Proceedings of the 14th International Space Syntax Symposium

#103.

Scaling-Up Space Syntax

Framing Evidence-Based Planning & Design

Sepehr Zhand; University College London, sepehr.zhand.18@ucl.ac.uk

Dr. Gareth Simons, University College London, gareth.simons@ucl.ac.uk

Prof. Kayvan Karimi, University College London, k.karimi@ucl.ac.uk

---

ABSTRACT

In the late 1970s, Space Syntax emerged as a way of understanding the built environment as a set of relations between spatial arrangements and overarching social, economic, and political processes. This understanding arose at a time when traditional modes of thinking on architecture and cities had been supplanted by modernist ideologies and the limitations of reductionist models of buildings and cities were becoming evident. The discourse of space syntax showed that analytical approaches to design and planning could not only identify problematic instances of realized projects but could also be applied to assess prospective design and planning programmes.

Despite technological advancements, the adoption of space syntax has largely remained confined to academia and specialized firms, limited by the complexity required to implement these theories and the financial overheads of integrating advanced analytical processes. This paper considers the emergence of Evidence-Based Design and Planning (EBDP) as a framework which potentially aids the adoption and scaling of analytical approaches – including Space Syntax – to the design and planning field more generally. We provide a brief overview of perspectives on EBDP, introduce examples of evidence in both procedural and scientific forms, and review the quickly evolving ecosystem of open data sources and computational toolsets that are increasingly available.

doi: 10.36158/9791256690329110

Maturing EBDP analytic toolsets and design methodologies are increasingly capable of overcoming technical and financial hurdles which historically hindered adoption of analytical approaches, therefore enhancing the applicability and scalability of evidence informed analytical approaches in urban design and planning. However, whereas such methods are increasingly powerful, accessible, and generalisable, challenges to their adoption remain.

KEYWORDS

Evidence-Based Design and Planning (EBDP), Space Syntax, Spatial Analysis, Open Data

1 INTRODUCTION

Evidence-Based Design and Planning (EBDP) emerged from a historical progression in the use of empirical observation, analysis, and systematic inquiry into design and planning methodologies. Early usage of observation and analysis to inform planning decisions can be seen, for example, in the work of Patrick Geddes who championed contextual analysis and advocated “survey before plan” and "diagnosis before treatment", emphasising the observation of existing conditions before implementing context-sensitive, minimally invasive interventions through “conservative surgery” (Batty and Marshall, 2017).

The desire to improve living conditions and the function of cities continued apace with the rise of modernity, heralding significant technological progress accompanied by utopian conceptions of idealised cities. These ambitious plans were aimed at addressing the challenges of rapid urbanisation driven by industrialisation and the consequential changes to urban populations and their spatial dynamics. Emerging technologies prompted new planning and design paradigms through what were – at the time – seen to be rational and scientifically informed approaches. Reimagined and remodelled cities were to optimise considerations such as the mass provision of housing, expansive motorways for private vehicles and transportation schemes, access to light, and generous green spaces (Corbusier, 1967). Though well intentioned, many modernist interventions and the ensuing ideas have caused a legacy of damage to cities with the issues clearly framed at the time by Jane Jacobs and Christopher Alexander. Heavy-handed and large-scale interventions had caused spatial fragmentation of the urban fabric at the human scale, lacking the finer-grained spatial complexity associated with liveable neighbourhoods and historic cities (Alexander, 2012; Jacobs, 2011; Whyte, 1980).

The criticisms voiced did not necessarily reject the incorporation of analytical thinking into design and planning (for example, both Jacobs and Alexander anticipated aspects of network analysis), though precipitated an era of reflection on the nature of cities and the "kind of problem" they represented, presaging a more contemporaneous perspective of cities as complex systems (Batty and Longley, 1994; Batty, 2013). This signalled an important paradigm shift where it became increasingly clear that a proclivity for scientific reductionism and engineered optimisation stood at odds with the rich spatial complexity underpinning the sustained development and growth of cities, with deep implications for their liveability and resilience. It would take some decades for more appropriate ways of measuring and analysis to emerge, including the genesis of Space Syntax (Hillier and Hanson, 1984). Over time, a broader family of methods spanning spatial analysis, landuse and mixed-use analysis, network analysis, and demographics and statistics more generally, has become widely accessible through open-source software. Related toolsets are increasingly refined, the data necessary to apply these techniques is more accessible, and the techniques to extract information through statistical and machine learning techniques are now available to a wider audience.

Against this backdrop, it is important to anticipate how EBDP and related developments can address barriers to wider adoption and scaling of analytic methods, including the use of Space Syntax. We commence with a broad overview of related literature and perspectives, proceeding to then review two notable forms of evidence and their ramifications: First, is the burgeoning scientific evidence base as spearheaded by the medical community. This form of statistical evidence underpinned by spatial analytic techniques continues to grow, linking urban design to factors such as walkability, health, energy, transport, economics, pollution, and climate. These studies are providing increasingly actionable information and can underpin evidence informed approaches to policy and planning; we provide examples of these forms of evidence to illustrate their form and potential breadth and utility for the design and planning community. Second, is the use of measurable methods to quantify characteristics of urban form as an iterative design evaluation tool, which can then be used to assess existing versus new and scenario against scenario. This form of evidence generation is readily utilized in Space Syntax and can be aided by the emergence of new analytic methods and data sources. We conclude with high-level overview of emerging tools, data-sources, and related challenges to their adoption in EBDP. We then conclude that EBDP developments are largely supportive to the furthered development and utility of Space Syntax, and that the potential of EBDP approaches is immense if the educational and technical barriers to adoption are successfully addressed.

2 THE EMERGENCE OF EBDP

Design and planning strategies of 19th and 20th centuries resulted in the generation of spatial layouts with disregard for social and physical context (Højriis et al., 2014) leading to misjudged interventions in the political, social and physical continuum (Carmona, 2014). These modernist and non-evidential approaches, widely formalised as land-use zoning policies, resulted in widespread segregation of residential and core service areas as an attempt to improve the urban experience (Macionis and Parrillo, 2001, p. 61; Sevilla-Buitrago, 2022, p. 111). These design approaches reduced generative social interaction through designing-out of the human scale (Gehl, 2010); controlled access to places, activities, resources, and information (Madanipour et al., 2000) introduced spatial barriers to interaction at the pedestrian scale and impeded social and functional integration. These observations, which stemmed from earlier criticisms originating with thinkers such as Jacobs, Mumford, and Whyte, were progressively developed and have given rise to methods which have increasingly sought to incorporate evidence and analytical thinking into design and planning of the built environment.

EBDP can be framed to have emerged in the postmodern context of the 20th century to address the manyfold and complex considerations in urban design and planning. Zeisel (1984) critically investigates evidence-informed methods and recognizes four categories of evidence feeding into the cycle of design and planning process: personal experiences (Jones, 1970; Korobkin, 1976), observations (Zeisel, 1975), design publications, and analytical review of implemented design (Foz, 1972). In the late 90s the Urban Task Force (UK) highlighted the importance of evidence-based planning, rigorous analysis and data-driven decision-making in shaping cities (Rogers, 1999). At a territorial level, the European Spatial Development Perspective made an effort to bring cohesion and cooperation across European countries through scientific approach and sharing of knowledge, experience, and evidence in planning (European Commission and Directorate-General for Regional and Urban Policy, 1999). From the early 2000s, the European spatial planning observation network (ESPON) has provided tools and reference benchmark datasets for cooperative evidence-based planning. These forms of evidence-based approaches are potentially instrumental for tackling the challenges of sustainability and social inclusivity through the generation of evidence informed policy.

Literature and discussion on EBDP has spanned different perspectives on its use and relevance. For example, Clarence (2002) looks at EBDP from a policymaking point of view and argues that although evidence is important, it is only one factor among many in the complex and messy process of policymaking. On the other-hand, Davoudi (2006) examines a body of literature, policy, and experiences to demystify the ideas underpinning EBDP and provides an account of EBDP, recognising that there are limitations and potential biases in evidence and in the generalisability of evidence and methods. Faludi and Waterhout (2006) introduce the term evidence-based planning and examine the extent to which evidence is being incorporated into the practice of planning, arguing that it is the intention that differs from previous efforts, in that it intends to maximize performance. Later, Davoudi (2012), through examination of positivist and traditional approaches to planning, warns against over-emphasis and over-confidence with regards to scientific approaches in planning. While calling for a change in traditional and objective thinking about space, she calls for careful consideration and improvement in interpretability of evidence and analytical thinking. It should be noted that many of these perspectives and categorizations do not necessarily reflect the more recent emergence of crowd-sourced and big-data alongside rapidly advancing spatial analysis and modelling techniques.

A distinction can be made between evidence-based design and planning (EBDP), research informed design (RID), and data-driven design (DDD). EBDP centres on the facilitation of available evidence into the design and planning cycle to address the complexity of urban phenomena across a range of considerations, with the aim of providing a holistic solution while leaving room for change and future adaptability. What is subject to improvement in the framing of EBDP is its applicability across scales and the integration of the process into technical and theoretical processes. In contrast to EBDP, RID involves the examination of specific cases to understand a narrowly defined area and how this affects the design process. Peavey and Vander Wyst (2017) provide a matrix explaining, step-by-step, the differences between the two. In general, the RID approach investigates a narrowly defined problem and applies the outcome broadly, while EBD investigates a broadly defined problem and applies the outcomes narrowly. Data-driven design, on the other hand, mainly relies on big data and is centred on technologically driven methods and computational thinking (Sailer et al., 2015).

With these considerations, it can be posited that Evidence-Based Design and Planning (EBDP) functions as a comprehensive conceptual framework which allows evidence and data to be incorporated into the design process in a systematic way to inform and enhance the resultant solutions. Originating from a critique of the rigid paradigms inherent in traditional and modernist perspectives on spatial planning and design, EBDP aspires to align design and planning with concurrent economic, cultural, and political research and processes. In design and planning practice, this framework can be considered as an iterative evaluation cycle providing a feedback loop for successive stages of work, thereby informing the decision-making process. Apart from prioritising evidence over intuition, EBDP differs from conventional design and planning processes in that it allows for changes at each stage of iteration as evidence is taken into consideration.

3 CHALLENGES TO THE APPLICATION OF EBDP

EBDP informs the process of design and planning through evidence and science-based analytical methods to address the shortcomings of rigid ideologic approaches to spatial design and planning. This places EBDP in a larger emerging field of the science of cities (Batty, 2013). Marshall (2012) considers potential caveats of adopting a scientific approach in urban planning and design: whereas personal experiences and observations are among the main forms of evidence informing the design process, the emerging evidence-based approaches sometimes rely heavily on big data and statistical methods. Marshall notes that these approaches may be used while overlooking existing scholarship and ignoring an element of ground-truthing. Oversimplified representations of urban models, spurious precision, or overstated claims in findings derived from data-centric approaches may jeopardise the use of evidential thinking in urban planning and design.

The gap between technical analysis and application to real-world problems, or the lack of availability of consistent and accurate datasets, poses a substantial challenge to the implementation of standardised analytical workflows. Further, on an intellectual level, the challenge of adopting evidence-based methods within the tradition of the design and planning disciplines requires an appreciation and objective understanding of the analytical methods used, as well as the subjective relationships driving urban processes and a space's materiality. Given the results provided by evidence-based methods, EBDP is premised on a cause-and-effect relationship between the evidence and an outcome. This has been noted by Nes and Yamu (2020) in relation to Space Syntax; adoption of theories and application of these to analytical evidence may primarily suggest a causal relationship, while other considerations such as cultural, political or social factors may also be needed to more fully explain phenomena.

From the "grand" point of view, the adoption of evidence-based practices within traditional establishments can be seen as a form of innovation. While incorporation of evidence into design thinking is not technically an innovation, the holistic approach as well as the iterative feedback informing the process is less frequently practiced. Rogers (2003) discusses the adoption of innovative practices into stages of knowledge, persuasion, implementation, and confirmations stages. From a practical point of view, pioneering EBDP theories and practices such as space syntax face challenges in all stages of adoption. Raford (2010) lays these out in relation to

Rogers' stages and argues that evidence-based practices such as space syntax have a high degree of complexity – in terms of theory and technical implementation – as well as little room for trialability. This causes lack of sufficient exposure to users – in this case designers and planners – which both reduces the confidence in using such methods on behalf of users and clients and increases the risks of incorporating them into the design and planning protocols. Further, it is important to note that within the conventional design and planning discourse, finding room for trialling and the incorporation of experimental steps to improve the solutions induces additional financial demands on the project, which many are reluctant to accept. Lastly, like all urban-related practices there can be a long duration time lag between implementation and post-occupancy assessments of EBDP practices, thus reducing its potential impact on policy and wider adoption. (Bolton et al., 2017)

4 EXAMPLES OF EVIDENCE

There are potentially multiple types of evidence which may be generated or applied in different ways. There are two notable forms of evidence with significant relevance for the design and planning process. The first – scientific evidence – has received widespread interest from the broader research community and provides rapidly emerging forms of tangible and actionable evidence which may support decision-making in the design and planning context. We provide some examples of these forms of evidence to clarify their potential form and utility. The second – measurement as comparative evidence – entails evidence generation through iterative analysis and comparison. This form of evidence is associated with Space Syntax methodologies and represents an important aspect of evidence generation and design evaluation in support of the design and planning process.

4.1 Scientific Evidence

Whereas architects, urban designers, and urban planners are increasingly aware of the need for walkable, compact, mixed-use urbanism, it remains more difficult to implement principles such as these in policy and practice. Researchers have found that policy wording frequently endorses these and related concepts, but that clear targets in relation to aspirations can be lacking. In cases where measurable targets are provided, there can be little explanation or justification for how these were selected 12/06/2024 18:32:00. One of the challenges is that high level policy and statistics, which may be valid at the city-scale, can be difficult to tangibly apply or measure at the street-scale where design and planning decisions have direct effect. This issue can be alleviated by the growing availability of open datasets and urban analysis toolsets which can be applied at an increasingly high resolution, with the benefit of providing more directly actionable information for designers and planners at the local scale (Boeing et al., 2022).

An example of this is the increasingly specific associations between urban form and walkability. Researchers have known for decades that community design is significantly associated with moderate levels of physical activity and have used indicators such as residential density, street connectivity, and land-use mix (Frank et al., 2005). The results of these forms of studies are generally consistent: higher density, more connectivity, and greater mixed-uses have a positive effect on walkability for work and amenities. In many cases of newer urban development, walkability has, in effect, been engineered out of daily life with detrimental effects to health, traffic congestion, and air pollution (Saelens et al., 2003). Whereas the general principles and methods are clearly understood, the applicability of these findings can be hampered by a great variety of methodologies and indices.

The use of open datasets and toolsets holds promise that measures can become more reproducible and widely applicable. By way of example, recent studies looking at the results of large scale studies on walking activity have modelled findings against specific urban attributes to suggest actionable thresholds for population density (5700 people per km^2), street network intersection density (100 per km^2), and access to public transport (25 per km^2) as a guide for constituting walkable urbanism (Cerin et al., 2022). Nevertheless, specific intricacies of how the datasets are prepared and cleaned (e.g. street network cleaning from the study's OpenStreetMap sources), and how properties are measured (e.g. grid cells used in the study versus radial cells or street network distances) can provide ongoing challenges to wider forms of application which may involve differences in spatial analytic methodologies.

An important benefit to rigorous evidence-based studies is an increased clarity on the veracity and limitations of common assumptions. For example, trees in the urban environment are commonly assumed to reduce land surface temperatures and to absorb CO2 from the atmosphere, but the benefits are more nuanced. Studies show that trees can provide wide-ranging benefits similar to parks while requiring less space (Cimburova and Berghauser Pont, 2021). Their contribution to the reduction of land surface temperatures can be quantified and modelled, showing, for example, that in the context of the USA the temperature reductions are in the range of 3 degrees Celsius (Wang et al., 2018). However, studies also show a more complex picture; perhaps counterintuitively, modelled temperature reductions in the central EU of 8-12 degrees Celsius are greater than the reductions of 0-4 degrees for the southern EU, the reason being that drier climates limit the evapotranspiration of the trees even if temperatures may be higher (Schwaab et al., 2021). Further, even if trees are widely cited as beneficial for CO_2 reduction, this is not necessarily the case in urban environments because of limited space for trees in relation to the scale of urban emissions. The presence of trees may even hinder air currents from removing local concentrations of air pollution (Pataki et al., 2021).

Evidence and meta-analysis can provide disambiguation on complex topics, a pertinent case being urban compactness and population density. Density is generally positively associated with public infrastructure, public and active transportation, economic benefits such as innovation and productivity, and reduced greenhouse gas emissions per capita. However, density can also be associated with detrimental effects on biodiversity, heat, social interaction, crime, pollution, and mental health. Further, some of these effects are non-linear, for example, transport related benefits may first increase and can then decrease for the highest densities. Whereas many of these drawbacks can be countered with design strategies, it is, for the same reason, important to be aware of these complex effects and potential strategies for their mitigation. This is made more challenging to anticipate when planning policy tends to gloss over the potential for detrimental effects (Berghauser Pont et al., 2021; *Demystifying compact urban growth*, 2018).

Medical and health research remains a strong driver of evidence-based research. For example, the effect of urban form on physical activity and obesity is robustly documented; notably, the IPEN physical activity and weight data gathered from 14,000 participants in 12 countries over 5 continents has been used to document associations for factors such as population density, intersection density, land-use mix, access to parks, transit stops, and composite indices combining these considerations. Positive outcomes are observed for physical activity, walking for transport and leisure, Body Mass Index, and the prevalence of obesity (Sallis et al., 2020). However, it should be noted that associations were not as consistently strong when measured against GIS data as compared to self-reported measures, possibly indicating a need to further refine GIS methodologies and the local-scale spatial precision of these forms of analysis. The impact of cities and urban form on health is far-ranging, with examples including the impact of nature on mental health (Bratman et al., 2019) and of trees on antidepressant prescriptions (Marselle et al., 2020). Application of evidence-based health metrics in the urban environment has been used to quantify the impact of Barcelona's Superblock model which estimates a reduction of premature deaths (Mueller et al., 2020) based on an analysis of green spaces and mortality (Gascon et al., 2016), physical activity (Woodcock et al., 2011), air pollution (Atkinson et al., 2018), and air temperatures (Guo et al., 2014).

Evidence is further instrumental in clarifying the impact of planning and transportation policy decisions on the reduction of Greenhouse Gas Emissions. For example, active transportation analysis for the EU shows, in tangible terms, the potential reduction in emissions per person because of mode-shift from cars to active transportation and from cars to public transportation, with cyclists having 85% lower lifetime emissions than non-cyclists. A 10% mode-shift from cars to bicycle can result in a 10% reduction in emissions, with a 3% reduction likewise possible for a 10% mode-shift from cars to public transportation (Brand et al., 2021). Research also provides substantial clarity on mobility transition policies. In the context of the United Kingdom, a rapid and large-scale reduction in car usage will be necessary to meet emissions reduction targets. Reliance on electrification is not sufficient to meet air pollution reduction targets, therefore requiring greater focus on active transportation, public transportation, and local landuse accessibilities to encourage walkability (Winkler et al., 2023).

Scientific evidence is further helpful in providing the impetus for supporting local planning decisions in the context of reactionary opposition to interventions supporting pedestrian and high-street. For example, cycling and pedestrian schemes are shown to have a generally positive impact on the economic performance of retail stores (Volker and Handy, 2021). Both Transport for London ("Walking & cycling: the economic benefits," n.d.) and the NYC Department for Transportation ("The economic benefits of sustainable streets," n.d.) have generated collections of statistics and urban design cases documenting the benefits of pedestrian-focused enhancements to the urban fabric.

4.2 Measurement as Comparative Evidence

Whereas the above describes forms of evidence derived from studies, we now turn our attention to the use of measurement-based analytic techniques which are applied as iterative design evaluation tools. It can be argued that a significant feature of EBDP is the use of geospatial data and spatial analytical methods and models. As suggested by Karimi (2012), the application of analytical tools for urban design and planning allows for the creation of an analysis baseline and the use of design evaluation stages where solutions or ideas can be assessed against benchmarks. With utilization of data-intensive methods and cross-disciplinary modelling and analytical methods, measurement can be used as a form of evidence providing a framework for comparing initial ideas and successive iterations of outputs. Thus, measurement as comparative evidence enables project development to have comparative measured alternatives at different stages. This facilitates the definition of the design problem through generating an evidence case before, during, or after the implementation of the project.

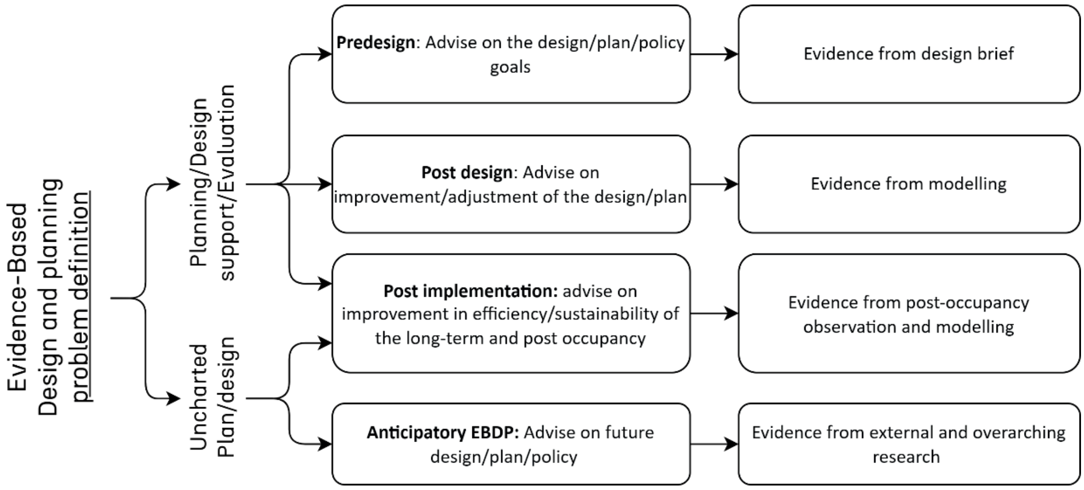

Figure 1 Evidence-based design and planning problem definition

As shown in Figure 1, the analytical thinking in EBDP and the use of measurement as evidence provides the possibility to inform, revise, or redefine the design and planning problem according to the available information and development stage of the project. While the nature of the measured data and scale of the project may vary substantially, this framework is generally applicable to varied urban design and planning problems. Collecting data either through empirical or quantitative methods, this EBDP framework is applicable from micro to macro scales, and these methods can be further scaled using quantitative methods and automated workflows.

	Empirical approaches	**Quantitative methods**
Input data	Observation – Not reproducible	Numerical data – reproducible
Scale of analysis	Micro, Meso	Meso, Macro
Data collection	Observation, gate counting etc	Official census, remote sensing, crowdsourcing, GIS, etc
Analytical techniques	Statistical methods, participatory methods, evaluation and feedback loops	Spatial statistics, mathematical modelling, geostatistics

Table 1 categories of urban design and planning problems

Moreover, the measurement, whether derived from models such as a spatial street network model or collected datasets, undergoes a series of stages including cleaning, exploration, and processing. This iterative process may provide feedback to revisit and potentially revise the initial problem definition, or to move forward towards facilitation of further processing and idea generation. In Figure 2, the loop depicted in the early stages of the project highlights the dynamic interaction between data collection and modelling, indicating that initial measurements can prompt refinements and revisions to the problem definition.

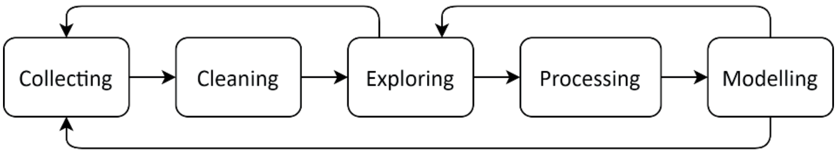

Figure 2 Data collection and processing loop. Adopted from (David S. Jordan, 2023)

In this context, input data for spatial analysis can be obtained through direct collection (see Figure 3), capturing features with spatial properties, or indirectly by considering intrinsic properties such as network centrality values. When incorporating data with spatial features directly, it's crucial to recognize that the collected data falls into two distinct categories. The first category comprises static material features such as buildings or natural elements, which are surveyed and mapped, their accuracy reliant on the resolution of observation and are subject to temporal changes. The second category involves recorded data linked to specific spatial units (e.g., a room, a street, or a 10x10km land grid) presented as aggregated values, such as vehicular speed data for a given street.

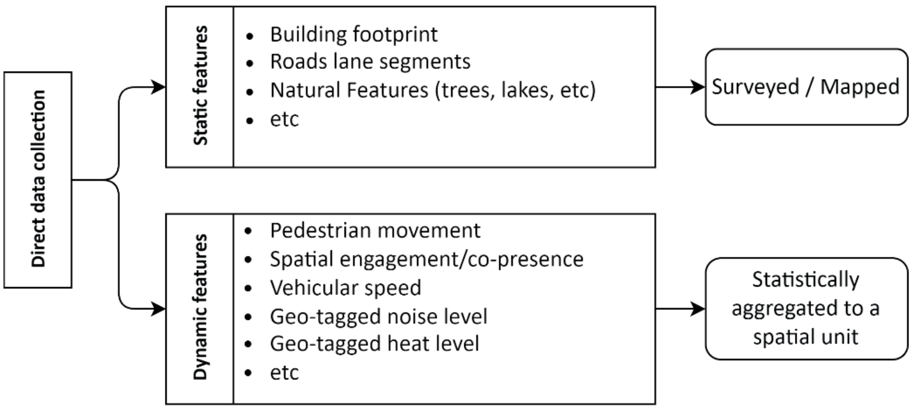

Figure 3 Dynamic and static spatial features

Further to direct data collection which shapes an evidence-informed framework, there are intrinsic attributes to the space that can inform spatial design. From this end, modelling, analysis, and measurement can unravel intangible or less obvious properties of space that would impact dynamics. While space syntax is a good example of such models – representing space as spatial configuration – the field of spatial analysis and modelling has advanced to provide other examples such as fractal geometries (Batty and Longley, 1994), gravity models

(Thompson et al., 2019), applied percolation theory (Arcaute et al., 2016), and other modelling and interpretation methods providing evidence from niche perspectives into spatial properties.

The plethora of evidence, modelling, and analytical techniques poses the challenge of how to use these rich and complex assortments of information as part of the design and planning process. In this respect, there have been attempts by the space syntax community to develop integrated models (Acharya et al., 2017) where the model iteratively blends a multitude of evidential inputs into a spatial network model optimising the balance between arrangement, order, structure, and functionality. A possible step towards these approaches is detailed by Karimi (2023) through synthesising analysis, interpretation, development, and idea generation in a manner that accommodates the use of evidence from different angles. The increased computational capacity requirements of such methods may require optimisation strategies and cross-disciplinary approaches.

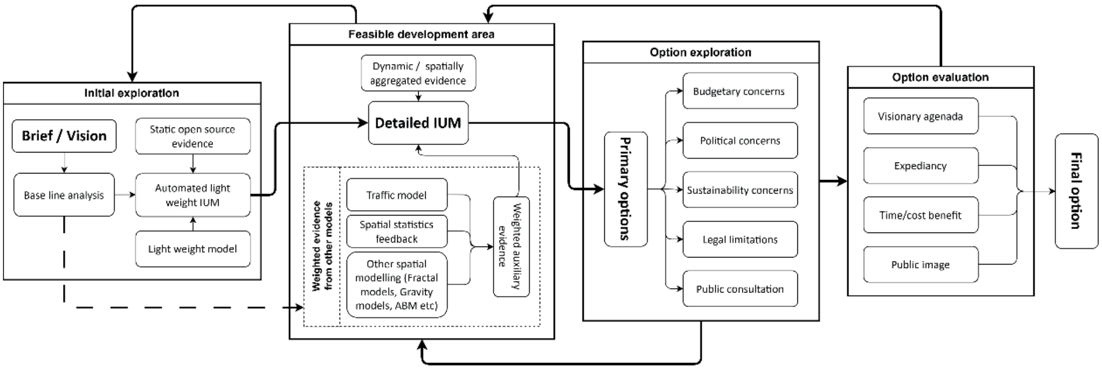

Figure 4 EBDP feedback loop

Figure 4 summarizes the suggested feedback loop for evidence-based design and planning while exemplifying how varied kinds of information and/or analysis can be fed into the process as evidence. This suggested pipeline relies on accommodating different formats of evidence (e.g., public consultation vs. traffic flow) while weighting the evidence based on an analytical output from a previous stage. From this perspective, different forms of feedback would enhance the outcome. Trying to avoid unnecessary and conflicting loops, this pipeline is structured in 4 stages of initial exploration, feasible development area study, option exploration and option evaluation, before suggesting a final output option.

Reducing the demand for computational capacity, this pipeline initially develops a baseline analysis with automated workflows and the use of openly available datasets. This frames the extents of a detailed feasibility development stage where multitude of analytical models and data is fed to shape a detailed integrated urban model (IUM) and options are produced to be assessed against initial agenda, public image, time/cost benefit etc. While the pipeline is flexible to accommodate change in iterations, the logical process of the pipeline points out to one concluding option which underpins all considerations based on their weighting and feasibility. Starting from space syntax analysis as an umbrella term for socio-spatial analysis (Karimi, 2018), the following expands on the way in which relying on open data and method and automate workflows facilitates this process.

5 DATA AND METHODS

A proliferation of emerging geospatial and demographic data sources has made it increasingly feasible to apply quantitative forms of analysis to the derivation of useful insights for evidence informed design and planning. It is, nevertheless, necessary to be aware of several nuances regarding the different forms of datasets and their potential usage, as well as the range of potential analytical toolsets and interfaces and how these might be suited to different forms of analysis and the varying skillsets of users.

5.1 Open Data and Generalisability

An important driver of the adoption of data and evidence informed urban analytical techniques is the availability of data. A fundamental distinction can be made between open data and its more restrictive proprietary counterparts. Closed data sources tend to hinder the adoption and applicability of analytical methods because the financial costs of data procurement can be substantial and restrictive licensing conditions may ringfence how such data is used and impacts whether results can be published or generalised. Open data sources, on the other hand, are freely available and tend to have significantly more permissive licenses. This makes it feasible for researchers to exploit these data sources with the benefit that resultant research and methodologies can become more widely available with a greater likelihood of adoption. Open data research and usage has accordingly been bolstered by the growing availability of open data licenses used by national governments such as the United Kingdom's Open Government License, under which data sources such as the Office for National Statistics census units and demographic statistics are available to users with a clear and permissive policy. Government level organisations, such as EU Copernicus, have likewise adopted open forms of data licensing, though in some cases, such as the United Kingdom's Ordnance Survey, only higher-level or simplified subsets of data are made openly available (e.g. OS OpenStreets) to preserve commercial interests through sales of richer content datasets (e.g. ITN, or MasterMap).

An interrelated subtlety is that international scale open datasets are highly generalisable from location to location. Examples include the Global Human Settlement Layer which openly publishes datasets such as global population (Schiavina et al., 2023a) and high density clusters (Schiavina et al., 2023b). OpenStreetMap (OpenStreetMap contributors, 2017) has become a notable repository of global scale urban information, and is resultantly immensely popular with urban analytics researchers because the widespread coverage provides international availability of data and allows research methods and findings to be applied in a more generalisable and replicable manner (Boeing et al., 2022). The caveat is that the reliance on crowd-sourced data and maintenance implies a greater variability in data quality; regions of the world without active local mapping contributors may have less robust data with the consequence that fewer forms of metrics can be computed. On the contrary, areas with high numbers of active contributors may be better mapped or updated more frequently than the equivalent official national datasets.

5.2 Variety of methods

A hindrance to the wider spread adoption of urban analytics as general-purpose planning tools is the overwhelming variety of methods and indices (Yap et al., 2022). Whereas researchers may increasingly untangle specific urban form characteristics in relation to target metrics such as walkability (Cerin et al., 2022), these can be difficult to apply in general usage because small changes in dataset preparation (e.g. OSM queries), data pre-processing and classification (e.g. network cleaning), procedural methodologies, and computational toolsets can undermine the direct interpretability or comparability of findings across working contexts. As a result, two general approaches have emerged. Firstly, the generation of large scale "horizontal" or light-weight models where the same data and methodological processes are applied for comparative forms of analysis across large spatial extents, thereby facilitating consistency and comparability (Boeing, 2018; Yap and Biljecki, 2023), though this approach can be complicated by the reliance on OSM data which can vary in quality from location to location. Secondly, the more typical location specific "vertical" models based on contextually targeted analysis. While this latter approach is hard to scale and therefore not generalisable, it is more familiar to traditional forms of observational evidence and analysis.

The benefits of the lightweight modelling approach include the ability to model parameters and the automation of analytical workflows, though require a substantial degree of urban analytic skills more commensurate with specialised urban data science and geospatial analysis. Nevertheless, the outputs of these datasets can be used to develop bigger-picture forms of analysis comparing a variety of metrics across geographic locations and city-sizes, allowing for the extraction of statistics and models. The benefit of these forms of comparative analysis is that outliers and patterns can be deduced, which may then inform subsequent benchmarking and decision making. (The authors are exploring the potential relevancy of these methods for the analysis of EU high-density clusters, with findings to be published separately.)

5.3 Methods and Toolsets

A barrier to wider adoption of quantitative methods is the use of geospatial data and related concepts which are not typically taught to students of architecture and urban design programmes. This includes concepts and methods such as Coordinate Reference Systems (e.g. geographic, projected, EPSG codes), geospatial data formats (e.g. Shapefile, Geopackage), geospatial databases for handling large datasets (e.g. Postgres & PostGIS), GIS platforms (e.g. QGIS), geometric data types (e.g. Points, Linestrings, Polygons, rasters), and related spatial operations (e.g. buffer, union, difference). Further, even where these methods are conveyed to scholars, approaches such as network analysis and methods for computing landuse accessibilities require access to specialised plugins or programming packages, presenting a further technical barrier to adoption.

The most accessible tools are those packaged as plugins to GIS interfaces (Hugentobler, 2017), such as the Space Syntax Toolkit (Gil et al., 2015) and the Place Syntax Tool (Stahle et al., 2023). These may still require some oversight and initial instruction on usage, as well as familiarity with the concepts underpinning the forms of analysis, but do not otherwise require direct knowledge of programming. Whereas standalone software packages have also been developed, such as DepthmapX (Turner et al., 2020), a growing assortment of programming packages have also emerged. These vary greatly in terms of their emphasis but also present overlap, even if underlying technicalities may differ. Due to being based on the open-source software ecosystem, the underlying data formats and workflows build on similar underlying packages such as networkX (Hagberg et al., 2008) and Geopandas (Jordahl et al., 2020) with the implication that urban analytics toolsets can often be used in combination. Notable examples include, OSMnx (Boeing, 2017), which places emphasis on the retrieval of OSM data and downstream analytics; Momepy (Fleischmann, 2019), which emphasises built form and morphological indicators, and Cityseer (Simons, 2023), which emphasises workflows for street-level high-resolution network centralities, landuse accessibilities, and statistical aggregations. Whereas these packages and the Python geospatial software ecosystem may seem highly technical to non-programmers, online documentation and the emergence of AI tools are accelerating learning and development, making these toolsets increasingly accessible to a wider audience.

6 CONCLUSION

Evidence-Based Design and Planning (EBDP) represents a transformative approach towards urban design and planning, integrating evidence of varied forms into design and planning decision making processes. This shift, propelled by improved access to data and spatial analytical tools, emphasizes the importance of informed decision-making to create sustainable, liveable, and resilient urban environments. EBDP has been variedly described since its inception, and continues to evolve, leveraging an increasingly diverse array of analytical tools, data sources, and design methodologies to address contemporary challenges. EBDP's emphasis on iterative learning, evidence integration, and adaptability highlights its potential to underpin change in design and policy contexts.

The broad developments encapsulated by EBDP can be seen to bolster and further leverage the utility of existing Space Syntax approaches. Whereas Space Syntax has been at the forefront of evidence generation through iterative and comparative measurement-based approaches, it stands to benefit from the rapidly expanding scientific evidence base clarifying the relationship between urban morphology and health, sustainability, and quality of life. The emergence of these forms of evidence provides strong support for the use of analytic methods, such as Space Syntax, in the design process. Access to emerging data sources, computational toolsets, and modelling methods offers further benefits and extensibility, though continue to present some challenges in the form of data access and quality, the variety and complexity of methods, and the enduring importance of education in the use and interpretation of these methods.

The adoption of EBDP currently continues to be challenging outside of academia due to conceptual complexity and reliance on Geographic Information Systems (GIS) and computational knowledge, which are beyond the traditional purview of design and planning education. AI may lower the barrier to entry but introduces a risk that practitioners might use these forms of increasingly accessible tools without sufficiently understanding their nuances. Similarly, the trend-cycles of buzz-words – Smart Cities, The Internet of Things, Machine Learning and Artificial Intelligence, Digital Twins – may be misapplied to mask newly reductionist interpretations of cities in the guise of urban analytics, much as was the case for modernism, even if the underlying technologies may be useful when applied judiciously (Sterling, 2014; Townsend, 2013).

7 ACKNOWLEDGEMENT

This paper is a part of TWIN2EXPAND project. This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101078890.

This project has received funding from the UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee under grant numbers 10052856 and 10050784.

REFERENCES

Acharya, A., Karimi, K., Parham, E., Guven, A., Uyar, G., 2017. City planning using integrated urban modeling Jeddah structure plan, in: Proceedings-11th International Space Syntax Symposium, SSS 2017. Instituto Superior Técnico, Portugal, p. 37.1-37.21.

Alexander, C., 2012. "A City is Not a Tree": from Architectural Forum (1965), in: The Urban Design Reader. Routledge.

Arcaute, E., Molinero, C., Hatna, E., Murcio, R., Vargas-Ruiz, C., Masucci, A.P., Batty, M., 2016. Cities and regions in Britain through hierarchical percolation. R. Soc. Open Sci. 3, 150691. https://doi.org/10.1098/rsos.150691

Atkinson, Richard.W., Butland, Barbara.K., Anderson, H.Ross., Maynard, Robert.L., 2018. Long-term Concentrations of Nitrogen Dioxide and Mortality: A Meta-analysis of Cohort Studies. Epidemiology 29, 460–472. https://doi.org/10.1097/EDE.0000000000000847

Batty, M., Longley, P.A., 1994. Fractal cities: a geometry of form and function. Academic press.

Batty, M., Marshall, S., 2017. Thinking organic, acting civic: The paradox of planning for Cities in Evolution. Landsc. Urban Plan. 166, 4–14. https://doi.org/10.1016/j.landurbplan.2016.06.002

Batty, Michael., 2013. The New Science of Cities. MIT Press, Cambridge, MA.

Berghauser Pont, M., Haupt, P., Berg, P., Alstäde, V., Heyman, A., 2021. Systematic review and comparison of densification effects and planning motivations. Build. Cities 2, 378. https://doi.org/10.5334/bc.125

Boeing, G., 2018. A multi-scale analysis of 27,000 urban street networks: Every US city, town, urbanized area, and Zillow neighborhood. Environ. Plan. B Urban Anal. City Sci. 2399808318784595. https://doi.org/10.1177/2399808318784595

Boeing, G., 2017. OSMnx: New methods for acquiring, constructing, analyzing, and visualizing complex street networks. Comput. Environ. Urban Syst. 65, 126–139. https://doi.org/10.1016/j.compenvurbsys.2017.05.004

Boeing, G., Higgs, C., Liu, S., Giles-Corti, B., Sallis, J.F., Cerin, E., Lowe, M., Adlakha, D., Hinckson, E., Moudon, A.V., Salvo, D., Adams, M.A., Barrozo, L.V., Bozovic, T., Delclòs-Alió, X., Dygrýn, J., Ferguson, S., Gebel, K., Ho, T.P., Lai, P.-C., Martori, J.C., Nitvimol, K., Queralt, A., Roberts, J.D., Sambo, G.H., Schipperijn, J., Vale, D., Van De Weghe, N., Vich, G., Arundel, J., 2022. Using open data and open-source software to develop spatial indicators of urban design and transport features for achieving healthy and sustainable cities. Lancet Glob. Health 10, e907–e918. https://doi.org/10.1016/S2214-109X(22)00072-9

Bolton, T., Francis, N., Froy, F., 2017. The Impact of Space Syntax on Urban Policy Making: Linking research into UK policy.

Brand, C., Dons, E., Anaya-Boig, E., Avila-Palencia, I., Clark, A., De Nazelle, A., Gascon, M., Gaupp-Berghausen, M., Gerike, R., Götschi, T., Iacorossi, F., Kahlmeier, S., Laeremans, M., Nieuwenhuijsen, M.J., Pablo Orjuela, J., Racioppi, F., Raser, E., Rojas-Rueda, D., Standaert, A., Stigell, E., Sulikova, S., Wegener, S., Int Panis, L., 2021. The climate change mitigation effects of daily active travel in cities. Transp. Res. Part Transp. Environ. 93, 102764. https://doi.org/10.1016/j.trd.2021.102764

Bratman, G.N., Anderson, C.B., Berman, M.G., Cochran, B., De Vries, S., Flanders, J., Folke, C., Frumkin, H., Gross, J.J., Hartig, T., Kahn, P.H., Kuo, M., Lawler, J.J., Levin, P.S., Lindahl, T., Meyer-Lindenberg, A., Mitchell, R., Ouyang, Z., Roe, J., Scarlett, L., Smith, J.R., Van Den Bosch, M., Wheeler, B.W., White, M.P., Zheng, H., Daily, G.C., 2019. Nature and mental health: An ecosystem service perspective. Sci. Adv. 5, eaax0903. https://doi.org/10.1126/sciadv.aax0903

Carmona, M., 2014. The Place-shaping Continuum: A Theory of Urban Design Process. J. Urban Des. 19, 2–36. https://doi.org/10.1080/13574809.2013.854695

Cerin, E., Sallis, J.F., Salvo, D., Hinckson, E., Conway, T.L., Owen, N., Van Dyck, D., Lowe, M., Higgs, C., Moudon, A.V., Adams, M.A., Cain, K.L., Christiansen, L.B., Davey, R., Dygrýn, J., Frank, L.D., Reis, R., Sarmiento, O.L., Adlakha, D., Boeing, G., Liu, S., Giles-Corti, B., 2022. Determining thresholds for spatial urban design and transport features that support walking to create healthy and sustainable cities: findings from the IPEN Adult study. Lancet Glob. Health 10, e895–e906. https://doi.org/10.1016/S2214-109X(22)00068-7

Cimburova, Z., Berghauser Pont, M., 2021. Location matters. A systematic review of spatial contextual factors mediating ecosystem services of urban trees. Ecosyst. Serv. 50, 101296. https://doi.org/10.1016/j.ecoser.2021.101296

Clarence, E., 2002. Technocracy Reinvented: The New Evidence Based Policy Movement. Public Policy Adm. 17, 1–11. https://doi.org/10.1177/095207670201700301

Corbusier, L., 1967. The Radiant City: Elements of a Doctrine of Urbanism to be Used as the Basis of Our Machine-age Civilization. Orion Press, New York.

David S. Jordan, J., 2023. Applied Geospatial Data Science With Python: Take Control of Implementing, Analyzing, and Visualizing Geospatial and Spatial Data With Geopandas and More. Packt Publishing.

Davoudi, S., 2012. The Legacy of Positivism and the Emergence of Interpretive Tradition in Spatial Planning. Reg. Stud. 46, 429–441. https://doi.org/10.1080/00343404.2011.618120

Davoudi, S., 2006. Evidence-Based Planning: Rhetoric and Reality. DISP 42, 14–24. https://doi.org/10.1080/02513625.2006.10556951

Demystifying compact urban growth: Evidence from 300 studies from across the world (OECD Regional Development Working Papers No. 2018/03), 2018. , OECD Regional Development Working Papers. https://doi.org/10.1787/bbea8b78-en

European Commission, Directorate-General for Regional and Urban Policy, 1999. ESDP – European Spatial Development Perspective: Towards balanced and sustainable development of the territory of the European Union. Publications Office.

Faludi, A., Waterhout, B., 2006. Introducing Evidence-Based Planning. DISP 42, 4–13. https://doi.org/10.1080/02513625.2006.10556950

Fleischmann, M., 2019. momepy: Urban Morphology Measuring Toolkit. J. Open Source Softw. 4, 1807. https://doi.org/10.21105/joss.01807

Foz, A.T.-K., 1972. Some observations on designer behavior in the parti. (Thesis). Massachusetts Institute of Technology.

Frank, L.D., Schmid, T.L., Sallis, J.F., Chapman, J., Saelens, B.E., 2005. Linking objectively measured physical activity with objectively measured urban form. Am. J. Prev. Med. 28, 117–125. https://doi.org/10.1016/j.amepre.2004.11.001

Gascon, M., Triguero-Mas, M., Martínez, D., Dadvand, P., Rojas-Rueda, D., Plasència, A., Nieuwenhuijsen, M.J., 2016. Residential green spaces and mortality: A systematic review. Environ. Int. 86, 60–67. https://doi.org/10.1016/j.envint.2015.10.013

Gehl, J., 2010. Cities for people. Island Press, Washington, DC.

Gil, J., Varoudis, T., Karimi, K., Penn, A., 2015. The space syntax toolkit: Integrating depthmapX and exploratory spatial analysis workflows in QGIS, in: Proceedings of the 10th International Space Syntax Symposium.

Guo, Y., Gasparrini, A., Armstrong, B., Li, S., Tawatsupa, B., Tobias, A., Lavigne, E., De Sousa Zanotti Stagliorio Coelho, M., Leone, M., Pan, X., Tong, S., Tian, L., Kim, H., Hashizume, M., Honda, Y., Guo, Y.-L.L., Wu, C.-F., Punnasiri, K., Yi, S.-M., Michelozzi, P., Saldiva, P.H.N., Williams, G., 2014. Global Variation in the Effects of Ambient Temperature on Mortality: A Systematic Evaluation. Epidemiology 25, 781–789. https://doi.org/10.1097/EDE.0000000000000165

Hagberg, A.A., Schult, D.A., Swart, P.J., 2008. Exploring Network Structure, Dynamics, and Function using NetworkX, in: Varoquaux, G., Vaught, T., Millman, J. (Eds.), Proceedings of the 7th Python in Science Conference. Pasadena, CA USA, pp. 11–15.

Hillier, B., Hanson, J., 1984. The Social Logic of Space. Cambridge University Press, Cambridge.

Højriis, J., Tengbjerg Herrmann, I., Nielsen, P.S., Bulkeley, P., 2014. A Comparative Study of Contextual Urban Design Approaches in the UK and DK, in: Proceedings of the 3rd International Workshop on Design in Civil and Environmental Engineering. Presented at the Third International Workshop on Design in Civil and Environmental Engineering, Mary Kathryn Thompson, pp. 37–46.

Hugentobler, M., 2017. Quantum GIS, in: Shekhar, S., Xiong, H., Zhou, X. (Eds.), Encyclopedia of GIS. Springer International Publishing, Cham, pp. 1707–1712. https://doi.org/10.1007/978-3-319-17885-1_1064

Jacobs, J., 2011. The Death and Life of Great American Cities.

Jones, R.E., 1970. Decision-Making. Polit. Stud. 18, 121–125. https://doi.org/10.1111/j.1467-9248.1970.tb00661.x

Jordahl, K., Bossche, J.V. den, Fleischmann, M., Wasserman, J., McBride, J., Gerard, J., Tratner, J., Perry, M., Badaracco, A.G., Farmer, C., Hjelle, G.A., Snow, A.D., Cochran, M., Gillies, S., Culbertson, L., Bartos, M., Eubank, N., maxalbert, Bilogur, A., Rey, S., Ren, C., Arribas-Bel, D., Wasser, L., Wolf, L.J., Journois, M., Wilson, J., Greenhall, A., Holdgraf, C., Filipe, Leblanc, F., 2020. geopandas/geopandas: v0.8.1. https://doi.org/10.5281/zenodo.3946761

Karimi, K., 2023. The Configurational Structures of Social Spaces: Space Syntax and Urban Morphology in the Context of Analytical, Evidence-Based Design. Land 12. https://doi.org/10.3390/land12112084

Karimi, K., 2018. Space syntax: consolidation and transformation of an urban research field. J. Urban Des. 23, 1–4. https://doi.org/10.1080/13574809.2018.1403177

Karimi, K., 2012. A configurational approach to analytical urban design: 'Space syntax' methodology. URBAN Des. Int. 17, 297–318. https://doi.org/10.1057/udi.2012.19

Korobkin, B.J., 1976. Images for Design: Communicating Social Science Research to Architects. Architecture Research Office, Harvard University.

Macionis, J.J., Parrillo, V.N., 2001. Cities and urban life / John J. Macionis, Vincent N. Parrillo., 2nd ed. ed. Prentice Hall, Upper Saddle River, N.J.

Madanipour, A., Cars, G., Allen, J., Riseborough, M., 2000. Social exclusion in European cities. Local Gov. Stud. 26, 140–141.

Marselle, M.R., Bowler, D.E., Watzema, J., Eichenberg, D., Kirsten, T., Bonn, A., 2020. Urban street tree biodiversity and antidepressant prescriptions. Sci. Rep. 10, 22445. https://doi.org/10.1038/s41598-020-79924-5

Marshall, S., 2012. Science, pseudo-science and urban design. URBAN Des. Int. 17, 257–271. https://doi.org/10.1057/udi.2012.22

Mueller, N., Rojas-Rueda, D., Khreis, H., Cirach, M., Andrés, D., Ballester, J., Bartoll, X., Daher, C., Deluca, A., Echave, C., Milà, C., Márquez, S., Palou, J., Pérez, K., Tonne, C., Stevenson, M., Rueda, S., Nieuwenhuijsen, M., 2020. Changing the urban design of cities for health: The superblock model. Environ. Int. 134, 105132. https://doi.org/10.1016/j.envint.2019.105132

OpenStreetMap contributors, 2017. Planet dump retrieved from https://planet.osm.org.

Pataki, D.E., Alberti, M., Cadenasso, M.L., Felson, A.J., McDonnell, M.J., Pincetl, S., Pouyat, R.V., Setälä, H., Whitlow, T.H., 2021. The Benefits and Limits of Urban Tree Planting for Environmental and Human Health. Front. Ecol. Evol. 9, 603757. https://doi.org/10.3389/fevo.2021.603757

Peavey, E., Vander Wyst, K.B., 2017. Evidence-Based Design and Research-Informed Design: What's the Difference? Conceptual Definitions and Comparative Analysis. HERD Health Environ. Res. Des. J. 10, 143–156. https://doi.org/10.1177/1937586717697683

Raford, N., 2010. Social and technical challenges to the adoption of space syntax methodologies as a planning support system (PSS) in American urban design. J. Space Syntax 1, 230–245.

Rogers, E.M., 2003. Diffusion of innovations / Everett M. Rogers., Fifth edition. ed. Free Press, New York.

Rogers, R.George., 1999. Towards an urban renaissance : final report of the Urban Task Force. Spon], London.

Saelens, B.E., Sallis, J.F., Frank, L.D., 2003. Environmental correlates of walking and cycling: Findings from the transportation, urban design, and planning literatures. Ann. Behav. Med. 25, 80–91. https://doi.org/10.1207/S15324796ABM2502_03

Sailer, K., Pomeroy, R., Haslem, R., 2015. Data-driven design — Using data on human behaviour and spatial configuration to inform better workplace design.

Sallis, J.F., Cerin, E., Kerr, J., Adams, M.A., Sugiyama, T., Christiansen, L.B., Schipperijn, J., Davey, R., Salvo, D., Frank, L.D., De Bourdeaudhuij, I., Owen, N., 2020. Built Environment, Physical Activity, and Obesity: Findings from the International Physical Activity and Environment Network (IPEN) Adult Study. Annu. Rev. Public Health 41, 119–139. https://doi.org/10.1146/annurev-publhealth-040218-043657

Schiavina, M., Freire, S., MacManus, K., 2023a. GHS-POP R2023A - GHS population grid multitemporal (1975-2030). https://doi.org/10.2905/2FF68A52-5B5B-4A22-8F40-C41DA8332CFE

Schiavina, M., Melchiorri, M., Pesaresi, M., 2023b. GHS-SMOD R2023A - GHS settlement layers, application of the Degree of Urbanisation methodology (stage I) to GHS-POP R2023A and GHS-BUILT-S R2023A, multitemporal (1975-2030). https://doi.org/10.2905/A0DF7A6F-49DE-46EA-9BDE-563437A6E2BA

Schwaab, J., Meier, R., Mussetti, G., Seneviratne, S., Bürgi, C., Davin, E.L., 2021. The role of urban trees in reducing land surface temperatures in European cities. Nat. Commun. 12, 6763. https://doi.org/10.1038/s41467-021-26768-w

Sevilla-Buitrago, Á., 2022. Against the Commons: A Radical History of Urban Planning. University of Minnesota Press.

Simons, G., 2023. The cityseer Python package for pedestrian-scale network-based urban analysis. Environ. Plan. B Urban Anal. City Sci. 50, 1328–1344. https://doi.org/10.1177/23998083221133827

Stahle, A., Marcus, L., Koch, D., Fitger, M., Legeby, A., Stavroulaki, G., Berghauser, P., Karlstrom, A., Miranda Carranza, P., Nordstrom, T., 2023. Place Syntax Tool: PST Documentation.

Sterling, B., 2014. The Epic Struggle of the Internet of Things. Strelka Institute for Media, Architecture and Design.

The economic benefits of sustainable streets, n.d.

Thompson, C.A., Saxberg, K., Lega, J., Tong, D., Brown, H.E., 2019. A cumulative gravity model for inter-urban spatial interaction at different scales. J. Transp. Geogr. 79, 102461. https://doi.org/10.1016/j.jtrangeo.2019.102461

Townsend, A.M., 2013. Smart Cities: Big Data, Civic Hackers, and the Quest for a New Utopia. W. W. Norton & Company, New York.

Turner, A., Friedrich, E., Varoudis, T., Sailer, C., Koutsolampros, P., 2020. depthmapX.

van Nes, A., Yamu, C., 2020. Exploring Challenges in Space Syntax Theory Building: The Use of Positivist and Hermeneutic Explanatory Models. Sustainability 12. https://doi.org/10.3390/su12177133

Volker, J.M.B., Handy, S., 2021. Economic impacts on local businesses of investments in bicycle and pedestrian infrastructure: a review of the evidence. Transp. Rev. 41, 401–431. https://doi.org/10.1080/01441647.2021.1912849

Walking & cycling: the economic benefits, n.d.

Wang, C., Wang, Z., Yang, J., 2018. Cooling Effect of Urban Trees on the Built Environment of Contiguous United States. Earths Future 6, 1066–1081. https://doi.org/10.1029/2018EF000891

Whyte, W.H., 1980. The Social Life of Small Urban Spaces. Conservation Foundation.

Winkler, L., Pearce, D., Nelson, J., Babacan, O., 2023. The effect of sustainable mobility transition policies on cumulative urban transport emissions and energy demand. Nat. Commun. 14, 2357. https://doi.org/10.1038/s41467-023-37728-x

Woodcock, J., Franco, O.H., Orsini, N., Roberts, I., 2011. Non-vigorous physical activity and all-cause mortality: systematic review and meta-analysis of cohort studies. Int. J. Epidemiol. 40, 121–138. https://doi.org/10.1093/ije/dyq104

Yap, W., Biljecki, F., 2023. A Global Feature-Rich Network Dataset of Cities and Dashboard for Comprehensive Urban Analyses. Sci. Data 10, 667. https://doi.org/10.1038/s41597-023-02578-1

Yap, W., Janssen, P., Biljecki, F., 2022. Free and open source urbanism: Software for urban planning practice. Comput. Environ. Urban Syst. 96, 101825. https://doi.org/10.1016/j.compenvurbsys.2022.101825

Zeisel, J., 1984. Inquiry by design: Tools for environment-behaviour research. CUP archive.

Zeisel, J., 1975. Sociology and architectural design.