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Global Street Experiment: A Geospatial Database of Pandemic-induced Street Transitions

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HIGHLIGHTS

- This study adds geospatial information to pandemic-induced street experiments.
- A comprehensive workflow was deviced to collect and verify intervention locations.
- The geospatial indicators were designed and computed to allow intercity comparisons.
- North American cities have more diverse intervention types compared to other cities.
- Temporal development of pandemic-induced street experiments show interconnectedness.

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ABSTRACT

Street experiment is a tactical urbanism practice that involves implementing temporary changes in street use through regulatory or physical interventions, aimed at people-centric street transition. During the Covid-19 pandemic, cities worldwide implemented street experiments to accommodate the need for socially-distanced physical and commercial activities. However, we know little about the locations and urban environments of these pandemic-induced street experiments on a global scale. This knowledge gap hinders us from understanding where these experiments took place, the conditions of the neighbourhoods involved, and the factors contributing to their longevity beyond the pandemic. We thus developed a geospatial database to document the pandemic-induced street experiments (PISE Database), enabling quantitative analysis of these interventions. We mapped the locations and calculated the neighbourhood environment attributes of 539 street experiments in 333 cities. Our contributions are twofold. Firstly, we enhanced the comparability of built environment indicators between cities, thereby advancing the construction of global geospatial datasets. Specifically, we established a standardised template encompassing unified neighbourhood-level built environment indicators and methodologies, for which we devised relative values to facilitate comparisons between different cities and defined study areas using the 15-minute walking city and Urban Centre concepts. Secondly, we conducted primary analyses based on spatial and temporal visualisations of the street experiment locations and durations, shedding light on locational patterns and development trajectories during times of crisis. This global, quantitative approach complements the growing body of local and often qualitative studies. Our work improves existing global quantitative databases and provides a robust foundation for future research on tactical urbanism.

1. Introduction

The street experiment represents a tactical urbanism methodology that employs regulatory or physical interventions to effectuate temporary modifications in street usage, with the primary objective of facilitating people-centric street transition (Bertolini, 2020; Lydon & Garcia, 2015; Stevens et al., 2021; Webb, 2018). Before the Covid-19 pandemic (later called the pandemic), street experiments were applied as a localised problem-solving technique to improve street vitality and community engagement. The global pandemic that hit cities worldwide in 2020 pushed street experiments to a wider adoption. Due to its rapid spread, cities worldwide imposed lockdowns at varied durations and intensities, especially after WHO announced a global pandemic on 11 March 2020 (WHO, 2020). In the same year, Italy locked down the

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country on 23rd February (Centers for Disease Control and Prevention, 2023), the Philippines declared a state of calamity on 16th March (Atienza, 2021), France announced a nationwide lockdown on 17th March (Mazoue, 2021), and US states imposed stay-at-home orders on various dates between 19th Mar to 7th Apr (timeanddate, 2020). The lockdown and restrictions on vehicular traffic allowed cities to reimagine streets as urban spaces. Cities implemented street experiments as emergency responses to address transportation solutions (e.g., pop-up bike lanes) and accommodate work-from-home lifestyles (e.g., shared streets, car-free streets). Street transformations that would typically require years to accomplish were achieved within days and weeks. The rapid development led researchers to speculate on a 'critical juncture' for the transition towards people-centric street designs resulting from the street experiments prompted by the Covid-19 pandemic (Glaser & Krizek, 2021; Gregg et al., 2022; Mehta, 2022).

Studies have been conducted to document the shifts in street mobility induced by the pandemic. The most prominent dataset is the Shifting Streets COVID-19 Mobility Dataset, an ongoing effort to catalogue mobility changes (the Shifting Streets Dataset). Using a crowdsourced method, it documented over 1300 took place worldwide from March to August in 2020. In order to standardise the crowdsourced data, Combs and colleagues (2021) developed a standardised survey to acquire descriptions of the intervention background, including factors such as action types, function, intensity, and space. The COVID Mobility Works is a parallel initiative to document international mobility responses (COVID Mobility Works, 2020). It was initiated by alliances of non-profit organisations and encompasses 572 interventions. Its records were not actively maintained and lacked important details such as duration. Furthermore, the Streets for Pandemic Response & Recovery project provides a summary of street transformation prototypes implemented during the pandemic, along with a compilation of case studies gathered from various locations worldwide (NACTO & GDCI, 2020).

However, the current databases lack information regarding the locations and urban environments of the pandemic-induced street experiments. This oversight neglects the crucial aspect of the physical changes that occurred as a result of these street experiments. To address this, it becomes essential to ascertain which streets underwent transformation through emergency responses and for what duration. The initial step towards answering these inquiries would involve documenting the location information of the street experiments. Moreover, Neighbourhood-level built environment is proven to be associated with physical activities and street use (Ewing & Cervero, 2010; Naseri et al., 2023), as these street changes were placed at strategic locations in neighbourhoods as emergency responses (Gregg et al., 2022). Without locations and neighbourhood environments, existing databases cannot support quantitative analysis and global comparisons, thus missing a crucial angle to analyse emerging street experiment practices.

Therefore, we developed a Global Pandemic-Induced Street Experiment Geospatial Database (PISE Database) that maps the pandemic-induced street experiments and calculates their built environment attributes at the neighbourhood level. We mapped the locations and computed the neighbourhood environment attributes of 539 street experiments in 333 cities worldwide. This work makes a dual contribution. Firstly, the construction of this geospatial database enhances the existing global built environment datasets. Specifically, we established a standardised template with unified neighbourhood-level built environment indicators and methodologies, for which we designed relative values to enable comparisons between different cities and defined study areas using the concepts of a 15-minute walking city and Urban Centres. Secondly, we conducted primary analyses using spatial and temporal visualisations of the street experiment locations and durations. The mapping process revealed a widespread shift towards people-centric street transitions during and after the pandemic. Our global and quantitative approach uniquely complements the growing body of local and often qualitative studies. Our work aims to enhance existing global quantitative databases and provide a comprehensive and robust foundation for future research on tactical urbanism.

2. Pandemic-induced street experiments

2.1. Locations and neighbourhood environments

Urban planners advocate for people-centric streets that fulfil two objectives: facilitating mobility and providing public spaces (von Schönfeld & Bertolini, 2017). The Covid-19 pandemic expedited the realisation of this vision. Street experiments that emerged during the pandemic exhibit a strong connection to pre-pandemic prototypes and functionalities. Implemented strategically, these interventions took place in specific locations, aiming to transform the streetscape and create more pedestrian-friendly environments.

In terms of mobility, temporary bike infrastructure, commonly known as pop-up bike lanes, was implemented to provide safe and socially distanced transportation options and exercise routes (Sunio & Mateo-babiano, 2022). These interventions served as substitutes for public transit, ensuring the continuity of essential city functions. These changes tended to be implemented on major roads, often drawing from existing plans conceived before the pandemic for expanding the bicycle network (Büchel et al., 2022). Many of these measures drew inspiration from Ciclovia, an originally Bogotá-based initiative involving temporary street closures for bicycle activities (Becker et al., 2022; Montero, 2020). Regarding public space, streets were closed to support outdoor activities during lockdown periods, commonly referred to as shared streets, slow streets, or similar terms (NACTO & GDCI, 2020). These transformations built upon the traffic calming concept that existed before the pandemic (Landgrave-Serrano & Stoker, 2022). Implemented as extensions of home spaces, these interventions were predominantly located in densely populated areas and occasionally in affluent neighbourhoods (Mehta, 2020). Furthermore, streets were utilised to facilitate outdoor dining and commerce. Although outdoor dining had existed prior to the pandemic, there was a rapid expansion of such initiatives during this time. In addition to occupying sidewalks, many establishments built on curb spaces by repurposing on-street parking spots (Gregg & Mandhan, 2022). This concept was inspired by the Parklet prototype, which originated in San Francisco and gained global popularity over the past decade (Littke, 2016). Outdoor dining areas served as essential social spaces and lifelines for businesses during the pandemic. However, these people-centric initiatives' encroachment on road space has resulted in direct competition with car-centric usage. As life gradually returns to normal, it becomes essential to understand how this transition can be preserved or how conflicts between different road users can be effectively managed.

Built environment and streetscape changes play a vital role in the transition towards a more sustainable urban mobility system (VanHoose et al., 2022). The locations chosen for street experiments have a significant influence on prototype selections and equitable outcomes. National Association of City Transportation Officials (NACTO) and Global Designing Cities Initiative (GDCI) (2020) propose various strategies for utilising different types of streets: neighbourhood streets can be transformed into shared or slow streets to accommodate local traffic and activities, while main/high streets can be repurposed for outdoor commerce and dining spaces, cycle lanes, and wider sidewalks. Major urban streets can serve similar functions as neighbourhood main streets but with the added consideration of public transit. Furthermore, edge streets and boulevards can be designated as car-free zones to prioritise pedestrians and cyclists during the pandemic, while also creating expanded space for active mobility in the post-pandemic era. Studies have identified more street experiment provisions in deprived areas (Aldred et al., 2021; Firth et al., 2021). Having spatial distribution data is crucial for addressing important research questions, such as equity in street transformation, the trajectories of intervention development, and impact evaluations.

Existing efforts to document emergency responses during the pandemic have primarily focused on categorising street changes, but we know little about where and at which neighbourhood conditions the global street experiments took place. The Shifting Streets Dataset, developed from a transport engineering perspective, classified 32 different types of actions that were implemented, describing changes in road space configuration and other regulatory strategies (Combs & Pardo, 2021). Another study, which analysed North American news reports, categorised the interventions into five types based on their purposes: outdoor dining, park and public space, shared streets, bike accommodation, and street closures (Gregg et al., 2022). Additionally, a report on pandemic response guidelines summarised street experiments into four categories based on the types of streets involved: neighbourhood streets, main/high streets, major urban streets, and edge streets and boulevards (NACTO & GDCI, 2020). These classifications can assist in collecting geospatial data around the experiment sites.

However, existing studies on large-scale street experiments have not adequately addressed the influence of built environment factors. Considering global-scale neighbourhood-level built environment measures is crucial for research on public health and sustainable cities (Boeing et al., 2022). Previous research has indicated a positive association between an accessible built environment and various outcomes, including increased physical activity, enhanced street use, and improved well-being (Adams et al., 2013; Ellis et al., 2016; Sallis et al., 2009). While the Shifting Streets Dataset (Combs & Pardo, 2021) represents a commendable effort in documenting street changes during the pandemic, it does not provide specific street locations. As a result, the description of street configuration changes becomes disconnected from their urban context. Establishing such connections on a large scale poses challenges; however, doing so can contribute to quantitative analyses and comparisons of interventions. This study aims to initiate discussions in the field of street experiments by calculating built environment indicators and highlighting the importance of considering these factors in future research.

2.2. Approaches to constructing a global geospatial database

A global street-level geospatial database can only facilitate quantitative analysis if it includes precise locations of street experiments and corresponding urban environment indicators. Constructing a cross-regional built environment database necessitates the use of standardised measures (Forsyth et al., 2006).

Firstly, a consistent unit of analysis is required. While using addresses and buffers to define study areas can provide reasonable estimates of accessible areas (Sallis et al., 2009, 2016), obtaining individuals' addresses may not always be feasible. Some studies have used small geographical areas as analysis units (Anguelovski et al., 2022; Triguero-Mas et al., 2022), but these units vary across cities. Alternatively, researchers employed sample points along street networks and network buffers, which offer a more streamlined unit of analysis that is independent of administrative boundaries or addresses (Liu et al., 2022). Walking access is often used as a reference for determining buffer thresholds, given the strong association between the built environment and walking behaviours (Giles-corti et al., 2022; Sallis et al., 2009). Moreover, planning concepts such as the 1 km/1 mile catchment areas (Vale et al., 2016) and 15-minute city (Guzman et al., 2021; Hosford et al., 2022; Marino et al., 2022) should be integrated when designing the study unit. These examples of consistent units of analysis determined two key parameters: location and boundary.

Secondly, built environment indicators can be derived from the framework of density, diversity, and design (Cervero & Kockelman, 1997; Lu et al., 2017; Zhao et al., 2020). Density can be computed in various forms, including population density (Boeing et al., 2022), residential density (Adams et al., 2014), and building density (Higgs et al., 2019). Diversity encompasses land use and amenity diversity, with indicators such as land use mix (Ferrari et al., 2020), and access to diverse amenities (Giles-corti et al., 2022). Design describes street network connectivity and includes metrics such as link-to-node ratio, intersection density (Ellis et al., 2016), and street network centrality, which measures the accessibility and importance of a street segment within its network (Lu et al., 2022; Sun, Webster, & Chiaradia, 2018). To enhance intercity comparability, researchers standardise indicator values using Z-scores (Boeing et al., 2022).

Thirdly, the availability of global open data and open-source GIS computing services has enabled large-scale computation of the built environment. Data sources like OpenStreetMap (OSM) (Barrington-Leigh & Millard-Ball, 2017) ensure consistent standards and wide-ranging availability of street networks, building footprints, and amenities. The Global Human Settlements (GHS) Urban Centres Database (UCDB) provides a unified way to define city boundaries, surpassing the inconsistencies of administrative boundaries delineated across regions (Dijkstra et al., 2019; Melchiorri, 2022). Online GIS computing services such as OSMnx (Boeing, 2017) and OpenRouteService (Neis & Zipf, 2008) enable global computations that mitigate issues related to projections and distortions.

Constructing a global street-level database requires unified definitions in the study area, built environment indicators, and data sources. By leveraging planning concepts and open data, we can establish a database that ensures comparability between cities.

3. Method

3.1. Constructing the global street experiment geospatial database

The Global Pandemic-Induced Street Experiment Geospatial Database encompasses four dimensions: 1) geospatial data, 2) built environment indicators, 3) intervention attributes, and 4) city characteristics. Table 1 provides an overview of the key datasets and variables. To construct the database, we conducted filtering, geospatial mapping, built environment computation, and refinement of intervention attributes. The workflow for this process is illustrated in Fig. 1.

3.1.1. Filtering qualified interventions

We defined the Covid-19 pandemic-induced street experiments as temporary changes in street use as a means of emergency response, intending to promote active mobility and the street as a public space. To identify eligible interventions, we initially used the *Source* and *Description* variables from the Shifting Streets Dataset. This dataset catalogued over 1400 records of repurposed street uses as emergency responses, primarily implemented between March and October 2020. The data sources included news articles, government press releases, interactive maps, open data, and social media posts. However, not all interventions documented in the Shifting Streets Dataset aligned with our research focus, such as bike share promotions or traffic light changes. Consequently, we applied the following criteria to filter the interventions:

- *Temporal logic*: we sought news and notifications released after the pandemic outbreak (March 11, 2020);
- *Pandemic connection*: the data source should explicitly mention the intervention's relation to the pandemic, employing terms such as 'pandemic,' 'epidemic,' 'coronavirus,' 'Covid-19,' 'outbreak,' 'lockdown,' or their synonyms;
- *Active mobility and public space*: the intervention should be associated with supporting active mobility, physical exercise, and the creation of social spaces. This can be indicated by phrases mentioning 'biking,' 'cycling,' 'bike lane,' 'walking,' 'pedestrian,' 'jogging,' 'outdoor dining,' 'parklet,' or 'shared street.'

We also established exclusion criteria and provided examples. Entries that were irrelevant to active mobility or public space were excluded. Examples include the development of mobile phone apps, modified public transit service routes or frequencies, and conversions of curb space into pick-up/loading zones. Interventions unrelated to street

Table 1
Data dictionary for major variables

Dimension	Datasets (name, description)	Variables	Meaning
Geospatial data	**Final_lines**	SLineID	Unique identifier for each street segment
	All street-based experiment locations, based on street segments	UID	Intervention unique ID, linkable to Shifting Streets Dataset
		Length	Geodesic length of a street segment
		fclass	Road types, OSM classification
		maxspeed	Maximum speed, OSM documentation
	Final_points	SPointID	Unique ID for point features
	All point-based experiment locations	UID	Intervention unique ID, linkable to Shifting Streets Dataset
	Study Areas	IsoID	Isochrone ID
	5-minute and 15-minute walking distance isochrones based on street segments or points	Area	Geodesic area of covered study area
Street experiment attributes	**se_attributes**	UID	Intervention ID
	attributes based on study areas	Action	Specific nature of action, Shifting Streets Dataset
		Date_start	Date started (yyyy-mm-dd)
		Current_status	Current status of the intervention, as of 1 January 2023
		Date_end	Ending date (yyyy-mm-dd)
		Days_operated	Number of days with implementation
		Types	Street experiment typology
Built environment indicators	**be_indicators**	Int_Dens	Intersection Density
	Indicators based on study areas	Ln_ratio	Link Node ratio
		Betweenness	Betweenness centrality
		Closeness	Closeness centrality
		D_edu	Density of education institutions (i.e., preschool, primary and secondary schools, college and university)
		D_gov	Density of government offices (i.e., capitol, city hall, government agencies)
		D_org	Density of organisation offices (i.e., non-profit organisations)
		D_biz	Density of business centres and offices
		D_food	Density of food and drink venues
		D_retail	Density of retail stores
		D_trans	Density of public transport stations (i.e., metro stations, bus stations)
		D_health	Density of health and medicine facilities
		D_park	Density of parks and plazas
		Mix	Entropy score of amenities mixture index
		D_pop	residential population density
City characteristics	**city_info**	UID	Intervention unique ID
	city related information	City	City in which the action occurred, Shifting Streets Dataset
		Urban_centre	Urban centre in which the action occurred, GHS Urban Centre Database
		Country_region	State or region in which the action occurred, Shifting Streets Dataset
		Country	Country in which the action occurred
		World_region	Geography where the action took place as per ISO3166
		City_admin_level	City administrative level
		City_rank	Levels of world city network integration, GaWC
		Urban_pop	Urban Centre resident population, GHS Urban Centre Database

space reallocation, such as changes in traffic light timing, free parking permits, and bike-sharing promotion programs, were also excluded. Additionally, interventions that discouraged street usage, such as the banning of outdoor activities, closure of park access, and restrictions on pedestrian circulation, were skipped. Inclusion and exclusion criteria and related keywords are presented in Table 2.

To ensure the geospatial data accuracy, we focused on achieving precision at the intersection level. We verified intervention locations using various sources and supplementary searches. Location information was presented in two formats: textual descriptions and maps. Textual descriptions came from news articles, government press releases, and social media posts. A clear description typically included street names and their endpoints. For example, a clear description looks like “A separate cycle path on the road on Hallesches Ufer from Hallesches Tor to Köthener Straße”. In cases where street descriptions were ambiguous, we reached a consensus through cross-verification involving at least two team members. Locations that lacked precise street names were excluded due to the lack of precision. Maps were obtained in different formats, each with varying levels of accuracy. Open geospatial datasets were the most accurate, followed by interactive maps, digital maps, and graphical representations. Open datasets and interactive maps were directly incorporated into the PISE Database, while digital maps served as references. Graphical representations, which were abstracted maps, were interpreted to identify actual streets before being used. For interventions lacking precise locational information, we conducted additional searches. In instances where webpages had been removed, we used the Wayback Machine to retrieve the earliest cached version. For non-English sources, we translated texts using Google Translate and Deepl and supplemented them with searches in local languages to maximise results. Interventions that lacked source information or precise locations were excluded.

Following this procedure, we finalised our dataset, consisting of 539

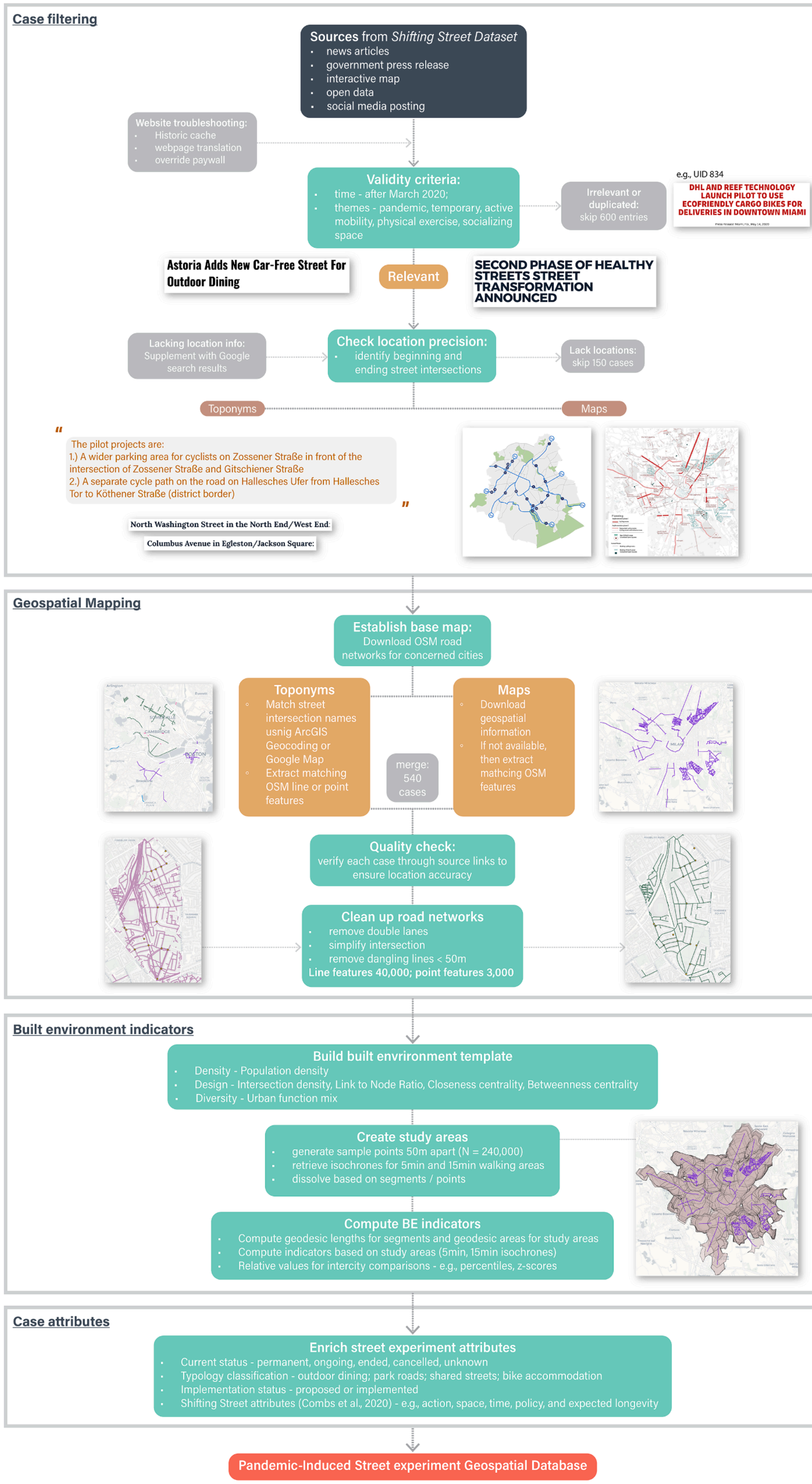

Fig. 1. Flowchart of PISE Database construction

Table 2
Filtering criteria

Themes	Keywords
Inclusion criteria	
Pandemic	Pandemic; epidemic; coronavirus; covid; covid-19; outbreak; lockdown; re-opening; corona-, etc.
Temporary	Temporary; temporary measure; pop-up; tactical; experiment; trial; pilot, etc.
Active mobility	Biking; cycling; bike lane; cycling lane; Ciclovia; biker; cyclist; cycleway, etc.
Physical exercise	Walking; pedestrians; jogging; physical activity; outdoor activity; car free; car ban etc.
Socialising space	Outdoor dining; alfresco dining; streateries; parklets; outdoor market; slow street; shared street; healthy street; open street; play street; school street, etc.
Exclusion criteria	
Unrelated to active mobility or public space	Mobile phone App development; modified public transit service frequency or routes; reduced fare for public transit; automatic door for public transit; 'rear door entry policy' for public transit; converting curb space to pick-up and loading zone; fast-tracking construction works; etc.
Unrelated to street space reallocation	Remove/automate traffic light beg button; issuance of free-parking permits; social distancing precautions: adding plastic foil, adding signs, mask-wearing policy (e.g., UIDs 135, 63); shared bike/car provision/promotion; financial support for bike purchase (e.g., UID 718); bike stores open as essential businesses (e.g., UID 68); shuttle bus service to help residents get groceries; delivery service provision (e.g., UID 424); drive-through businesses; creating bike parking spaces (e.g., UID 1336, 659), etc.
Discouragement of active mobility and public space usage	Banning outdoor activities (e.g., UID 203); park access closed (e.g., UID 1491, 180); restrict pedestrian circulation (UID 375)

interventions across 37 countries and 333 cities spanning six world regions.

3.1.2. *Mapping street experiment locations*

We traced or downloaded street experiment sites based on the available types of location information (Fig. 1). For textual description and non-geospatial maps, we extracted matching segments from the OSM road networks, an open-source platform for academic and commercial uses (Barrington-Leigh & Millard-Ball, 2017). When downloadable geospatial maps existed, we appended them to the PISE Database. During the mapping process, we excluded features that did not meet our research criteria (Table 2). For instance, maps depicting alterations to public transit routes or existing bike networks were excluded. Point features were included to represent parklets or outdoor dining locations. We conducted case-by-case cross-verification to ensure consistency between the source information and our maps. We maintained precision at the intersection level and leveraged Google Maps and GIS geocoding services to enhance feature accuracy.

To ensure accurate street length computation, we performed clean-up procedures on the street segments, which involved removing dangling geometries, short branches (less than 50 m, equivalent to half of a small street block length), and duplicated traffic lanes (Fig. 1). The cleaning process involved ArcGIS geoprocessing tools and manual refinement due to the complexity of street morphology. For example, although some street segments in neighbourhoods were shorter than 50 m, they were retained to ensure network completeness. On the other hand, redundant street segments at highway intersections were eliminated. To account for projection distortions, we computed street lengths using geodesic length. The mapped interventions can be linked to the Shifting Streets Dataset through a unique intervention identifier (UID).

3.1.3. *Computing built environment indicators using open data and open-source APIs*

To construct a set of global neighbourhood-level built environment indicators, we undertook the following steps: 1) established a template with unified indicators and consistent methods, 2) designed relative values to enable intercity comparisons; 3) defined study areas using concepts of walking areas (5-minute, 15-minute) and Urban Centres; 4) retrieved street network and isochrones from an open data platform and open-source APIs.

First, we created an indicators template (Table 3) that can be applied universally to enable comparisons within and between cities. The template consisted of seven indicators that are commonly used and widely available across different regions. These indicators covered three categories, residential population density, street network structure, and urban amenities density and diversity:

- Population density is associated with walking and cycling for transportation (Brownson et al., 2009; Naseri et al., 2023). It also influences the locations of shared streets, which were used as physical activity spaces for stay-at-home residents (NACTO & GDCI, 2020).
- Street network structure indicators have been validated to impact street vitality, accessibility, and usage. Street connectivity is measured using the intersection density and link-to-node ratio (Ellis et al., 2016). Better street connectivity encourages walking behaviour and, therefore, could be conducive to shared street usage. Network centralities, such as closeness centrality and betweenness centrality, measure the importance and permeability of a given street segment within the overall street network (Sun, Webster, & Chiaradia, 2018). Closeness centrality measures the reciprocal of the average shortest path distance from an edge, while betweenness centrality measures the sum of the fraction of all pairs of shortest paths that pass through an edge. These centrality measures serve as

proxies for assessing the locational importance of the selected streets. For instance, a street with higher betweenness is likely to have more pedestrian traffic (Rhoads et al., 2021).

- Urban amenities generate trips. Retail stores and food and drink venues contribute to urban vitality (Li et al., 2022), while institutions and healthcare facilities generate need-based trips (Mouratidis & Yiannakou, 2021). Additionally, parks and public transport stations have been found to increase bike ridership (Naseri et al., 2023). We computed the number and entropy of the amenities related to daily usage (Zhao et al., 2020).

We devised relative values for all indicators to enable comparisons between cities. For network centrality, we obtained the percentile ranking of the street experiment sites with respect to the street network they reside in. For population density, intersection density, link-to-node ratio, amenities density, and function mix, we defined the relative values as percentage differences between the street-based built environment indicators and the city average.

Secondly, we defined study areas for the built environment indicators, which were computed based on street segments. These study areas were defined at three levels:

- The first level is a *5-minute walking area* (~417 m with a speed of 5 km/h) that describes the closest proximity achievable when travelling on foot (Krizek, 2003; Zhao et al., 2020). This range was particularly relevant during the pandemic when people were discouraged from travelling longer distances.
- The second level is a *15-minute walking area* (~1251 m), which represents the coverage of a neighbourhood under normal conditions, equivalent to a radius between 1 km and 1 mile. These benchmarks have been used to measure walking accessibility, particularly the 15-minute city planning concept (Guzman et al., 2021; Hosford et al., 2022; Marino et al., 2022; Vale et al., 2016).

  The two levels of walking areas were computed as the isochrones (HeiGIT, 2022) around the street segments or points. To create these isochrones, we generated sample points at 50 m intervals for all mapped street segments. We obtained 250,000 sample points, and an additional 3,000 points were included for outdoor dining and parklet areas. These point-based isochrones were then dissolved based on the corresponding street segments to form walking areas. To account for projection distortion, the walking areas were computed using geodesic areas (unit: sq. km). These walking areas served as the spatial units for calculating population density, intersection density, link-to-node ratio, and urban amenities density and diversity.
- For the third level, *Urban Centre* was used to define boundaries of urban clusters and compute city-level averages. Urban Centre is characterised as the high-density clusters of contiguous grid cells, each covering an area of 1 sq. km, with a minimum density of 1,500 inhabitants per sq. km and a minimum population of 50,000 (Dijkstra & Poelman, 2014; Florczyk et al., 2019). Urban Centres were used over city administrative boundaries to address the mismatch between administrative boundaries and actual urban boundaries. By using the Urban Centre layer, we consolidated adjacent towns into their major metropolis. For example, the street networks of Cambridge and Boston are well integrated, and considering them as a single entity would produce more accurate network centrality computations.

  Urban Centres served as the study areas for network centrality analysis and computing relative values. While most walking areas fell within the boundaries of Urban Centres, there were some instances where they intersected or fell outside. For walking areas that intersected with Urban Centres, we modified the Urban Centre boundaries to include the portions of the walking area that fell outside. These boundary adjustments were minor and did not impact the computation result. For those walking areas that were completely outside of Urban Centres, we used administrative boundaries of the respective cities instead. This approach was adopted for small towns with less complex street networks, where the administrative boundaries provided a more easily defined study area.

We leveraged open data and open-source GIS application programming interfaces (APIs) to compute indicators at the global level. The population was obtained from the Global Human Settlement (GHS) Population Grid (Schiavina et al., 2022), with the 100 m grid population count summarised and divided by the study areas to derive population density. Global street networks (road, bike, pedestrian) were retrieved from OSM, while urban amenities were collected through Foursquare, a provider of worldwide point of interests (POIs) data. Walking time isochrones were obtained from OpenRouteService, an open-source API for global GIS computing. Urban Centres were sourced from the GHS Urban Centre Database (Florczyk et al., 2019; Florczyk et al., 2018), and city boundaries were acquired using OSMnx, an API for retrieving OSM city information (Boeing, 2017).

3.1.4. Refining intervention attributes

We enriched intervention attributes by conducting internet searches. While Shifting Streets Dataset provided variables to describe intervention backgrounds such as action types, function, intensity, and space, there were instances where certain variables had missing values and required additional research through internet searches.

To evaluate the street experiments, we initially determined the intervention statuses as of January 2023, which was three years after their initial deployment. The intervention status served as an outcome to measure the street experiments. We derived it by analysing the intervention end dates, which allowed us to determine whether the intervention had ended or was still ongoing. This outcome enables a longer-term analysis of these experiments. We regarded a program as ended if the street configuration had reverted to normal state without any policy change or long-term plans in place. The main sources of information for determining the status included the Shifting Streets Dataset, news articles, and press releases. In cases where this information was unavailable, we inspected Google Street View images to compare the street configuration before 2020 with the most recent conditions. If a street was absent from street experiment configurations in its latest image, we considered it to have ended.

In addition to determining the status, we also introduced an urban function-based intervention classification for the interventions. This classification aimed to depict the different functions and locations, with adjustments made based on the typology proposed by Gregg et al. (2022). For example, *parklets* were reclassified from *park and public space* to reflect their typical location on neighbourhood streets rather than park roads. Parklets serving outdoor dining functions were included in *outdoor dining and commerce* category, while those serving non-commercial functions were placed in *shared street* category. Furthermore, the category previously labelled as *parks and public spaces* was changed to *park and greenspace* to better describe changes in park spaces. We classified interventions using the following types:

- *Outdoor dining and commerce* - the main function was to promote outdoor business activities and accommodate normal commercial functioning during the pandemic. These interventions provided gathering spaces, boosted street vitality, and supported economic recovery. However, since they involved commercial activities, the host streets were susceptible to privatisation.
- *Park and greenspace* - the main function was to improve the experience and accessibility of parks and greenspaces, particularly by helping residents' entry into parks and trails. These interventions involved closing park roads to vehicular access, creating more space for physical activities. One key aspect of this category was the provision of greenspace, which is essential for public health and well-being. However, it is important to note that these interventions could create barriers for residents who were located further away.

Table 3
Built environment template

Built environment indicators (Adams et al., 2014; Boeing et al., 2022; Naseri et al., 2023; Sun, Webster, Ni, et al., 2018)	Formulae	Intercity comparability
Population Density (Adams et al., 2014; Boeing et al., 2022; Ellis et al., 2016; Schiavina et al., 2022)		
Population density D_p	$D_p = \frac{N_p}{A}$ where D_p is population density, N_p is the number of people estimated by GHS population grid, and A is the study area, 5-minute and 15-minute isochrones of street experiment sites.	– Absolute values – Percent difference from its Urban Centre average
Street network structure These measures have been validated to represent the accessibility and vitality of the streets (Ellis et al., 2016; Sun, Webster & Chiaradia, 2018)		
Intersection density I	$I = \frac{N}{A}$ where I is intersection density, N is the number of intersections within the buffered area, and A is the study area, 5-minute and 15-minute isochrones of street experiment sites.	– Absolute values – Percent difference compared to the Urban Centre average
Link-to-node ratio R An index of connectivity is equal to the number of links divided by the number of nodes within a study area. Links are defined as roadway or pathway segments between two nodes. Nodes are intersections or the end of a cul-de-sac.	$R = \frac{N_l}{N_n}$ where R is the link-node ratio, N_l is the number of links within the study area, N_n is the number of nodes within the study area.	
Network centrality c_B and $C(e)$ **Betweenness centrality c_B** of an edge, e is the sum of the fraction of all-pairs shortest paths that pass through e (Brandes, 2008; Sarlas et al., 2020).	$c_B = \sum_{s,t \in V} \frac{\sigma(s,t\|e)}{\sigma(s,t)}$ where V is the set of nodes, $\sigma(s,t)$ is the number of shortest (s,t)-paths, and $\sigma(s,t\|e)$ is the number of those paths passing through edge e.	– Absolute values – Percentile ranking in the urban centre street network
Closeness centrality C of a node u is the reciprocal of the average shortest path distance to u over all $n-1$ reachable nodes. **Closeness centrality C of an edge e** is the average of the centrality of its adjacent nodes (Newman, 2010).	$C(u) = \frac{n-1}{\sum_{v=1}^{n-1} d(v,u)}$ where $d(v,u)$ is the shortest distance between v and u, and $n-1$ is the number of nodes reachable from u. Notice that the closeness distance function computes the incoming distance to u for directed graphs. $C(e) = \frac{C(u_s) + C(u_t)}{2}$ where u_s is the source (start) node and u_t is the target (end) node.	
Urban amenities density and diversity Amenity density and functional mix are related to walking, cycling, physical activities and street use intensity (Long and Zhao, 2020; Lu et al., 2021; Sun, Webster, Ni, et al., 2018).		
Amenities density d_a Amenities included educational institutions, government, organisations, and business offices, food & drink venues, healthcare facilities, parks & plazas, retail stores, and public transport stations (Zhao et al., 2020).	$d_a = \frac{N_a}{A}$ where d_a is the amenity density, N_a is the number of amenities within the study area, A is the study area.	– Absolute value comparison – Percent difference compared to the urban centre average
Function mix M The entropy formula was derived from the Shannon Index (Mavoa et al., 2018; Sun, Webster, Ni, et al., 2018; Zhao et al., 2020).	$M = -1\left(\sum_{i=1}^{m} p_i \times \ln p_i\right)/\ln(m)$ $p_i = \frac{n_i}{N}$ where M is the function mix, m is the number of amenity categories, i is one amenity category, n is the number of amenities in each category, N is the total number of amenities within the study area.	– Absolute value comparison

This category was differentiated from the outdoor dining category based on its non-commercial usage. An expansion of park and greenspace indicates an expanded public space provision (Carmona, 2022).

- *Shared street* - the main function was to create a network of non-motorised streets that enable safe physical distancing for walking, biking, and outdoor social spaces. Shared streets were typically implemented on neighbourhood streets by either fully or partially closing streets to vehicular traffic. Outdoor social spaces were designated places for socially distanced encounters. These included meeting zones, which were located at foot traffic hotspots, and parklets, which were parking-lot-sized patios with seating.
- *Bike accommodation* - the main function was to promote cycling by developing road infrastructure. This type of intervention provided temporary bike lanes on traffic lanes (e.g., pop-up bike lanes). These changes were expansions of active mobility plans and promoted to reduce car reliance.

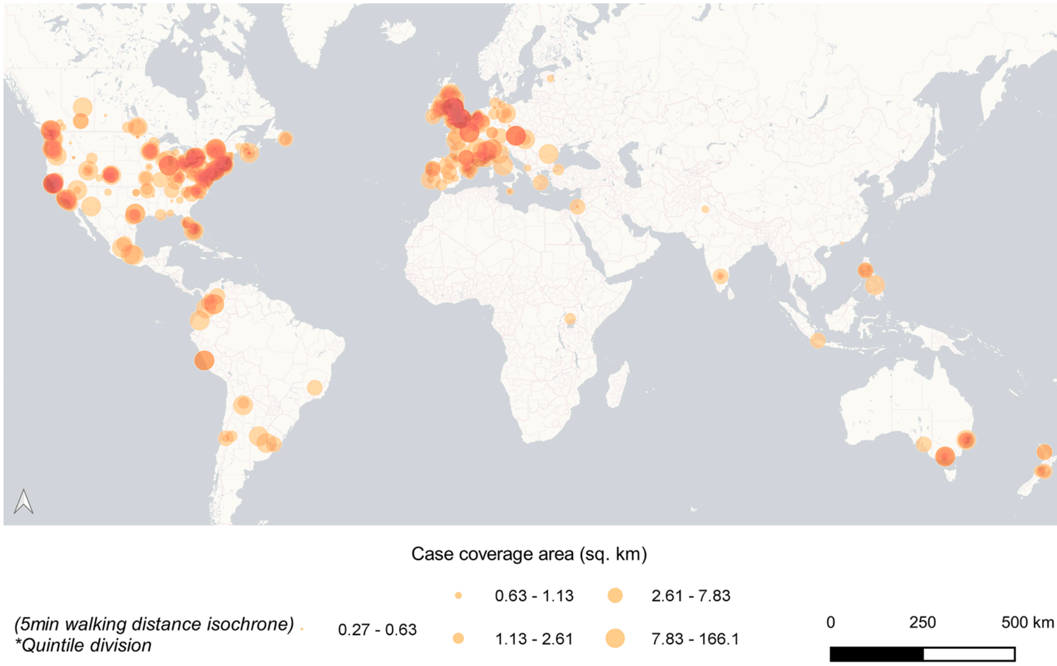

Fig. 2. Global Distribution of the Covid-19 Pandemic-Inducted Street Experiments

- *Street closure* – this type entails interventions that serve more than one main function. Street interventions that included shared streets and bike accommodations were categorised as street closures. They reflected more detailed road space reallocations, with bikers and pedestrians allocated into their designated lanes.

Furthermore, we incorporated city-level information to provide details about the host cities' characteristics. This addition aimed to assist researchers in studying the level of commonality, complementarity, and connectivity within the world city network (Derudder & Taylor, 2020). During the pandemic, city officials were highly interconnected facilitating knowledge sharing and policy transfer. For instance, the pop-up bike lane initiative originated in Bogotá and was soon adopted by Berlin, Paris, and Milan (NACTO & GDCI, 2020). City sizes and global connectedness may contribute to the city's adoption of street experiments. The GaWC city ranking, which measures a city's integration into the global city network (Beaverstock et al., 1999), was included to describe the extent of this integration. Additionally, information on the Urban Centre population and city administrative levels was included to describe the city's size and importance.

3.2. Data exploration: Spatial and temporal visualisations of the street experiments

We provided descriptive statistics and created maps to visualise the scope of the mapped street experiments. Initially, we summarised the number of interventions in each type, the length of each intervention, the number of sites per intervention, and their corresponding summary statistics. We then calculated and visualised the total coverage of the interventions (sq. km) using a 5-minute walking area. Furthermore, we presented the spatial distribution of street experiments in representative cities, selected based on their isochrone coverages and locations. We specifically chose street experiments with the largest coverage, measured in the main geographical regions. We presented six representative cities from North America and Europe & Central Asia, due to abundant candidate cities in these regions, and three each from Latin America and East Asia & Pacific. Moreover, we visualised streets with high closeness centrality percentiles in four cities to illustrate areas that are comparable in terms of built environment measurements. This highlights comparable regions in different cities. Regarding the temporal aspect, we summarised the interventions' chronological sequence using stacked area charts. Specifically, we displayed interventions that began between 16 March and 31 October 2020, which represented the

Table 4
Intervention descriptive statistics

	Line-based						Point-based		
	Number of interventions	Minimum length (m)	Average length (m)	Median length (m)	Maximum length (m)	Standard deviation	Number of interventions	Total number of points	Average number of points
All types	525	32.59	11005.63	2165.73	359251.92	31158.19	25	2709	108
Types									
Outdoor dining and commerce	132	32.59	2039.22	458.18	66891.01	7039.39	15	2313	154
Park and greenspace	30	46.95	8438.13	4072.95	60874.15	11674.88	NA		
Shared street	151	63.31	9058.62	3272.77	119284.53	17398.23	7	198	28
Bike accommodation	185	57.22	20008.81	3625.81	359251.92	47817.43	NA		
Street closure	27	63.17	6894.64	2170.54	62452.48	14298.89	3	198	66

peak development months. These interventions were categorised as *Continuing*, *Stopped*, or *Unknown* and visualised separately. Lastly, we visualised the dissemination trajectory of intervention ideas using their start dates. We selected the first ten interventions, referred to as the early adopters (Glaser & Krizek, 2021), and connected their centroids to show the development sequence. We intended to create opportunities for exploring hypotheses related to international knowledge transfer under the influence of the pandemic.

Several decisions were made to enhance the credibility of the methodology, although certain limitations should be acknowledged. Firstly, we chose the Shifting Streets Dataset, which is the most comprehensive database available and has undergone continuous maintenance and publication in an academic journal. However, it is important to note that this dataset does not provide complete documentation of all street experiments implemented during the pandemic, as some initiatives may have been overlooked due to language barriers or limitations in professional networks (Combs & Pardo, 2021). Secondly, this geospatial database serves as a foundation for conducting global-scale studies. Our recording of experiment end dates was done at the intervention levels. Although it would be ideal to document start and end dates at the street level, the data availability and the dynamic nature of interventions presented challenges in collecting such information on a large scale. Further studies may consider gathering street-level outcomes for smaller-scale investigations. Third, it could be challenging to draw a hard line when classifying street experiments. However, through manual investigations, the team reached agreements on interventions where inconsistencies arose.

4. Results

4.1. Global coverage of the PISE Database

PISE Database comprises 34,557 street segments and 2,709 points, representing 539 street experiments conducted in 333 cities worldwide. The cumulative length of the street interventions amounts to 5,105 km, with a coverage area of 3,806.6 sq. km, as computed using the 5-minute walking isochrones. Most recorded interventions are located in European and North American cities (Fig. 2). The intervention with the largest coverage spans 166 sq. km, while the smallest covers an area of 0.273 sq. km. Table 4 provides summary statistics of the length and coverage area by type. Below are further descriptions differentiated by type:

- The *Outdoor dining and commerce* type is represented as point features (N = 2,313). On average, there are 154 sites per intervention, indicating that 154 businesses obtained permits to operate along sidewalk or curb space in a city. However, these interventions have the shortest total street lengths per intervention. This is evident in their design, where tables are placed in a modular fashion in front of restaurant premises, occupying only a small portion of the street. For example, in Chicago, a full street closure can be activated only if a group of three or more businesses applies together.
- The *Park and greenspace* type is less commonly applied (N = 30), but they have the longest median length, indicating their extensive size within each intervention. Parks tend to take considerable areas

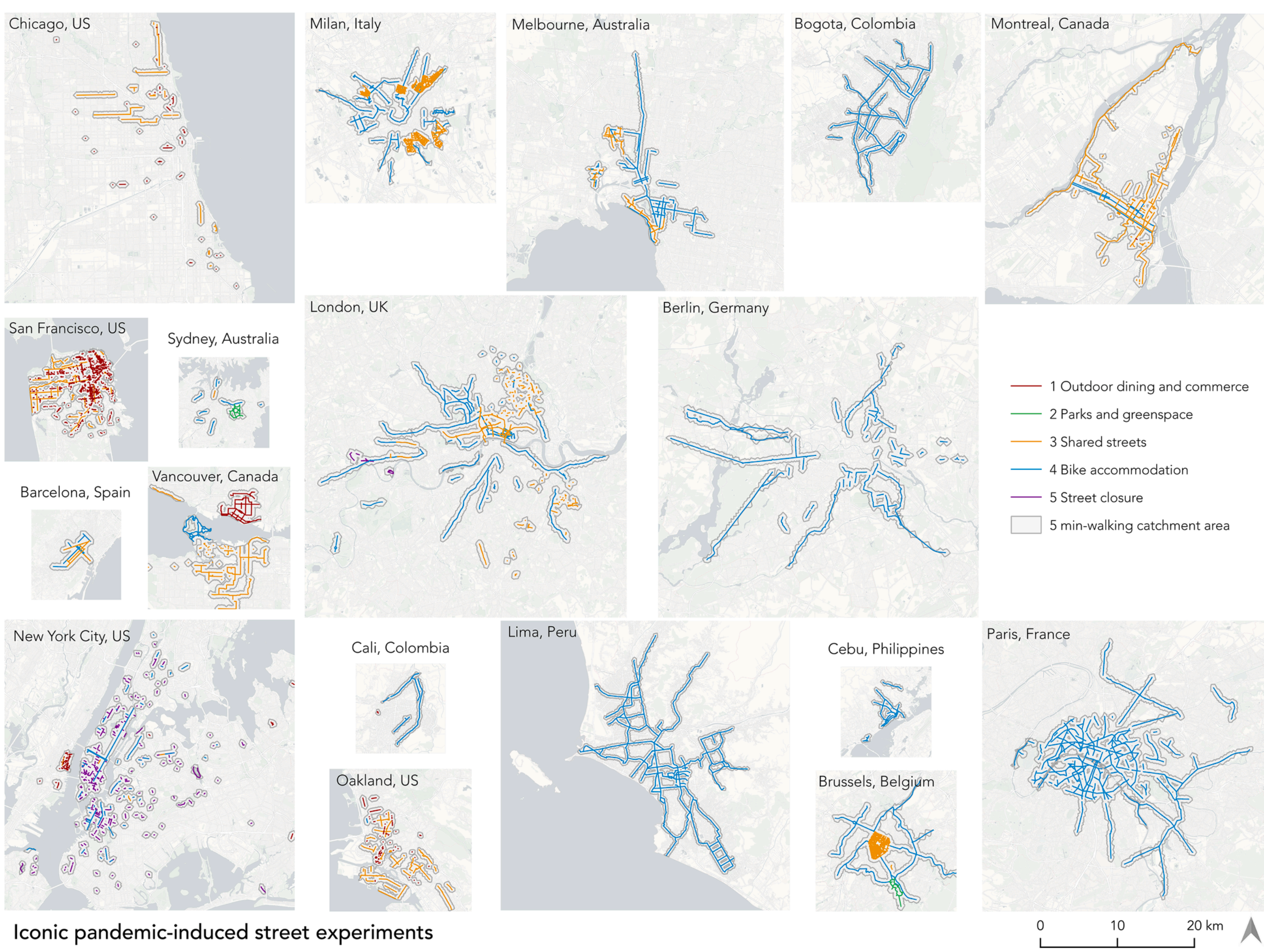

Fig. 3. Visualisation of street experiment locations during the pandemic outbreak

compared to residential housing, and park roads are more continuous and have fewer intersections. This is reflected in the lengths of park road closures.

- The *Shared street* type has a median length of 3,273 m and an average of 28 points per intervention. These interventions tend to take place on neighbourhood streets, resulting in shorter median lengths compared to parks. The point features, which represent non-commercial outdoor social spaces such as parklets, are less prominent compared to outdoor dining businesses. Parklets are designed to transform public spaces, whereas outdoor dining patios are privatised public spaces. The distinction between these types could lead to diverging developments in the streetscape. Increased provision of public space within shared streets may encourage community engagement but could also result in empty seating and potential urban blight. On the other hand, greater privatisation of public space through outdoor dining may contribute to social inequality, but it can also stimulate urban vitality due to better management by business owners.
- The *Bike accommodation* is widely applied (N = 185). This type has the most extensive coverage, with the maximum recorded length reaching 35.9 km in a single intervention. Bike accommodations tend to be large-scale implementations. Paris, for instance, implemented 50 km of pop-up bike lanes, and Bogotá reached 105 km at peak times.
- The *Street closure* type exhibits less distinct prototypes, as they encompass a combination of different interventions such as pop-up bike lanes, shared streets, parklets and outdoor dining. This mixed usage of street interventions may have several implications. On the positive side, it allows for a more people-centric street experience and may result in a longer lifecycle. However, the combined usage can also incur conflicts, particularly due to the limited car access.

4.2. Spatial distribution and intercity comparisons

Fig. 3 shows street experiment distributions in selected cities, all represented at the same map scale. North American cities, including Chicago, New York, Oakland, San Francisco, Montreal, and Vancouver, present more diversity in street experiments, with a particular emphasis on commercial-based temporary measures such as outdoor dining. The prevalence of outdoor dining in these cities reflects their reliance on economic vibrancy. This aligns with previous literature, which highlighted outdoor dining as a crucial support for business owners (Finn, 2020; Mandhan & Gregg, 2023). The business communities, including the retail and restaurant sectors, played a significant role in advocating for outdoor dining and commerce (Glaser & Krizek, 2021). Latin American cities, such as Bogotá, Cali, and Lima, implemented extensive temporary bike networks. The concept of Ciclovia was exported to cities worldwide even before the pandemic (Montero, 2017). The expertise developed by Bogotá in implementing temporary cycling streets contributed to the expansion of temporary bike networks in other cities. The dissemination of Bogotá's pop-up bike lane concept to European cities was well documented in the news (Associated Press, 2020). Pop-up bike lanes functioned as a timely tool for promoting active mobility in Europe, aligning with Europe's greater transport agenda - the Sustainable Urban Mobility Plan (SUMP).

Cities show distinct patterns that relate to their pre-pandemic pursuits. Brussels, for example, fast-tracked the creation of a 40 km bike network, focusing on major regional routes (Galindo, 2020). The city already had a regional cycle plan before the pandemic (Hope, 2015), enabling them to quickly respond on a large scale. During the pandemic, Paris added 50 km of bike lanes to major axes to complement the reduced public transit capacity (City of Paris, 2020). While the immediate goal was to address the transit challenges, the underlying objective of the city was to transform into a bike city by 2024, the year of the Paris Olympics (POLIS, 2022). The implemented temporary bike lanes were integrated into their 2021–2026 bike plan, allowing the city to leverage the pandemic to expedite its transformation into a cycling city. Open Streets in New York City are short and spread out because the locations were decided through a bottom-up application-based process (NYCDOT, 2020). In San Francisco, the implementation of continuous slow streets was strategically chosen by the San Francisco Municipal Transportation Agency (SFMTA). This deliberate selection aimed to create a network of interconnected slow streets (SFMTA, 2020).

Street experiments cluster in patterns that align with their respective types. These findings are consistent with research conducted by NACTO and GDCI (2020). Neighbourhood streets tend to have more shared streets, as observed in Chicago and Brussels. Outdoor dining sites, on the other hand, are typically concentrated in downtown areas, as exemplified by San Francisco. This correlation can be attributed to the restaurant locations, as these areas are more likely to have a higher concentration of dining establishments. Consequently, restaurant streets are prone to privatisation. Bike accommodations tend to take place on

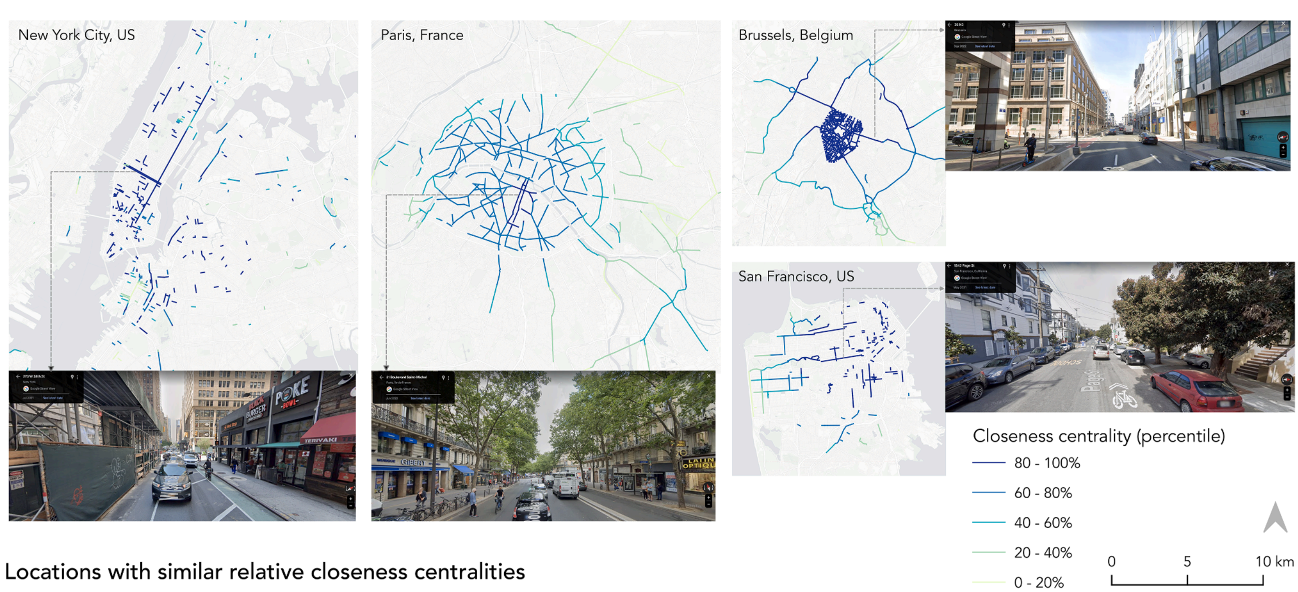

Fig. 4. Street sections with similar built environment measures

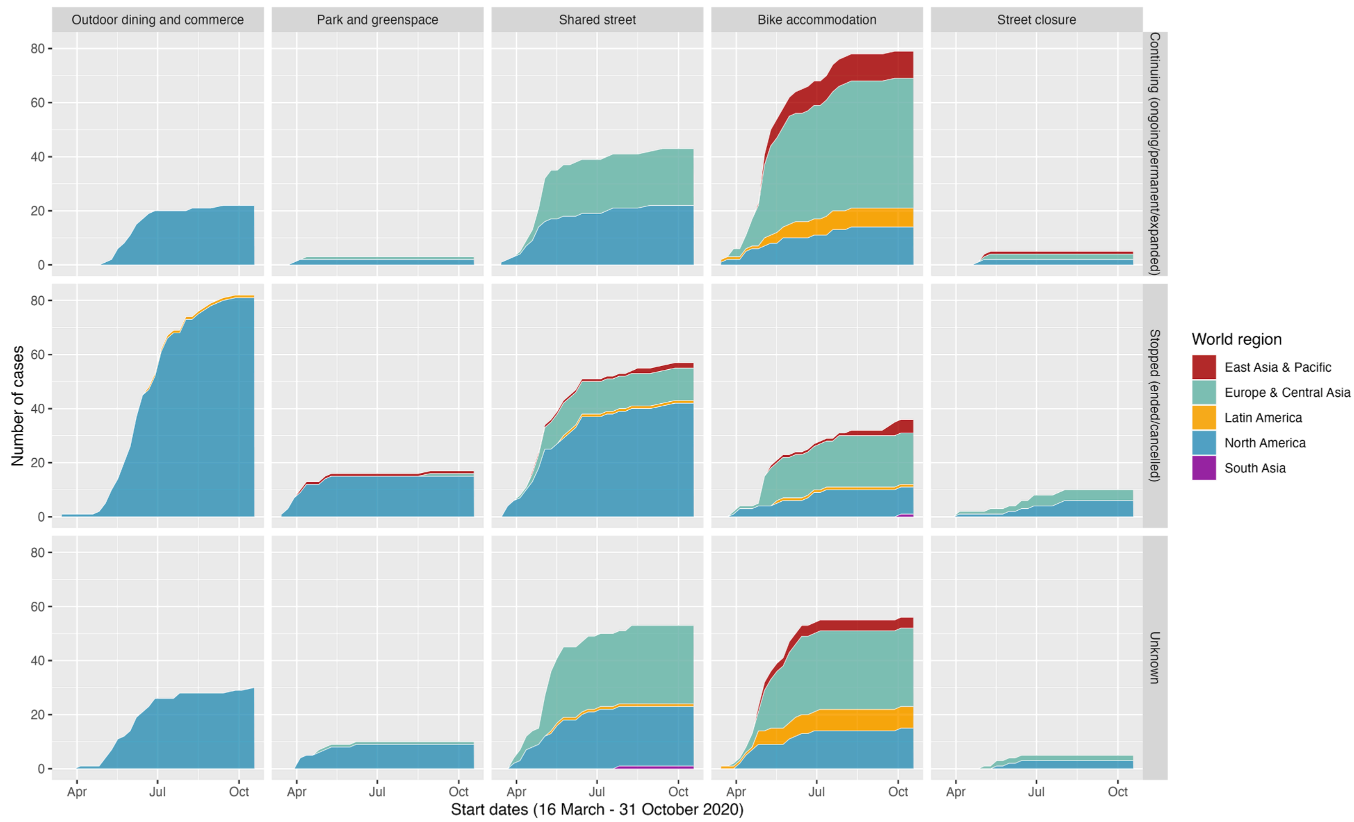

Fig. 5. Cumulative counts of interventions initiated between 16 March and 31 October 2020

major roads and in longer segments, as shown in Paris and Bogotá. Wide roads and continuous networks provide favourable conditions for incorporating bike lanes.

Street locations and their characteristics are described in built environment indicators and can be further investigated. Fig. 4 illustrates a comparison of streets with high relative closeness centrality (0.6–1.0) in four cities. This indicates that the average distance of the shortest path to reach these streets from other nodes is shorter than 60% of street segments within the respective city. Hence, the selected streets are easily accessible as they are a short distance from the rest of the network. Built environment indicators facilitate intercity comparisons. However, when examining the street views in the four cities, it becomes apparent that streets with similar relative closeness centrality can present distinct streetscape configurations. This points out the importance of considering multiple indicators and relative figures to compare and understand street characteristics across different cities.

4.3. Temporal development and dissemination trajectories

We visualised interventions' cumulated counts differentiated by

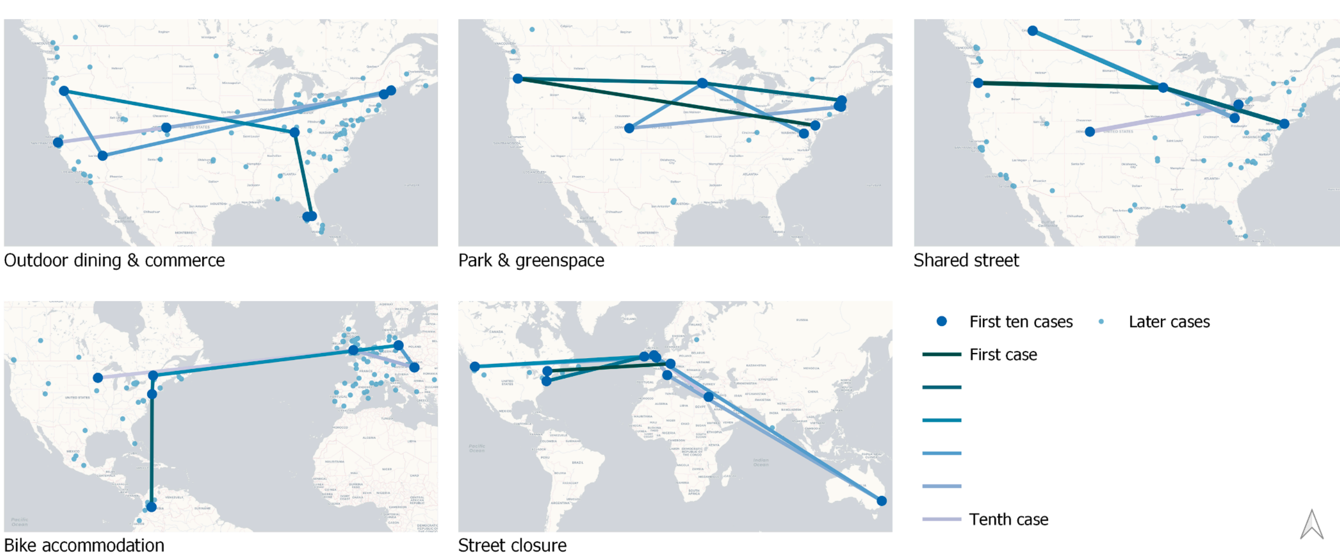

Fig. 6. Dissemination trajectories in the first two months of the pandemic

their experimental outcomes in Fig. 5. Note that the pandemic impacted cities at different periods, which may contribute to the temporal differences observed in the data. These differences can be attributed to various factors such as reaction speed, impact time, and knowledge transfer between cities. The reaction speed is more homogeneous in European cities than in North American cities, as indicated by the steep upward slope in the stacked charts. European cities saw peaks in bike accommodation and shared street deployments in May 2020. The database logged multiple intervention prototypes for North American cities. Park closures peaked in April when parks became overcrowded with people seeking outdoor activities (Gregg et al., 2022; McCormick, 2020). To maintain social distancing, parks banned car access to discourage visitation while maximising activity space. Outdoor dining and commerce and shared streets saw an increase in May, likely due to warmer temperatures and policy changes in the North American context, transitioning from stay-at-home orders to gradual opening. Businesses needed to continue operations when indoor activities were restricted. Regarding the ending interventions, European cities have fewer ended interventions than North American cities, which may indicate the alignment of their temporary measures with long-term plans. Around one-third of the interventions were not updated since their initial implementation. Nevertheless, a considerable number of interventions have continued to operate until now. This highlights the importance of conducting long-term studies to assess the lasting effects of these street experiments.

The earliest interventions for each street experiment type, as depicted in Fig. 6, highlight intercontinental connections. It is noteworthy that all types, except for bike accommodation, originated from US cities. This observation underscores the strong momentum in American cities to respond and adapt to changes.

- For *outdoor dining and commerce*, the earliest interventions originated from smaller US cities such as Tampa, FL, Winter Haven, FL, and Bellevue, WA, starting from May 2020. Major cities picked up shortly after. The reasons behind the time differences remain unclear. Possible explanations are a) city's reliance on economic activities, which may have prompted smaller cities to take faster actions, and b) bureaucratic system complexities, which may have allowed smaller cities for faster decision-making and implementation.
- *Park closure* also originated in the US, with cities such as Philadelphia, PA, Minneapolis, MN, and Portland, OR implementing these measures starting on 20 March 2020. These closures were primarily concentrated in northern major cities.
- *Shared street* also had its origin in the US, with cities like Portland, OR and New York City, NY, followed by Canada and Europe. Shared streets allow for shared usage by pedestrians and cyclists, often achieved through partial or full closures to cars. Grassroots initiatives were rare in the pandemic-induced street experiments. This could be attributed to people's fear and the restrictive orders during the lockdown period, which limited the ability for grassroots movements to emerge. The first government-led street closure took place in New York City, which drew international attention (Glaser & Krizek, 2021). New York City has a history of activism in street transformation, as evidenced by its Plazas Program which has been running for over a decade (NYC DOT, 2008). Their action during the pandemic may have served as a symbol for other cities. Subsequently, many cities implemented their own street closure programs soon after (e.g., Calgary, AB, Cleveland, OH, and London, ON).
- *Bike accommodation* started in Bogotá in mid-March, less than a week after the global pandemic declaration and weeks before Covid-19 surged in the city. Bogotá's long-standing program, Ciclovia, played a crucial role in this swift response, as it facilitated established interdepartmental collaboration and enabled the coordinated deployment of extensive bike lanes. In Europe, cities are guided by the EU Mobility Strategy and thus are more inclined to use the pandemic as an opportunity to accelerate their bike infrastructure upgrade. With existing publicly consulted plans in place before the pandemic, these cities were better positioned to implement changes within a short time (Glaser & Krizek, 2021).
- *Street closure* includes interventions with mixed types, mostly combining shared streets and bike accommodation. In early April, Stuttgart, Germany implemented street closures to accommodate pedestrians and cyclists. Note that this intervention differs from shared street interventions in terms of its specified streetscape allocations. In the Street closure type, bike lanes and activity spaces are explicitly delineated, whereas in Shared Street type, street spaces are self-organised.

5. Discussion

In this study, we mapped the locations, formulated built environment indicators, and documented the outcomes of pandemic-induced street experiments. Our approach involved constructing a database construction through intervention filtering, location mapping, built environment indicator computing, and intervention attribute refinement. The built environment indicators were computed using open data and open-source APIs. To ensure intercity comparability, we established a built environment template and calculated relative values for all indicators. In addition, we enriched the street experiment attributes, especially their status and classification. Furthermore, we analysed the interventions' spatial and temporal patterns through geospatial data visualisation to provide plausible hypotheses for future studies. Our mapping and documentation of the street experiment offer a geospatial perspective that empowers quantitative research in understanding people-centric street transitions.

5.1. *A global geodatabase of pandemic-induced street experiments*

This work contributed to the development of a global geospatial database, enabling quantitative analysis and intercity comparisons. We addressed several challenges in computing the global geodatabase, which can be lessons for future studies.

To enable cross-city comparisons, we established a neighbourhood-level built environment template with uniform indicators with relative values, ensuring comparable results. A similar approach has been applied in large-scale public health studies (Adams et al., 2014; Boeing et al., 2022). Our focus on urban mobility differentiates it from existing global databases. We selected the built environment indicators widely recognised as measures of connectivity and urban vitality, including intersection density, centrality, and amenities density and diversity. These measures were supported by open data, global street networks and urban amenities. An essential aspect of our approach was incorporating both relative and absolute values of the built environment measures to enhance inter-contextual comparability. For network centrality, we used percentile ranking to assess the relative importance of a street segment within its network. This method accounts for inherent differences among cities, enabling robust global or regional analyses.

In addition, we dealt with the discrepancies in administrative boundaries by adopting three levels of computational scales. The first two levels are the 5-minute and 15-minute walking time isochrones, which are recognised as distances representing walkable access across regions. For the third level, we used the Urban Centre concept to consolidate continuously populated regions into analysis units, ensuring accurate built environment computation. This approach was particularly beneficial for network measures, as it allowed for integrating road networks within each Urban Centre, thereby avoiding arbitrary cut-offs that result from relying solely on administrative boundaries in previous global built environment studies. This approach also allowed for reconciling discrepancies between city information provided by the Shifting Streets Dataset and the actual jurisdictions of some street experiments. The Urban Centre concept provides a globally validated method to define city agglomerations. However, it should only be used for built environment computation and not other aspects of street experiment interpretations.

Facing data availability issues, we leveraged open data and open-source APIs to construct the geodatabase. A globally available open data with consistent documentation and standards was crucial for enabling our study. We used the OSM network data to map the street experiment sites and compute built environment indicators, eliminating the need to collect street network data from each city's open data portal. While city-released street network data may offer higher accuracy, the varying degrees of availability and standards may pose challenges in creating a global database. Likewise, we retrieved urban amenities data from Foursquare, a global POI data provider. We used open-source API and platform to address the inevitable issues of projection distortion in a global-scale study. With the advancements in cloud computing, online geospatial services have become increasingly available, enabling efficient large-scale computation. We adopted Equal Area Projections from platforms (e.g., OpenRouteService) to achieve more accurate global isochrones calculation. We also minimised area and length distortions by computing geodesic area and length, which takes into account the three-dimensionality of the Earth's surface.

5.2. Spatial and temporal understanding of people-centric street transitions

Our geospatial database enables spatial and temporal analyses of the development trajectories of the pandemic-induced street experiments over three years (March 2020–January 2023). These interventions have sparked discussions among scholars regarding the transformative potentials of these emerging street use changes (Becker et al., 2022; Glaser & Krizek, 2021; Gregg et al., 2022).

The locations in our database enable spatial visualisation of interventions at a global level, allowing us to understand the transitions towards people-centric streets. Transition refers to the shift towards a new dynamic equilibrium, characterised by developments resulting from interacting processes and involving innovation within the societal subsystem (Loorbach & Rotmans, 2006; Rotmans et al., 2001). However, there remains insufficient evidence regarding street experiments, even with initiatives implemented years before the pandemic (Chaudhuri & Zieff, 2015; Stankov et al., 2020). This scarcity of evidence is primarily due to previous study designs being constrained to short-term and local scales, often concluding shortly after the experiment. In addition, interventions before the pandemic were developed in different years and places, making large-scale studies challenging. The PISE Database enables a longer-term quantitative analysis on a global scale to understand people-centric street transitions (Beukers & Bertolini, 2021; Wolfram, 2016).

The temporal information in our database helped hypothesise the intervention development trajectories. The global data revealed distinct development trajectories for different street experiment types. For example, outdoor dining emerged and prospered in the US, originating from smaller cities rather than major cities known for street experiments before the pandemic. This indicates that small cities can serve as innovators in street transformation initiatives, challenging the notion that they always follow the lead of major international cities. However, it is unclear whether the pioneering actions in small cities have influenced major cities. This area may require in-depth intervention studies to uncover. Bike accommodation interventions, on the other hand, were initiated in Bogotá, then in the US, and prospered in European cities. European cities have been more synchronised under the active mobility strategies released by the EU. Each city had its plans in place before the pandemic, which aided in expediting the implementation of bike accommodations during the pandemic (Glaser & Krizek, 2021). However, fast-tracking existing plans may present less transformative potential, as it tends to 'fit and conform' rather than 'stretch and transform' (Beukers & Bertolini, 2021; Smith & Raven, 2012). Furthermore, the temporal information in the PISE Database allowed us to identify intervention statuses (i.e., permanent, ongoing, and ended), which serves as an outcome variable for analysing determining factors that contribute to the success or conclusion of the interventions.

5.3. Future research directions

The PISE Database can be further developed in two aspects. First, it can be continually expanded to include more intervention types and wider triggering factors. It may consist of street reallocations serving purposes beyond public space and mobility. Curb spaces, in particular, have experienced increased competition for usage since the pandemic (Honey-Rosés et al., 2020). Activities such as delivery, parking, and bus transit can either enhance or compete with the street experiments identified in this study. For example, Toronto designed loading platforms in bike lanes to accommodate both needs (Romanska, 2021). The database should also include non-pandemic-related street reallocations to explore how these interventions may have influenced changes in conventional planning approaches in the post-pandemic era (Verhulst et al., 2022). Considering climate change as another pressing issue, street experimentation techniques are being adopted to accelerate active mobility provisions (Lieswyn et al., 2022). The inclusion of crowd-sourced input would be advantageous in maintaining up-to-date and accurate information. Second, the database needs to be studied along with the city's existing public space and mobility networks to understand the significance of these interventions. Key questions to explore include: Would interventions more likely stabilise in neighbourhoods or city centres? How do these interventions align with the city's transport strategic plans? How will street experiments continue to facilitate urban street transformations without the pandemic as an external stimulus? The database could serve as a starting point for spatial and quantitative studies on street experiments.

6. Conclusion

In this paper, we developed a global geodatabase by mapping locations and calculating neighbourhood-level built environments for pandemic-induced street experiments. As the first global geospatial database of its kind, it contributes to street experiment studies by providing precise location data of these pandemic-induced interventions. It also contributes to the construction of a global built environment database by incorporating enhanced computation for built environment indicators. We employed internationally recognised planning concepts and built environment indicators to enable quantitative analysis and intercity comparisons. Our research supports spatial and temporal analyses of street experiments on a global scale. With this database serving as a baseline for the pandemic period, it enables future studies on the evolution of these street experiments. This can open new research avenues for tactical urbanism as an emergency response for urban development worldwide.

CRediT authorship contribution statement

Jianting Zhao: Conceptualization, Methodology, Visualization, Investigation, Data curation, Writing – original draft. **Guibo Sun:** Conceptualization, Methodology, Writing – review & editing, Supervision, Resources. **Chris Webster:** Writing – review & editing, Supervision.

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.

Data availability

Data will be made available on request.

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