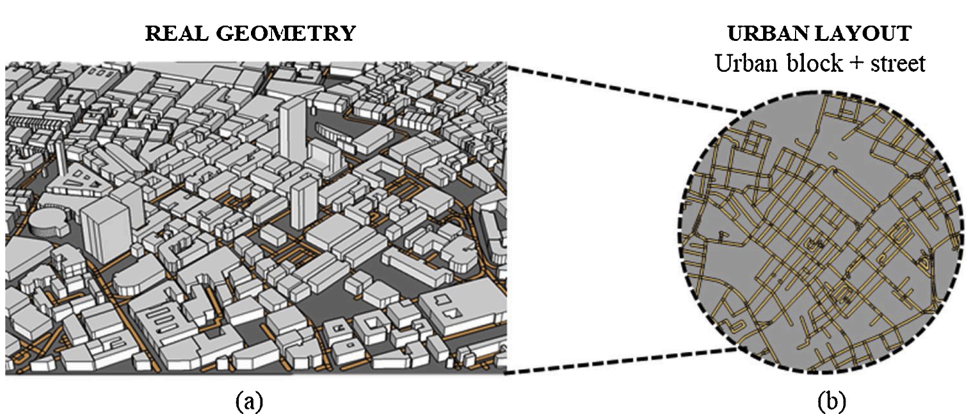


Fig. 1. (2 columns) Schematic illustration of real urban geometry: (a) real geometry and (b) the corresponding urban layout.

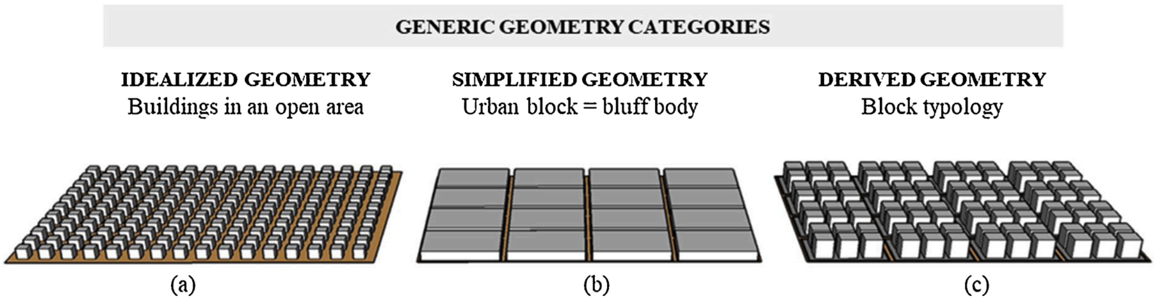


Fig. 2. (2 columns) Schematic illustration of urban geometry categories: (a) idealized geometry, (b) simplified geometry, and (c) derived geometry.

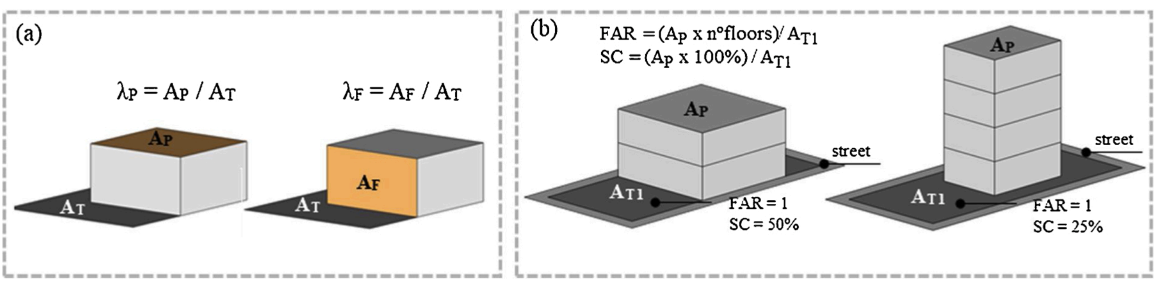


Fig. 3. (2 columns) Schematic illustration of urban metrics: (a) planar area density (λ_p) and frontal area density (λ_f), and (b) urban indices: floor area ratio (FAR) and surface coverage (SC).

Shi, Zheng et al., 2019; Yang, Shi, Shi et al., 2019). Simulations that oversimplify or do not consider block typology can lead to a misunderstanding regarding the impact of the urban geometry.

Block typology is configured by different unbuilt and built relations, represented by parameters such as density, surface coverage, built volume, and canyon aspect ratio. The urban indices (e.g., FAR and SC) are strongly correlated to density and describe the relationship between unbuilt and built spaces. Although FAR and SC can vary significantly within the same city, several studies parameterize these indices using the mean values of a sample region. For example, in different European cities, the FAR index values range from 1.5 to 5.2, while the SC values vary from 50 % to 75 % (EIFER and LSE Cities, 2011). In Japanese cities, the FAR varies from 1.2 to 2.6, and the SC ranges from 17 % to 50 % (Cheshmehzangi and Butters, 2016) in regions with buildings up to three floors. Values of FAR above 4 indicate high-density cities, values between 2 and 4 indicate medium densities, and values less than 2 indicate low densities (Yang, Shi, Zheng et al., 2019; Yang, Shi, Shi et al., 2019).

SC can be described in terms of urban porosity or permeability, an important factor for increasing air quality (An et al., 2019; Yuan et al., 2014a). For example, inserting spaces between buildings yields a greater porosity and results in a higher wind permeability (Yuan et al., 2014a). Arrangements with at least a 20 % permeability maintain a lower pollutant concentration at pedestrian height (An et al., 2019). However, when fixing FAR values (5) and varying the SC (11%–77%) for the same plot area, the local ventilation performance is not linearly related to SC but strongly depends on the buildings' arrangement (Peng et al., 2019). To summarize, FAR is an index that reflects the density of the construction; conversely, the urban configuration may present a variety of changes with the same floor area ratio (Yang, Shi, Zheng et al., 2019; Yang, Shi, Shi et al., 2019). Therefore, to understand the impact of urban morphology on pollutant dispersion, it is important to study the relationship between urban indices and block typology. Consequently, the urban block geometry is crucial for obtaining accurate results. Thus, performing air quality studies in support of urban planning is crucial for improving the block typology used in numerical models.

3. Methods

The research strategy followed two steps: (*i*) identifying the most common typologies and (*ii*) analyzing the metrics. This integrated approach combined a literature review with an empirical analysis of sample areas in selected cities.

The literature review covered studies published in refereed journals on the ScienceDirect platform, written in English, and employing 3D computational domains and/or wind tunnel geometries, using the keywords "pollutant dispersion," "urban," "CFD," and "wind tunnel." Within these parameters, 221 studies published between January 1996 and January 2020 were identified and investigated (see Appendix A for the complete description). Around 80 % of these studies occurred within the last decade (Fig. 4), indicating an increase in research in this field and the topic's novelty.

The empirical analysis was conducted on the densest cities in Europe, America, and Asia. These cities were Tokyo, Hong Kong, and Shanghai in Asia; Barcelona, Paris, and London in Europe; and New York and Sao Paulo in America (Demographia, 2018). The sample area of each city (Fig. 5) was selected based on (*i*) plain topography, (*ii*) a territorial size of approximately a 500 m radius, (*iii*) proximity to the central area, and (*iv*) a regular urban layout. These criteria were defined sequentially to reduce urban variables, remain compatible in size with microscale model studies (Hang and Li, 2010), represent the densest city region, and allow further parameterization. The samples were identified with Google Earth's support, and each city was examined via satellite imagery.

3.1. Identification of the most common typologies

The reviewed papers were categorized according to the following criteria: the type of urban geometry (generic or real), geometric configuration, and urban block typology. Three categories of generic geometries were identified: idealized, simplified, and derived. Additionally, the studies were divided into seven categories based on the geometric configuration: square blocks, rectangular blocks, mixed blocks, intersection, street canyon, street canyons, and other shapes (Table 1).

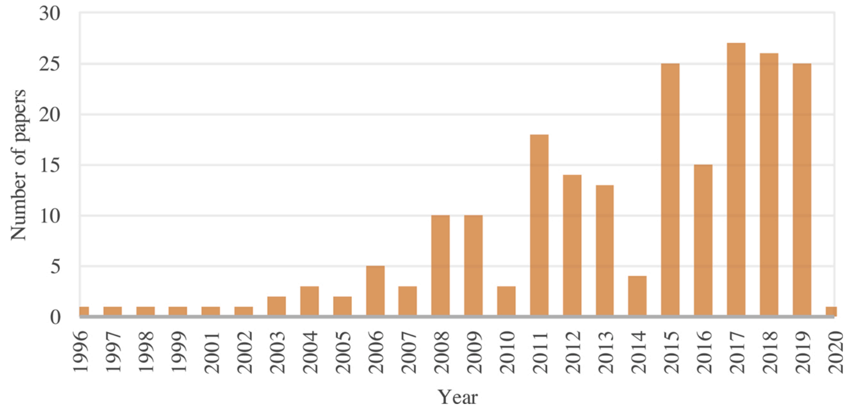


Fig. 4. (1.5 columns) Number of papers examining pollutant dispersion per year.

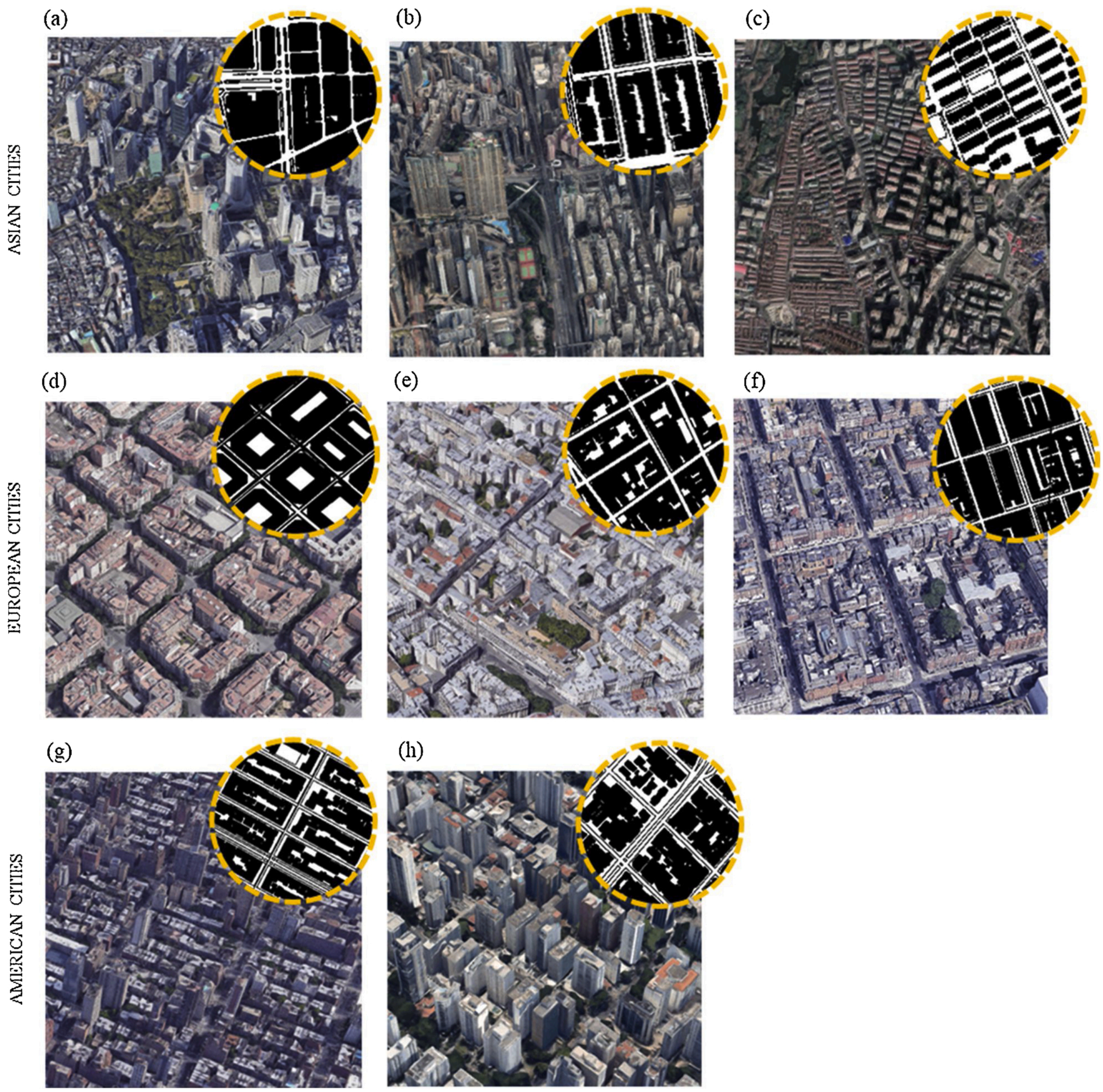
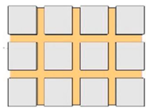
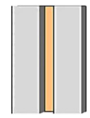
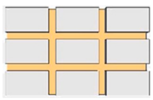
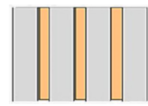
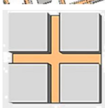


Fig. 5. (2 columns) Satellite view and figure-ground of each selected city's sample: (a) Tokyo, (b) Hong Kong, (c) Shanghai, (d) Barcelona, (e) Paris, (f) London, (g) New York, (f) Sao Paulo. Source: Google Earth, 2019.

Table 1
Classification and description of categories based on the geometric configuration.

GEOMETRIC CONFIGURATION					
Classification	Illustration	Description	Classification	Illustration	Description
Square blocks		Configurations comprised of several regular quadrilateral blocks of equal length and width	**Street canyon**		Street with buildings on both sides, usually of infinite length in generic geometries
Rectangular blocks		Configurations comprised of several regular quadrilateral blocks of equal length on two adjacent sides	**Street canyons**		Configurations comprised of several street canyons
Mixed blocks		Configurations formed by at least two different block shapes, and where a predominant shape is not identified	**Other shape blocks**		Configurations formed by blocks of complex shapes, including triangles, circles, or shapes other than square and rectangular
Intersection		The junction of two road segments			

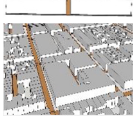
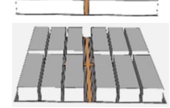
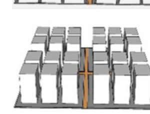
The most commons block typologies were identified using Merlier et al. (2018) categorization, based on different cities (Dresden, Singapore, Barcelona, Copenhagen, Quito, and Marrakesh). Their proposal suggests five types of urban blocks: single building (cube array), row buildings, U-shaped blocks, enclosed blocks (single courtyard), and continuous patio arrays (inner courtyards). Additionally, our study's empirical analysis revealed three new categories to add to these preexisting classifications: detached buildings, mixed, and other. The empirical analysis further identified three block shapes: square, rectangular, and other. Therefore, eight block typologies were defined in total: U-shape, mixed, other, inner courtyards (several courtyards), courtyard (single courtyard), row buildings, detached buildings, and single block, as illustrated in Table 2. These categories were quantitatively analyzed to provide an overview of the customary field practice.

3.2. Metric analysis

The metrics analyzed included plan area density (λ_p), frontal area density (λ_f), canyon aspect ratio (H/W), building height (H), FAR, and SC. Additionally, the empirical analysis identified the dimensions of urban layout parameters: street width and urban block dimensions, including width (W), length (L), and their ratio (L/W).

For the metric analysis, of the 221 total papers, 65 were selected according to the following criteria: (*i*) they used generic geometries, (*ii*) they had a defined/identified block dimension, and (*iii*) they contained the necessary values for analyzing the metrics. These papers represent a total of 110 urban arrangements classified into the following generic geometric categories: 97 idealized, 5 simplified, and 8 derived. To compare the values of usual modeling metrics with the urban indices, an H of 18 m was assumed for the papers that did not use a real height value. This value corresponds to a building with 6 floors, in accordance with the reference height used in similar papers. Moreover, the metric calculations in real cities adopted approximated values for common elements, representing the values most often used. Subsequently, the most common typologies and the most common block shapes were identified. To propose a sequential geometric parameterization based on real cities, the mean metric values and urban indices of European cities were used. The European cities included in this study presented a typological pattern and uniform values for the analyzed parameters. Nonetheless, the same block typologies can represent Asian or American cities by adjusting the values for H, FAR, and SC (see section 4.2).

Table 2
(2 columns) Classification and description of urban block typologies.

BLOCK TYPOLOGY					
Classification	Illustration	Description	Classification	Illustration	Description
U-shape		An urban block with one side open, forming a "U"	**Courtyard**		A non-occupied area in the block forms a central patio
Mixed		Formed by at least two block typologies and where a predominant typology is not identified	**Row buildings**		Attached buildings appearing as a row
Other		Formed by a tower or hybrid typology	**Detached buildings**		Buildings separated by spaces
Inner courtyards		Non-occupied areas in the block form more than one patio	**Single block**		A dense shape forming a bluff body

4. Results

4.1. Analysis of the most common typologies

Fig. 6 provides a flow chart of the literature review. Some papers analyzed more than one urban geometry, making the total number of urban geometries larger than the number of papers. A large number of studies rely on generic geometry (idealized, simplified, or derived). However, the relevant number of studies using real geometry is not surprising, especially given the increase in available computational power in years.

Fig. 7 presents an overview of the most prominent geometric practices, showing that about 50 % of the studies with generic geometries applied the idealized building array. Meanwhile, 36 % of the papers relied on real geometries, which are commonly used to understand the specifics of a given region. Only a few studies employed simplified and derived geometries. As discussed previously, the use of block typology (derived geometries) in CFD studies is relatively recent in comparison with idealized or real geometries.

Furthermore, Fig. 8 exhibits the quantitative distribution of geometric configuration categories and block typologies found in the literature review. Several studies focused on street canyons (single and multiple). However, while studies applying idealized geometry tended to focus on street canyons and square-shaped blocks, studies of real cities primarily centered on rectangular-shaped blocks, mixed blocks, or other configurations. By definition, idealized and simplified geometries are based on a single block typology. On the other hand, in studies using derived geometries, the most common typologies are courtyards (single and multiple) and row buildings. Moreover, real geometries frequently involve a mixed typology.

Table 3 presents the predominant block shapes and typologies in the empirical analysis. The rectangular block shape predominates in most cities. However, in Barcelona, despite the occurrence of some rectangular block shapes, the squared configuration is more common. Furthermore, in Asian cities, the complex block shape, with various angles and sinuosity, occurs frequently. In terms of block typology, European cities present clearer typological patterns involving courtyards and inner courtyards. Nevertheless, a compact block typology (i.e., a single block), with nonexistent spaces between buildings, occurs in denser areas, such as London. In Asian and American cities, attached buildings forming row buildings or a single block (a bluff-body shape) are predominant. Despite their prevalence, the detached building typology, with short spaces between buildings, is also observed in Asian and American cities.

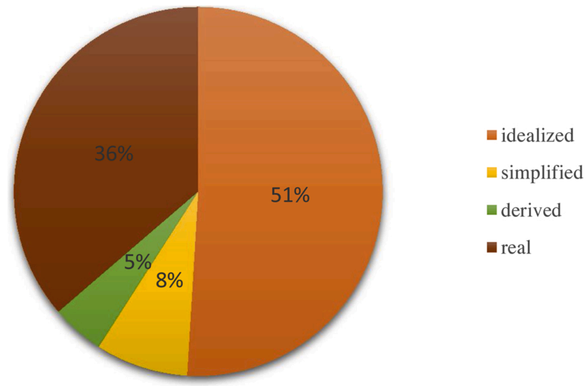


Fig. 7. (1.5 columns) Distribution (%) of the geometry categories found in the literature review.

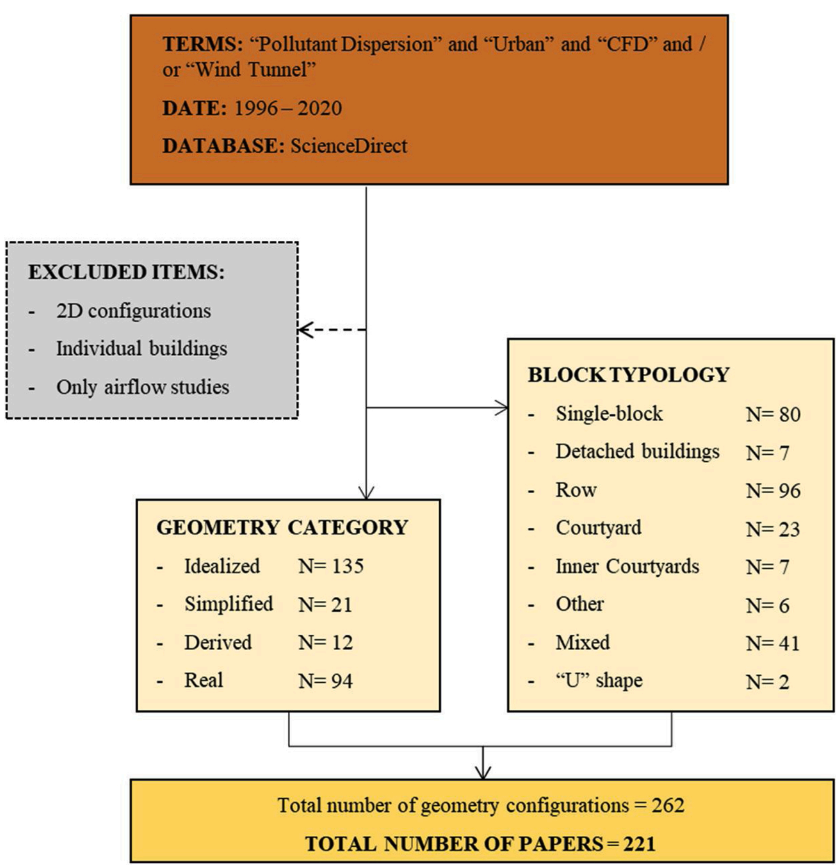
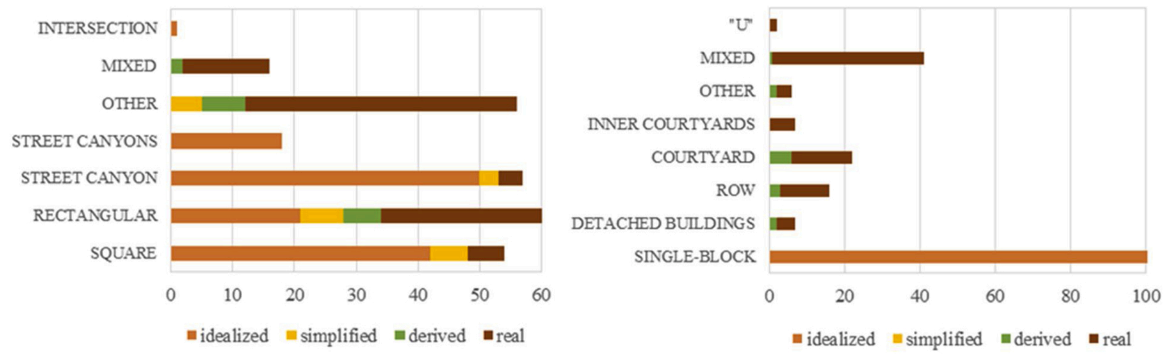


Fig. 6. (1.5 columns) – Flow chart of the literature review.



(a) (b)

Fig. 8. (2 columns) Distribution of articles found in the literature review concerning (a) geometry configurations and (b) urban block typologies.

Table 3
(2 columns) Block typologies of selected cities.

Region		Block shape			Block typology					
Continent	City	Square	Rectangular	Other	Detached buildings	Row	"U"	Courtyard	Inner courtyards	Single block
ASIA	Tokyo		×		×					×
	Hong Kong		×		×	×				×
	Shanghai		×	×	×	×				
EUROPE	Barcelona	×						×		
	Paris		×					×	×	
	London		×					×	×	×
AMERICA	New York		×		×	×				×
	Sao Paulo		×		×					×

4.2. Metric analysis of the selected geometries

Table 4 summarizes the metrics used in the 65 selected papers (the full table is available in Appendix B). Overall, the parameters calculated for idealized geometries reveal a large standard deviation, indicating a significant variation between the studies. Likewise, studies employing derived geometry exhibit a large standard deviation since these studies focus on regions with diverse densities. In contrast, studies applying idealized and simplified geometries always value the SC at 100 % because these geometries do not consider the buildings' arrangement, treating the block as a bluff-body.

Table 5 summarizes the metrics from studies that examined real cities. In general, European cities have uniform values of urban indices. Conversely, in Asian and American cities, the building heights vary on the same block, showing deviations up to 39 m. The presence of high-rise buildings accentuates this deviation and can increase the FAR up to 16, configuring a high-density region. Despite these differences, an SC value of approximately 80 % was identified in all selected cities. Urban layout characteristics are also more uniform in European cities than in Asian and American cities. For instance, the block shape proportion (L/W) ranges from 1 to 3.3 in the selected cities. Likewise, the street width differs from 12 m (local streets) to 21 m (main avenues).

The differences between the parameters found in the literature and in real cities are evident. The values of H, λ_p, and FAR in generic geometries are significantly smaller than in real cities, especially in Asia and America. The SC values are an exception. In idealized and simplified geometries, these index values are larger than in real ones because, as previously discussed, these types of geometries do not consider the buildings' arrangements. However, derived geometries present SC values similar to real cities.

4.3. Discussion and urban block parameterization proposal

Comparatively, the four types of geometries (idealized, simplified, derived, and real) show evident differences in typologies and metrics values. In urban-array typologies, the generic categories focus especially in the single block cube. This typology is also found in real cities; however, the predominant urban block shape is the rectangle. Moreover,

Table 4
(2 columns) Summary urban arrangements metrics statistics in selected papers.

Geometry Category	Number of papers	Statistics		Modeling metrics			Urban indices		Urban layout
			Height	λ_p	λ_f	H/W	FAR	SC	Street width
IDEALIZED	53	Mean	22	0.31	0.25	1.16	2.5	100	25
		Median	20	0.25	0.25	1	2.5	100	20
		St. deviation	11.8	0.18	0.18	0.83	3.3	0	16.5
SIMPLIFIED	5	Mean	18.6	0.8	0.21	1.55	6.2	100	12
		Median	16.2	0.58	0.19	1.35	4.24	100	12
		St. deviation	1.2	0.11	0.01	0.1	0.98	0	0
DERIVED	7	Mean	30	0.47	0.32	1.6	3.4	67	30
		Median	17.35	0.37	0.18	0.96	2.2	57	17.35
		St. deviation	21.1	0.1	0.2	1.0	1.9	14.0	21.1

Table 5
(2 columns) Metrics of urban arrangements in selected sample cities.

Region		Height			Modeling metrics			Urban indices		Urban layout			
											Urban block		
		Mean	Median	St. D	λ_p	λ_f	H/W	FAR	SC	Street	L × W	Area	L/W
ASIA	Tokyo	55	60	29.5	0.6	0.56	6	16	80	10	130 × 70	9100	1.9
	Hong Kong	55	60	33.2	0.6	1.13	5	16	80	12	130 × 43	5590	3.3
	Shanghai	60	60	39	0.6	0.58	3.8	16	80	16	272 × 142	38,624	1.9
EUROPE	Barcelona	18.9	18	2	0.6	0.16	1.5	5	80	12	116 × 116	13,456	1
	Paris	18.6	18	2.75	0.6	0.18	1.5	5	80	12	150 × 92	13,800	1.6
	London	17.4	18	3.4	0.6	0.18	1.5	5	80	12	131 × 85	11,135	2.4
AMERICA	New York	46	48	28.3	0.6	0.54	3	13	80	16	220 × 73	16,060	3
	Sao Paulo	48.7	48	24.8	0.5	0.4	3.7	11	65	13	170 × 100	17,000	1.7

the absence of setbacks among buildings in real cities forms a contiguous geometry, the row. These row buildings are the most studied typology in idealized street canyon configurations. Furthermore, in European cities, courtyards (central and inner) are the most common block typology. Finally, detached buildings (cube shaped) are more prevalent in American and Asian cities and are more common in low-density residential areas. Nonetheless, this typology proportion resembles the idealized array, which is highly common in literature studies.

The differences between the geometric categories are even more evident in the metrics values. Concerning the urban layout characteristics, the median street width in idealized geometries was 20 m, in contrast with 12 m in real urban areas. The urban block area varied from 2.600 m^2 in idealized geometries to 13.395 m^2 in real cities. Also, the urban block proportion (L/W) changed from 0.9 in idealized geometries to 1.5 in real cities. As discussed in the previous section, the urban layout in idealized geometries compresses the block area while enhancing the streets' widths, providing a larger ratio between built and unbuilt areas than in real environments. Consequently, this arrangement produces a less dense configuration compared to real urban areas.

Finally, the difference in built density between the generic and real categories is considerable. For example, the mean FAR value was 2.4 in idealized geometries and 7 in simplified geometries, while real cities

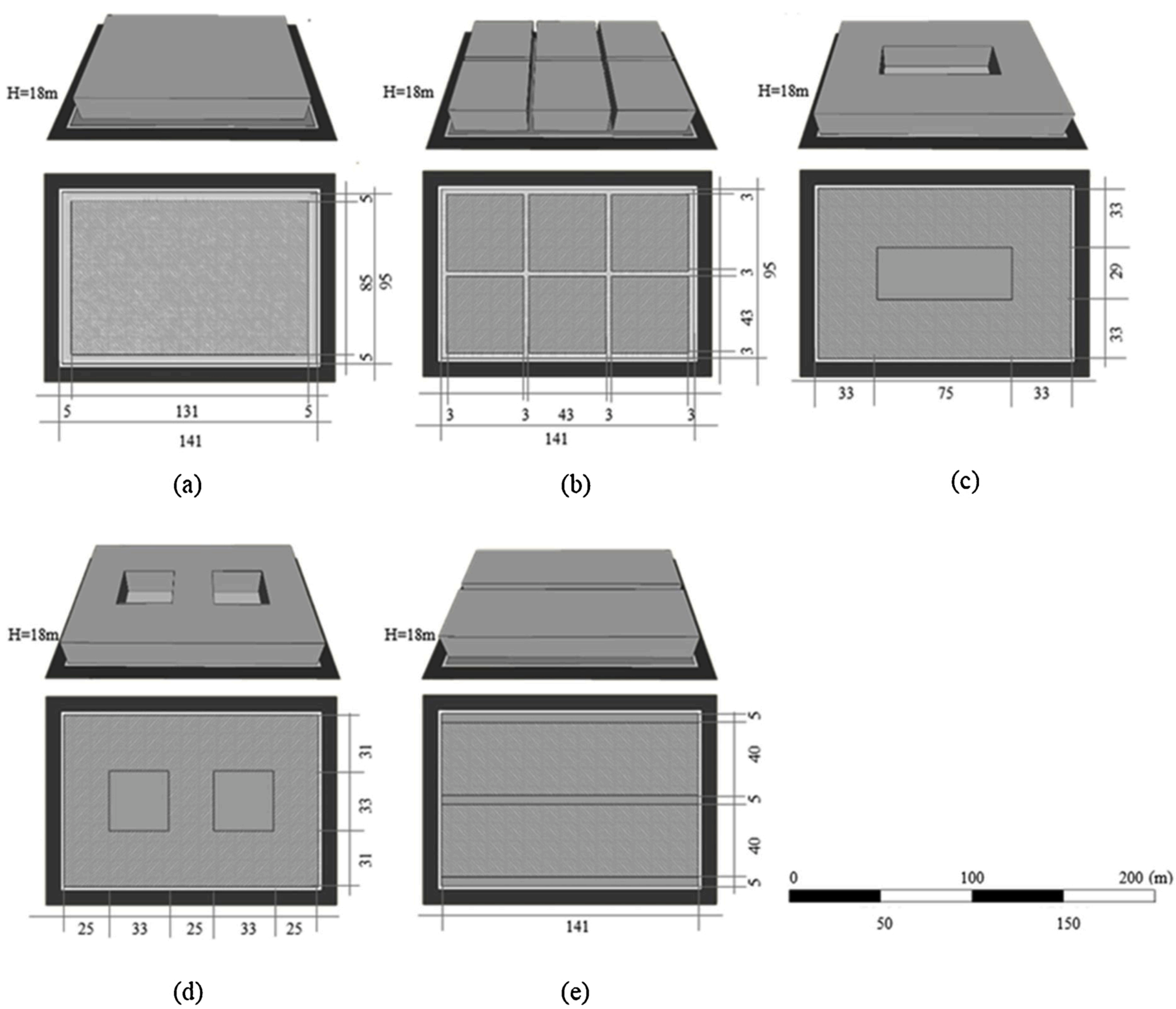


Fig. 9. (2 columns) Block typologies derivative proposal: (a) single block; (b) detached buildings; (c) courtyard; (d) inner courtyards; (e) row.

exhibited a mean value of 5. This study concludes that idealized geometries tend to underestimate these parameters, while simplified geometries tend to overestimate them. Additionally, it is important to emphasize that the built density can be misinterpreted if only the modeling metrics are applied. For instance, λ_f correlates the built area with the building height, while FAR expresses the built volume. Moreover, λ_p considers the streets in the total area instead of focusing on the relation of urban blocks as the SC does. Including urban indices is key for enhancing the built-density description. This inclusion can increase the applicability of a study's results for urban planning.

We thus propose five conventional urban block typologies to represent real geometries: single block, detached buildings (cube-shaped), courtyard, inner courtyards, and row buildings. Fig. 9 presents a schematic representation of the urban block typologies, using dimensions based on European cities. Although this representation is based on average values for European cities, it can be extrapolated to other regions and densities by adjusting the values of H, FAR, and SC.

The suggested urban layout contains urban blocks of 95m × 141m and has a street width of 12 m. The urban index values for the block parameterization proposal based on the selected cities include a FAR value of 5, an SC equivalent to 80 %, and a building height of 18 m. It is noteworthy that urban indices are employed in urban blocks to limit the built area. Therefore, the dimensions of the buildings inside the block were calculated to produce a FAR value of 5, an SC equivalent to 80 %, and a building height equal to 18 m. This process is similar to the building restrictions that architects and engineers incorporate into building designs. Consequently, to maintain the urban block dimensions, some adjustments in the urban index values are required, as shown in Table 6. Given that the numbers chosen express an average, these adjustments are appropriate.

Although the proposed typologies serve as a generic representation of a real urban structure, real cities are highly heterogeneous, especially in regions where growth is organic rather than planned. Nevertheless, when the goal is planning new areas or improve existing regions, a common strategy is to define the urban indices for zones. This strategy leads to diverse block typologies. In this context, the use of the proposed typologies creates a wide range of applicability in urban air quality studies, which can contribute to the urban planning guidelines in several regions. Moreover, by adjusting the urban index values, the typologies proposed above can represent denser regions. It is also possible to propose several configurations using more than one block typology to study more complex environments.

Table 6
(2 columns) Definition of values for the urban block metrics.

BLOCK TYPOLOGY	λ_p	λ_f	FAR	SC (%)	H (m)
SINGLE BLOCK	0.63	0.18	5	83	18
DETACHED BUILDINGS	0.63	0.17	5	83	18
CENTRAL COURTYARD	0.64	0.19	5	84	18
INNERS COURTYARD	0.64	0.19	5	84	18
LONGITUDINAL ROW	0.64	0.19	5	84	18

5. Conclusions

To achieve a healthier urban environment, the results of air quality modeling studies should be more applicable to urban planning. To achieve this aim, it is necessary to properly represent urban geometry. In modeling studies, urban geometry can be generic (idealized, simplified, or derived) or real. More than 60 % of the reviewed literature studies relied on generic geometries. This type of geometry reduces the complexity of CFD simulations and allows for a broader application of the results. However, more than 50 % of the studies used an idealized array, which does not consider the block typology and frequently leads to unrealistic urban geometries.

Idealized geometries tend to underestimate city density, while simplified arrays tend to overestimate it. In contrast, the derived arrays, which consider the predominant block typology of a real region, are more accurate in representing the city. In this sense, the concept of block typology should be more frequently used in numerical simulations of urban pollutant dispersion. In short, the derived block typology provides the simplicity of a generic configuration combined with the complexity of actual regional characteristics.

Comparatively, the geometric categories (idealized, simplified, derived, and real) exhibit differences in typologies and metric values. Moreover, the built density can be misinterpreted if only the modeling metrics (λ_p and λ_f) are applied without the use of urban indices (FAR and SC). For example, λ_p considers the streets in the total area, while the SC focuses on the relation of urban blocks. Additionally, λ_f correlates the built area with the building height, while FAR expresses the built volume. Therefore, we propose using FAR in association with SC to obtain a more precise representation of the built density.

Regarding the urban layout, almost 50 % of the reviewed studies used the square shape, while in real cities, the rectangular shape predominates. Furthermore, the street width in real cities is narrower than in generic geometries. As a result, we propose an urban layout with rectangular urban blocks of 13.000 m^2 (95 × 141 m) and streets of 12 m. Five block typologies were selected for the block typology parameterization: single block, detached buildings, courtyard, inner courtyards, and row-buildings. Finally, the urban-index values were set at a FAR value of 5, an SC of 80 %, and an H of 18 m, which represents cities of medium to high density. The proposed block parametrization offers the advantages of a generic geometry with the representativeness of real urban environments to pollutant dispersion modeling studies. Consequently, the results of these studies will be able to more accurately assist the urban planning guidelines of several regions worldwide.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Overview of the pollutant dispersion studies

#	Authors (year)	UG	BS	Block typology	#	Authors (year)	UG	BS	Block typology
1	(Sini et al., 1996)	I	SC	single block	27	(Yassin et al., 2008)	I	R	courtyard
2	(MacDonald et al., 1997)	I	S	single block	28	(Kang et al., 2008)	I	SC	single block
3	(Leitl and Meroney, 1997)	I	SC'S	single block	29	(Gromke et al., 2008)	I	SC	single block
4	(Scaperdas and Colvile, 1999)	S	R	single block	30	(Solazzo et al., 2008)	I	SC	single block

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#	Authors (year)	UG	BS	Block typology	#	Authors (year)	UG	BS	Block typology
5	(Craig et al., 2001)	I	S	single block	31	(Murena et al., 2008)	R	R	inners courtyards
6	(Mavroidis and Griffiths, 2001)	I	S	single block	32	(Hanjalić and Kenjereš, 2008)	R	O	mixed
7	(Chan et al., 2002)	I	SC	single block	33	(Cai et al., 2008)	I	SC	single block
8	(Borrego et al., 2003)	R	R	row	34	(Yang and Shao, 2008)	I	S	single block
9	(Chang and Meroney, 2003)	I	R	single block	35	(Yassin, 2011)	I	SC	single block
10	(Kim and Baik, 2004)	I	S	single block	36	(Huang et al., 2009)	I	SC'S	single block
11	(Baker et al., 2004)	I	SC	single block	37	(Hang et al., 2009)	I	R; S; O	row; single block; other
12	(Pospisil et al., 2004)	R	O	courtyard; mixed	38	(Kato and Huang, 2009)	R	R; O	row; single block
13	(Yassin et al., 2005)	R	R; O	detached buildings; row; mixed	39	(Murena et al., 2009)	R	R; O	inners courtyards
14	(Xie et al., 2005)	I	SC'S	single block	40	(Li et al., 2009)	I	SC	single block
15	(Chu et al., 2005)	S	R	single block	41	(Kondo and Tomizuka, 2009)	R	R; O	row; single block; mixed
16	(Xiaomin et al., 2006)	I	SC	single block	42	(Xie and Castro, 2009)	R	R	single block
17	(Mumovic et al., 2006)	R	R	mixed	43	(McNabola et al., 2009)	I	SC	single block
18	(Dixon et al., 2006)	R	O	mixed	44	(Buccolieri et al., 2009)	I	SC	single block
19	(Borrego et al., 2006)	R	O	mixed	45	(XIE et al., 2009)	I	SC	single block
20	(Neofytou et al., 2006)	R	O	mixed	46	(Fernando et al., 2010)	I	R	row
21	(Milliez and Carissimo, 2007)	I	R	row	47	(Parra et al., 2010)	S	S	single block
22	(Di Sabatino et al., 2007)	I	S	Single block	48	(Belalcazar et al., 2010)	R	O	mixed
23	(Baik et al., 2007)	I	SC	single block	49	(Tchepel et al., 2010)	R	O	mixed
24	(Wang and McNamara, 2007)	I	I	row	50	(Garbero et al., 2010)	I	S	single block
25	(Huang et al., 2008)	R	O	Single block	51	(Boppana et al., 2010)	I	S	single block
26	(Santiago and Martín, 2008)	R	R	inners courtyards	52	(Gousseau et al., 2011)	R	R	single block
53	(Branford et al., 2011)	I	S	single block	80	(Tominaga and Stathopoulos, 2012)	I	R	single block
54	(Salim et al., 2011)	I	SC	single block	81	(Moonen et al., 2012)	I	S	courtyard
55	(Soulhac et al., 2011)	R	R	inners courtyards	82	(Franke et al., 2012)	I	S; R	single block
56	(Zhang et al., 2011)	I	SC	single block	83	(Leuzzi et al., 2012)	I	R	row
57	(Solazzo et al., 2011)	R;S	SC	single block					
58	(Gu et al., 2011)	I	SC	single block	84	(Hang, Li, Buccolieri et al., 2012)	I	SC'S	single block
59	(Schatzmann and Leitl, 2011)	R	M	mixed; courtyard	85	(Soulhac et al., 2013)	I	S	single block
60	(Salim et al., 2011)	I	SC	row	86	(Hajra et al., 2013)	I	R	single block
61	(Liu et al., 2011)	R	M	mixed	87	(Hang et al., 2013)	I	S	single block
62	(Tominaga and Stathopoulos, 2011)	I	SC	single block	88	(Moonen et al., 2013)	I	SC	single block
63	(Luo and Li, 2011)	I	S	single block	89	(Michioka et al., 2013)	R	O	detached buildings
64	(Cheng and Liu, 2011)	I	SC'S	single block	90	(Bright et al., 2013)	I	SC	single block
65	(Buccolieri et al., 2011)	I	SC	single block	91	(Sanchez et al., 2013)	R	R	mixed
		R	S	courtyard	92	(Amorim et al., 2013)	R	O	mixed
66	(Bady et al., 2011)	D	R	detached buildings	93	(Santiago et al., 2013)	S	S	single block
67	(Hang and Li, 2011)	I	S	single block (tower)			S	R; O	single block
68	(Hang et al., 2011)	I	S	single block	94	(Gallagher et al., 2013)	R	O	mixed
69	(Gromke, 2011)	I	SC	single block	95	(Vos et al., 2013)	I	S + R	courtyard
70	(Nikolova et al., 2011)	R	O	courtyard			I	R	detached buildings
71	(Carpentieri et al., 2012)	R	R	Single block	96	(Garcia et al., 2013)	R	O	mixed
72	(Hang, Li, Sandberg et al., 2012)	I	S	single block	97	(Wang et al., 2013)	R	O	row
73	(Kikumoto and Ooka, 2012a)	I	SC'S	single block	98	(Yuan et al., 2014b)	D	R	row; typology variations
74	(Kwak and Baik, 2012)	I	SC	single block	99	(Lin et al., 2014)	I	S	single block
75	(Hertwig et al., 2012)	D	O	courtyard	100	(Tiwary and Kumar, 2014)	D	O	courtyard
76	(Kikumoto and Ooka, 2012b)	I	SC'S	single block	101	(Ng and Chau, 2014)	I	SC'S	row
77	(Kim et al., 2012)	I; S	SC	single block	102	(Shen et al., 2015)	I	S	single block
78	(Liu et al., 2012)	R	O	mixed	103	(Kumar et al., 2015)	I	R	single block
79	(Baik et al., 2012)	I	SC	single block	104	(Carpentieri and Robins, 2015a)	R	R	single block
105	(Kwak et al., 2015)	R	R	mixed	131	(Gromke et al., 2016)	I	SC	single block
106	(Park et al., 2015)	I	S	single block	132	(Muilwijk et al., 2016)	I	SC	single block
107	(Toparlar et al., 2015)	R	O	courtyard			R	O	courtyard
108	(Efthimiou et al., 2015)	D	O	courtyard	133	(Jeanjean et al., 2016)	R	O	mixed
109	(Tsegas et al., 2015)	R	M; O	inners courtyards	134	(Soulhac et al., 2016)	I	S	single block
110	(Stabile et al., 2015)	I	SC	single block			I	S	single block
111	(Jeanjean et al., 2015)	validation - I	SC	single block	135	(Blocken et al., 2016)	R	O	mixed
		R	O	courtyard	136	(Yang et al., 2016)	I	SC	row
112	(Hang et al., 2015)	I	S	single block	137	(Paas and Schneider, 2016)	R	O	mixed
113	(Tan et al., 2015a)	I	SC	single block	138	(Pesic et al., 2016)	I	SC	single block
114	(Vernay et al., 2015)	R	R	other	139	(HUANG et al., 2016)	I	SC	single block
115	(Lo and Ngan, 2015)	I	SC'S	row	140	(Jin et al., 2016)	S	SC	single block
116	(Tan et al., 2015b)	I	SC'S	single block	141	(Thaker and Gokhale, 2016)	S	O	single block
117	(Yang et al., 2015)	I	SC	single block	142	(Fallah-Shorshani et al., 2017a)	R	R	mixed
118	(Gromke and Blocken, 2015a)	I	S	single block	143	(Mons et al., 2017)	R	R	courtyard; single block

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#	Authors (year)	UG	BS	Block typology	#	Authors (year)	UG	BS	Block typology
119	(Vranckx et al., 2015)	I	SC	single block	144	(Shen et al., 2017)	R/ S	SC: R; S	single block; detached buildings
120	(Habilomatis and Chaloulakou, 2015)	I	SC	single block	145	(Ai and Mak, 2017)	I	SC'S	single block
121	(Gromke and Blocken, 2015b)	I	S	single block	146	(King, Khan et al., 2017)	I	S	single block
122	(Zhong et al., 2015)	I	SC	single block	147	(King, Gough et al., 2017)	I	S	single block
123	(Scungio et al., 2015)	I	SC	single block	148	(Chen et al., 2017)	I	S	single block
124	(Buccolieri et al., 2015)	I	S	single block	149	(Juan et al., 2017)	R	S; R	"U"
125	(Ghermandi et al., 2015)	R	O	detached buildings	150	(Fallah-Shorshani et al., 2017b)	R	R	mixed
126	(Ramponi et al., 2015)	I	R	single block	151	(Ben Salem et al., 2017)	I	S	single block
127	(Carpentieri and Robins, 2015b)	I	R	single block	152	(Du et al., 2017)	R	O	mixed
128	(Murena and Mele, 2016)	I	SC	single block	153	(Fu et al., 2017)	R	SC	single block
129	(Yu and Thé, 2016)	I	R	Single block	154	(Kang et al., 2017)	R	R	row; single block
130	(Gallagher, 2016)	R	O	mixed					
155	(Moradpour et al., 2017)	I	S	single block	182	(Liu, Pan et al., 2018)	I	S	single block
156	(Santiago et al., 2017)	S	R; O	single block	183	(Gao et al., 2018)	R	O	row; detached buildings
157	(Xue and Li, 2017)	I	SC	single block	184	(Wise et al., 2018)	R	O	mixed
158	(Hang et al., 2017)	I	SC'S	single block	185	(Hang et al., 2018)	I	S	single block (tower)
159	(He et al., 2017)	I	SC'S	single block			I	R	single block
160	(Fan et al., 2017)	I	SC'S	row	186	(Scungio et al., 2018)	I	SC	single block
161	(Nosek et al., 2017)	I	SC	single block	187	(Llaguno-Munitxa and Bou-Zeid, 2018)	I	SC'S	single block
162	(Hong et al., 2017)	R	O	row; "U"	188	(Buccolieri et al., 2018)	R	R	inners courtyards; single block
163	(Chen et al., 2017)	I	S	single block	189	(Dhunny et al., 2018)	R	O	mixed
164	(Fuka et al., 2018)	I	R	single block	190	(Du and Ming Mak, 2018)	R	O	mixed
165	(García-Sánchez et al., 2017)	R	M	mixed	191	(Carpentieri et al., 2018)	I	R	single block
166	(Toja-Silva et al., 2017)	R	O; R	courtyard; row	192	(Dai et al., 2018)	I	R	Single block
167	(García-Sánchez et al., 2017)	R	O	courtyard; single block	193	(Wang et al., 2018)	I	R	row
168	(Liu et al., 2017)	I	S	single block	194	(Toja-Silva et al., 2018)	I; R	S; R	Single block; courtyard; row
		R	R	row; mixed; detached buildings	195	(An et al., 2019)	I; R	S; R	Single block
169	(Li and Xue, 2018)	R	R; O	single block	196	(Mei et al., 2019)	I	SC'S	row
170	(He et al., 2018)	D	R	row	197	(Tan et al., 2019)	I	SC	single block
171	(Liu, Heidarinejad et al., 2018)	R	R	row	198	(Su et al., 2019)	I	SC	single block
172	(Efthimiou et al., 2018)	D	O	courtyard	199	(Lin et al., 2019)	I	S	single block
173	(Nakajima et al., 2018)	I	S	single block	200	(Xiao et al., 2019)	R	M	single block
174	(Hang et al., 2018)	I	S	single block	201	(Dai et al., 2019)	I	R	single block
175	(Weerasuriya et al., 2018)	R	R	mixed	202	(Lee and Mak, 2019)	R	O	mixed
176	(Tolias et al., 2018)	D	O	courtyard	203	(Gallagher and Lago, 2019)	I	SC	single block
177	(Mohammad et al., 2018)	I	S	single block	204	(Yuan et al., 2019)	D	R	row
178	(Rafael et al., 2018)	R	O	courtyard; mixed	205	(Rivas et al., 2019)	S	O	single block
179	(Li and Xue, 2018)	R	O; M	mixed	206	(Santiago et al., 2019)	R	O	courtyard; single block; mixed
180	(Sha et al., 2018)	I	S	single block					
181	(Shi et al., 2018)	R	R; O	mixed	207	(Zhang et al., 2019)	I	SC	single block
208	(Yang, Shi, Zheng et al., 2019; Yang, Shi, Shi et al., 2019)	I	S	single block	215	(Mo and Liu, 2019)	I	S	single block
209	(Marucci and Carpentieri, 2019)	I	SC	single block	216	(Bahlali et al., 2019)	I	R	row
210	(Thouron et al., 2019)	S	O	single block	217	(Li et al., 2019)	I	SC	single block
211	(Yang, Shi, Shi, Marvin and Xia, 2019)	I	S	single block	218	(Bahlali et al., 2019)	I	R	single block
		R	O	mixed	219	(Lenz et al., 2019)	R	S;R	courtyard
212	(Merlier et al., 2019)	S	O	single block	220	(Fellini et al., 2019)	R	S; M	courtyard; inners courtyard
213	(Huang et al., 2019)	I	SC	single block	221	(Yang, Chen et al., 2020)	R	O	mixed
214	(Longo et al., 2019)	I	R	single block					

Legend: UG – urban geometry; I –Idealized; S – Simplified; D – Derived; R – Real; BS – Block Shape; S – Square; R – Rectangular; SC – Street Canyon; SC'S – Street Canyons; O – Other; M – Mixed.

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