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From associations to action: Parametric urban design science for cardiometabolic health

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ABSTRACT

The built environment influences cardiometabolic health by impacting human behaviours and environmental exposures. However, the current focus on identifying associations between static built environment measures and cardiometabolic health outcomes has limited practical relevance for urban design. Current approaches fail to capture the spatial complexity of urban environments or provide actionable guidance for urban design. In this paper, we discuss how parametric urban design science can offer a paradigm shift in the ability to link the built environment with cardiometabolic health research. It can break down fixed built environment measures into spatially specific parameters and account for interdependencies among built environment measures. This shift moves beyond only investigating correlations and can generate evidence directly relevant to urban design practice. This paper identifies parametric urban design science advantages and outlines future steps for its application in research on the built environment and cardiometabolic health.

1. Introduction

Cardiometabolic diseases, including type 2 diabetes, cardiovascular diseases, and obesity, are leading contributors to the global burden of disease (Eroglu et al., 2024; Mensah et al., 2023). They have significant social and economic costs on individuals, communities, and healthcare systems. For example, cardiovascular diseases alone account for approximately one-third of all global deaths annually (Lindstrom et al., 2022). These cardiometabolic conditions are influenced not only by individual behaviours like physical activity and diet but also by the environments in which people live (Rajagopalan et al., 2024b). Urban design features—such as public open spaces, residential density, mixed land use, and street connectivity—play a role in shaping cardiometabolic health by influencing behaviours and environmental exposures (Koohsari et al., 2020). Several studies have explored associations between various built environment measures and cardiometabolic health (Den Braver et al., 2018; Liu et al., 2023). For instance, a systematic review and meta-analysis found that higher neighbourhood walkability and better access to green spaces were associated with a reduced risk of type 2 diabetes (Den Braver et al., 2018). However, despite growing interest in this field, several limitations in this research area hinder its practical implementation in real urban environments.

The first limitation is that most studies rely on associations between static built environment measures and cardiometabolic health. For example, a researcher may examine how the number of parks within one mile of home is related to the likelihood of someone having heart disease. Static built environment measures refer to fixed quantities, such as the total number of public open spaces or the average residential density within a given area. These measures often fail to account for the underlying spatial configurations or arrangements. Each spatial configuration may distinctly influence behaviours, such as physical activity and stress, which serve as pathways linking the built environment to cardiometabolic health (Koohsari et al., 2020; Sarkar and Lai, 2023). For instance, although the availability of proximal destinations may be associated with better cardiometabolic health (Malambo et al., 2018; Seo et al., 2019), whether these benefits arise from concentrated clusters of destinations or their even distribution across a neighbourhood remains unclear. Investigating associations between static built environment measures and cardiometabolic health provides preliminary

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insights into 'what works', but fails to explain how to translate such findings into actionable urban design solutions. Static measures do not account for the diverse ways built environment features can be implemented and configured, each of which may influence cardiometabolic health differently.

Identifying 'thresholds' for these static built environment measures can be introduced as a step toward connecting research findings to urban design practice (Koohsari et al., 2013), but these are also limited. One study used non-linear regression models to identify minimum thresholds for urban design attributes, such as population density exceeding 5700 people per km^2, associated with meeting physical activity criteria through walking (Cerin et al., 2022). However, these thresholds reflect static measures that fail to account for the spatial diversity and complexity of real-world urban contexts. In the example of density, Talen and Wileden (2024) argue that such measures are inherently complex, and their spatial outcomes depend heavily on contextual factors such as scale, land use, and regional structure. As a result, such thresholds cannot offer guidance on how these should be spatially arranged in practice.

A second limitation is using an isolated approach to analyse built environment measures in relation to cardiometabolic health. Research often examines individual measures, such as the availability of public open spaces, destinations, residential density, or street connectivity, without accounting for their interactions (Koohsari et al., 2020). In reality, these measures are interconnected, and changes to one measure can influence others. For example, as physical space within a neighbourhood is finite, devoting more space to public open spaces may reduce the area available for commercial purposes. Therefore, findings that independently suggest increasing public open spaces or availability of shops for improved cardiometabolic health may lead to conflicting implications for urban design in practice. This lack of integration and consideration for interdependencies prevents the development of science-based evidence for urban design practice.

Addressing these gaps requires a paradigm shift in how built environment features are conceptualised, measured, and analysed to support cardiometabolic health. In the remainder of this paper we discuss how parametric urban design—a distinctive approach in urban design science—can contribute to tackling these challenges.

2. What is parametric urban design?

Parametric urban design extends parametricism to urban morphology using parametrically defined coordinates (instead of fixed geometries) to specify relations between streets, blocks, and buildings (Mehaffy, 2011; Schumacher, 2009). By encoding relationships between these elements as adjustable parameters, parametric urban design generates coherent urban forms that respond flexibly to site-specific constraints and diverse spatial requirements (Çalışkan, 2017; Çalışkan et al., 2024). For instance, a street layout is usually designed with fixed dimensions, and any changes require redesigning the layout. Parametric urban design creates that street layout by setting parameters such as road width and intersection spacing. This street layout can be automatically updated by changing these parameters. This parametric modelling supports urban design to integrate contextual constraints and spatial requirements and creates solutions suited to site-specific needs (Mehaffy, 2011; Talmor Blaistain and Fisher-Gewirtzman, 2025).

3. How parametric urban design bridges the gaps

Parametric urban design science can address the two aforementioned gaps in the literature on the built environment and cardiometabolic health. First, parametric urban design can deal with the challenge of operationalising fixed built environment measures into actionable urban design solutions. While fixed metrics such as residential density or public open space coverage are commonly used in research, they do not have the spatial specificity needed for urban design interventions. For example, a study might find that a 20 % increase in residential density is associated with lower obesity. Such findings, though valuable, do not clarify how this density increase should be achieved spatially within a real neighbourhood. Fixed measures, like residential density, can result in entirely different spatial configurations. Increasing density by 20 % could be achieved by evenly distributing additional units across a neighbourhood, clustering them into medium-density buildings, or concentrating them in a single high-rise tower within a centralised hub (Fig. 1). These configurations can influence human behaviours, environmental exposures, and cardiometabolic health outcomes in different ways. For example, a distributed increase in residential density can raise destination access which is associated with higher physical activity (Kärmeniemi et al., 2018). By contrast, concentrating new residential units into a single high-rise tower can centralise facilities and amenities. However, it may increase near-road traffic noise and air pollution exposure around the hub, which is associated with cardiometabolic risk (Münzel et al., 2025; Rajagopalan et al., 2024a). This variability in spatial configurations allows designers to interpret built environment measures in ways that are not necessarily supportive of pedestrian-oriented, human-scaled environments. Perhaps a 60-m-high tower in a residential neighbourhood with an average building height of three stories could be proposed, justified on the basis of studies suggesting higher density benefits cardiometabolic health. This lack of specificity in fixed measures may partly explain the inconsistent and mixed findings in research linking these built environment measures to cardiometabolic health (Lai et al., 2023; Lam et al., 2021).

Parametric urban design science overcomes this limitation by breaking fixed built environment measures into governing parameters that define how these measures are spatially arranged. Thus, in the above example of residential density, key parameters such as building height, spacing between buildings, clustering, and proximity to public open spaces determine how density is configured across a neighbourhood. This step alone, however, does not entirely eliminate the challenge of variability, as different spatial configurations of these parameters may still result. The value of parametric urban design is that it does not only provide evidence on a parameter like building height and its relationship with cardiometabolic health, it translates the built environment into spatially defined parameters and quantifies them. Parametric urban design can measure the existing distribution of building heights across a neighbourhood and represent them computationally. Researchers can then investigate how specific configurations, such as clustering or even distribution of building heights, influence cardiometabolic health. This approach reduces the ambiguity inherent in fixed built environment measures and delivers actionable evidence for urban design practice.

Second, parametric urban design science addresses the isolated approach to analysing built environment features by considering their interdependencies. The built environment operates as a system of interconnected measures, and changes to one measure can influence others. Traditional statistical models adjust for these measures independently but cannot reflect the trade-offs inherent in the built environment. Fig. 2 illustrates how increasing residential density in a neighbourhood can create interrelated impacts. Scenario (a) represents the current status of the neighbourhood. In scenario (b), increasing residential density through mid-rise and high-rise buildings leads to major changes. In scenario (b), street connectivity typically increases as additional links and shorter blocks are introduced. Higher street connectivity is associated with more walking and cycling (Mohammad et al., 2021). However, the same configuration can reduce the amount of public open spaces and decrease per capita access to these spaces. Higher public open space access is associated with better cardiometabolic profile including lower risks of obesity, hypertension, and cardiovascular disease (Bu et al., 2024; Lai et al., 2023). These interconnected changes demonstrate how modifications to one parameter can have cascading effects on multiple aspects of the built environment and cardiometabolic health.

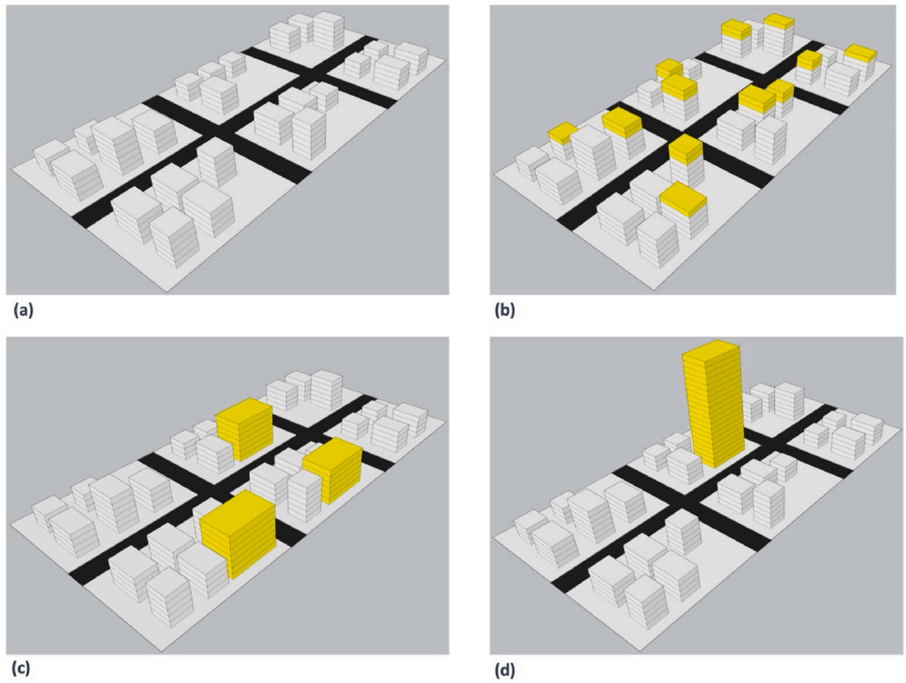

Fig. 1. Substantially different spatial scenarios representing a 20 % increase in residential density: (a) Baseline scenario, (b) Evenly distributed density increase, (c) Clustered medium-density scenario, (d) Centralised high-density tower.

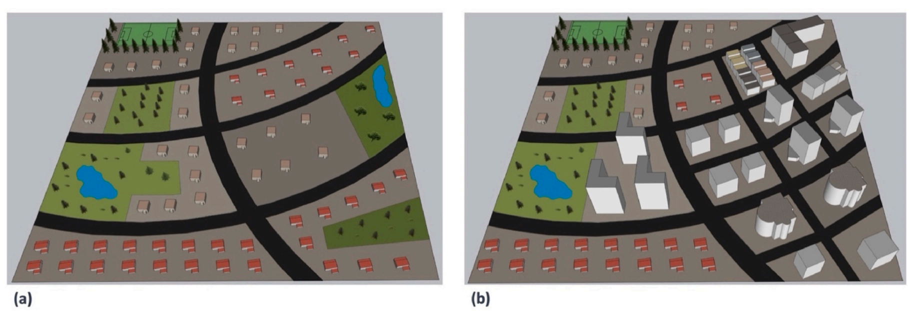

Fig. 2. Hypothetical impact of increased residential density on public open spaces and street connectivity: (a) Current neighbourhood, (b) Increased residential density with reduced public open spaces and enhanced street connectivity.

Parametric urban design science overcomes this limitation by encoding these interdependencies into algorithmic models, where built environment features are expressed through a set of parameters to reflect their interconnected nature. For example, the interdependencies in Fig. 2 can be represented through parameters such as:

$$BE_{impact} = f\,(H, S, C, GS, SI)$$

- H: building height (e.g., average number of floors),
- S: spacing between buildings (e.g., average distance between structures),
- C: clustering (e.g., distribution of buildings near transit nodes or amenities),
- GS: green space parameters (e.g., size, distribution, or accessibility of public open spaces),
- SI: intersection spacing (e.g., average distance between intersections or street nodes).

The modelling operator *f* denotes a simulation model, such as a digital twin, an agent-based framework, or a geospatial artificial intelligence (GeoAI) model with latent parameters. This moves beyond a simple additive index and represents interdependencies and trade-offs. Implementation of such a simulation model involves identifying inputs and parameters ranges from observed spatial data and calibrating it to urban big data (e.g., mobility and microclimate) (Janowicz et al., 2020). As a step further, future *f* can also integrate health outcomes as additional parameters. By integrating health into *f,* the interaction between the built environment and health can be modelled explicitly.

These parameters can be applied in cohort studies to investigate how specific configurations of the built environment influence cardiometabolic health outcomes. Researchers might analyse whether increasing building height (H) while preserving green space parameters (GS) mitigates the adverse effects of increased density on stress levels. Similarly, parametric modelling could evaluate how increasing street intersections (SI) while maintaining green space (GS) through rooftop gardens or distributed small parks might support cardiometabolic health. Parametric models can simulate such interrelated built environment parameters and represent the synergies that exist within the built environment.

4. Conclusion and next steps

Several studies have highlighted preliminary evidence regarding the associations between built environment measures—such as residential density, public open space availability, and street connectivity—and various cardiometabolic health outcomes (Rajagopalan et al., 2024b). However, the evidence remains abstract, is sometimes contradictory, and, in most cases, cannot be specifically translated into actionable, science-based urban design interventions. Even when current findings can be implemented in practical settings, these can result in radically different built environment forms depending on a designer's prerogative rather than science. Such spatial variations can have different impacts on behaviours, environmental factors, and related cardiometabolic health outcomes. Parametric urban design creates an opportunity to analyse relationships between the built environment and cardiometabolic health in a way that generates actionable and translatable evidence for urban design practice. A parametric approach moves beyond identifying associations to focus on operationalising urban design solutions that work in real-world contexts. Its outputs include scenario maps, parameter tables, built environment exposure surfaces, and trade-off summaries that support health-supportive urban design.

Despite its significant potential, several key issues must be resolved to advance this approach. Much of the research linking the built environment and cardiometabolic health has been conducted by clinicians, epidemiologists, and public health scholars. While their contributions are invaluable, their focus has traditionally been on health outcomes, which may limit the integration of urban design as a field. As a result, urban design is sometimes oversimplified and reduced to including a single built environment variable (such as residential density or walkability score) in cohort studies or statistical models. Urban design, however, requires specialised training and a comprehensive understanding of spatial configurations which can be informed by scientific principles (Koohsari et al., 2024). It is also a community-driven process that incorporates the opinions and desires of residents (Nisha and Nelson, 2012; Talen, 2015). Therefore, generating actionable urban design solutions requires diverse methods, such as parametric approaches, and engagement with community input. Effective progress in this area requires greater interdisciplinary collaboration, where clinicians, public health scholars, and urban designers work closely together. Additionally, in research on cardiometabolic and built environment, the main contribution of the parametric urban design approach is improved exposure assessment rather than testing associations. Evidence on ground-truth health outcomes for different spatial urban design arrangements and realisations remains limited. Future large cohort studies with sufficient geographic variability in health outcomes and neighbourhood structures are needed to test these associations empirically. Urban design changes are also constrained by funding and political agendas (Colenbrander and Barau, 2019), not solely by health concerns. Future studies should examine how parametrised spatial scenarios perform under these constraints for cardiometabolic risk prevention. Furthermore, parametric urban design requires computational resources and data infrastructure. Software tools like Grasshopper can be used to model parametric design (Ericson, 2017). Using these tools to integrate spatial data at neighbourhood scales with cardiometabolic outcomes requires collaboration with data and computer scientists to handle the complexities of advanced modelling tasks. GeoAI and machine learning advancements present new opportunities to refine parametric urban design (Gao et al., 2024). These technologies can optimise models, identify spatial patterns, and predict cardiometabolic outcomes of urban design interventions. As an example, parametric tools (e.g., Grasshopper) vary intersection density and block size to generate parametrised spatial scenarios. Agent-based or network analysis can estimate residents' walking minutes and route choices across these scenarios. Microclimate or digital-twin models quantify shade hours and near-surface air temperature for each configuration, and GeoAI can assess morphology and greenness from imagery. Various stakeholders can then use these models. Public health teams can link built environment exposure surfaces to cohort or administrative records to quantify risk. Urban designers can test spatial scenarios against budget and regulations and report trade-offs. Local authorities can use the visual outputs to communicate health-supportive built environment change options with communities. Nevertheless, as a parametric approach, several method-specific limitations remain. Results depend on data quality and parameter specification, and require local recalibration (Çalışkan and Barut, 2022). Model outputs are also estimates and need verification with observed behaviours and health outcomes. Furthermore, parametric design requires computational and modelling skills (Woodbury, 2010), which should be integrated into built environment and health curricula (Von Richthofen et al., 2018). Finally, a parametric approach does not establish causal effects of the built environment on health outcomes. It clarifies built environment exposures and pathways, which can support causal inference when combined with appropriate study designs (e.g., longitudinal cohorts, natural experiments).

In conclusion, parametric urban design science offers a framework to generate actionable and directly relevant evidence to support cardiometabolic health in urban design practice. However, while there are notable exemplars of parametric urban design, such as Kartal Pendik in Istanbul and Longgang City Center in Shenzhen (Lang, 2020), its application to modelling the relationship between the built environment and cardiometabolic health remains largely unexplored. Future empirical studies are necessary to investigate its advantages and disadvantages in context-specific applications.

CRediT authorship contribution statement

Mohammad Javad Koohsari: Conceptualization, Writing – original draft, Writing – review & editing. **Andrew T. Kaczynski:** Writing – review & editing. **Emily Talen:** Writing – review & editing. **Koichiro Oka:** Writing – review & editing.

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

No data was used for the research described in the article.

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