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The built environment and multidimensional poverty: exploring accessibility as a mediator of spatial opportunity

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ABSTRACT

While research has established links between the built environment and urban poverty, the mechanisms through which spatial opportunities influence multidimensional poverty remain poorly understood. This study examines how accessibility mediates the relationship between spatial opportunity and multidimensional poverty, while accounting for other built environment characteristics. Using household-level data, we applied structural equation modelling to analyse the complex pathways through which spatial opportunity affects poverty via accessibility, alongside considering the influence of density, design, distance to public transport, and diversity. The research reveals that accessibility plays a crucial mediating role, enabling spatial opportunities to translate into tangible reductions in multidimensional poverty. Specifically, while spatial opportunity alone may not guarantee poverty reduction, improvements in accessibility significantly enhance the potential positive impact of these opportunities. Furthermore, the study identifies distance to public transport as a factor positively associated with multidimensional poverty, and diversity exhibiting a negative association. The findings suggest that simply changing spatial opportunities may be insufficient for poverty reduction; accessibility plays a crucial mediating role that must be considered in urban interventions. The findings suggest that urban interventions aimed at poverty reduction should prioritise enhancing accessibility to existing and new spatial opportunities. This study advances our understanding of how built environment interventions can address urban poverty by highlighting the conditional importance of accessibility in shaping the relationship between spatial opportunities and poverty, and by underscoring the need for careful consideration of local context when designing urban interventions.

1. Introduction

The relationship between the urban built environment and socio-economic outcomes, particularly poverty, represents a critical challenge in contemporary urban development. Globally, eradicating poverty is a central Sustainable Development Goal (SDG), yet despite considerable efforts, this target remains elusive (United Nations General Assembly Res 70/1 2015; United Nations Habitat, 2022; United Nations General Assembly Economic and Social Council, 2023). Multidimensional poverty has shifted from rural to urban areas, leading to the "urbanisation of poverty" (United Nations Habitat, 2022). While numerous factors contribute to urban poverty, this paper focuses on the role of the built environment, arguing that its complex nature and inherent spatiality exert a significant influence.

A fundamental debate exists regarding whether and how physical environments influence social phenomena. Urban planning scholars argue that the built environment shapes socio-economic outcomes through complex mechanisms that affect human behaviour and opportunities (Næss, 2016; Yang & Zhang, 2025). This perspective aligns with critical realist philosophy, suggesting that the geographic distribution of built structures and their functions influences social aspects of human life. Conversely, mainstream sociological perspectives have traditionally questioned the capacity of physical elements to shape social phenomena (Dunlap & Catton Jr, 1983). This theoretical tension necessitates empirical investigation of the pathways through which built environment characteristics might influence poverty outcomes.

This paper aligns with the argument, advanced by Næss (2016), and grounded in critical realism, that the geographic distribution of built

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environment structures (e.g., buildings, transport networks) and the location of functions within these structures significantly influence social aspects of human life and behaviour. According to the ecological model of human development, the built environment can be seen as part of the macrosystem that plays a role in people's development, shaping their outcomes (Bronfenbrenner, 1994). From the literature on urban planning, we know that it is possible to transform society and influence human well-being through land use planning, urban development and designing the built environment's form and characteristics (Sanyal, 2018). Concepts such as spatial mismatch (Kain, 1968, 1992), accessibility and equity interaction van Wee (2022), and neighbourhood effects (Galster, 2012) further illustrate the influence of the built environment on human activity and socio-economic outcomes. Moreover, studies using remote sensing demonstrate that the physical characteristics of urban settlements often reflect the socio-economic conditions of their inhabitants (Arribas-Bel et al., 2017; Duque et al., 2015). While a growing body of literature examines the relationship between aspects of the built environment and various social phenomena, relatively few studies have focused on the built environment's features and poverty as a multidimensional construct.

We propose that two key components of the built environment are particularly crucial in understanding its relationship with multidimensional poverty. The first is accessibility, which refers to the ease with which people can reach various activities and destinations (Geurs & Van Wee, 2004; Hansen, 1959). The second is spatial opportunity, which encompasses the collection of opportunities available within a given area that influence residents' socio-economic outcomes. Note that the term is conceptualised variously such as the geography of opportunity (Galster & Killen, 1995), spatial opportunity structure (Galster & Sharkey, 2017), and opportunity in geography (Green, 2015). In this paper, we use the term spatial opportunity henceforth to refer to this collection of opportunities in space and align with Green (2015).

While accessibility and spatial opportunity offer a valuable framework for understanding the built environment's influence on poverty, current research faces several limitations that prevent a comprehensive understanding of this relationship. First, despite recognition that poverty is multidimensional, most studies examine its relationship with the built environment through singular dimensions (Liang et al., 2022). Second, built environment measures often focus on individual elements rather than considering multiple dimensions simultaneously (Zhu et al., 2022). Third, analytical approaches have typically employed univariate or simple multivariate analyses (Mepparambath et al., 2024; Næss, 2016), failing to capture the complex, simultaneous interactions between built environment components and poverty indicators.

This study addresses these gaps through two main contributions. First, we develop robust and comprehensive measures of both the built environment and multidimensional poverty. Second, we employ an exploratory structural equation modelling (SEM) framework to analyse the complex interplay between multiple built environment components and multidimensional poverty indicators, paying particular attention to accessibility's potential mediating role between spatial opportunity and poverty. This approach allows us to capture the simultaneous interactions expected within the built environment and their effects on poverty.

Our research seeks to answer the question: How does the built environment, as a complex system of interacting components, relate to multidimensional poverty? Specifically, we examine how different components of the built environment interact in this relationship. The findings contribute to both theoretical understanding and practical policy. Theoretically, we aim to advance knowledge about how components of the physical environment affect socio-economic phenomena, particularly through the mediating role of accessibility. Practically, we seek to provide evidence-based guidance for urban planning interventions, suggesting that effectively addressing multidimensional poverty may require interventions that consider and improve both accessibility and spatial opportunities concurrently.

The rest of the paper is arranged as follows: Section 2 reviews the literature to expound on the key constructs and research gaps. Section 3 presents the methodology, including the conceptual and analytical framework, focusing on the SEM method. Section 4 presents and discusses the results and limitations. Finally, Section 5 concludes with implications for theory and practice.

2. Literature review

2.1. Measures of poverty

The capability approach by Sen (1979, 1993; 1995) serves as a robust framework to conceptualise poverty as a multidimensional construct in the context of the built environment. In this approach, functionings are defined as "beings or doings" that people value, signifying a state of existence such as being healthy or participating in activities such as work or leisure. "Capabilities" are viewed as the opportunities to achieve these "functionings", that is, the spatial opportunity people have to do and achieve the things that they value (Sen, 1979, 1993, 1995). Based on this approach, a person is poor or deprived if they cannot achieve the "beings" or "doings" they value, which are multi-dimensional. Recent applications of this approach in urban contexts have demonstrated its utility in understanding the relationship between built environment characteristics and poverty or socio-economic outcomes (Cao & Hickman, 2019; Humberto et al., 2020).

2.2. Measures of the built environment

The built environment encompasses human-made physical features, including buildings and transport networks, and alterations of natural features (Cervero & Kockelman, 1997; Næss, 2016). Two key concepts are particularly relevant to understanding its relationship with poverty: accessibility and spatial opportunity structure.

Accessibility, defined by Hansen (1959) as "the potential of opportunities for interaction," represents the extent to which land use and transport systems enable people to reach and participate in desired activities (Geurs & Van Wee, 2004). This conception aligns with Sen's capability approach, suggesting that accessibility influences people's capabilities and functionings. Places with better accessibility tend to exhibit better socio-economic outcomes and less deprivation. In the accessibility framework, context factors and normative judgements influence the equity issues we observe (van Wee, 2022).

Geurs and Van Wee (2004) present one of the widely used reviews of accessibility measures, which identifies four perspectives: infrastructure-based, location (or place)-based, person-based, and utility-based. Each of these perspectives is driven by the purpose or background of the study and the context in which accessibility is being measured. Location-based measures have proven particularly valuable for built environment research, as they fit the description of the built environment, are easier to interpret in urban planning contexts, and capture both land use and transport components, including demand and supply effects (Geurs & Van Wee, 2004; Chen & Jia, 2019; Sundquist et al., 2021). Among location-based measures, the floating catchment area (FCA) approach has gained prominence due to its theoretical strength and interpretability. The three-step floating catchment area (3SFCA) method represents an advanced approach within this framework, addressing earlier limitations in demand estimation through additional adjustment steps (Chen et al., 2024; Chen & Jia, 2019; Wan et al., 2012).

The concept of spatial opportunity (Galster & Sharkey, 2017; Knaap, 2017) provides another crucial framework, defined as the geographically connected collective mix of artificial and natural systems affecting an individual's achieved status. While traditional spatial opportunity measures include social indicators (Knaap, 2017) that can confound analysis, Green's (2015) "opportunity in geography" approach focuses more appropriately on physical community assets. This approach better aligns with conceptualizing the built environment as a physical phenomenon distinct from social outcomes. However, one limitation of Green's approach is its reliance on institutional assets rather than a broader set of community assets.

2.3. The built environment and socio-economic outcomes

The review by Ewing and Cervero (2010) comprehensively examines how built environment components influence social phenomena. Their analysis reveals that built environment variables such as density, design, diversity, and accessibility to destinations significantly affect mobility and travel , which in turn influence liveability and public health. Their review identified important limitations in existing research, particularly regarding inadequate sample sizes and challenges in controlling for residential self-selection when estimating built environment effects on travel.

Multiple studies have shown that aspects of the built environment are associated with poverty or well-being (Benita, 2022; Collyer et al., 2022; Dendup et al., 2021; Jin et al., 2020 ; Liang et al., 2022; Marotzke et al., 2020; Turrell et al., 2013; Venerandi et al., 2018; Wang et al., 2023; Yang et al., 2021; Zhu et al., 2022). Recent empirical evidence further highlights the complexity of poverty dynamics and their relation to geographic and socio-economic conditions. Feng et al. (2024) illustrate how spatio-temporal changes in rurality significantly impact poverty governance, emphasising the importance of regional specificity in poverty alleviation policies. Berki et al. (2025) show how built and social environments together influence vertical social mobility outcomes among disadvantaged urban populations, underlining the intersecting roles of spatial and social factors.

However, most studies examine individual components of the built environment rather than using comprehensive measures within a single analytical framework. This fragmented approach presents both conceptual and analytical limitations, given the complex nature of the built environment and its interconnected elements and processes.

Methodologically, the literature has employed various approaches, from logistic regression to spatial forms of regression (Benita, 2022; Cooper et al., 2014; Marshall et al., 2014; Sarkar et al., 2013; Sarkar et al., 2015; Venerandi et al., 2018). Although these studies shed light on the association between some factors of the built environment and poverty, they often fall short in exploring the mechanisms through which multiple indicators interact to influence outcomes. The need for analytical approaches that account for complex mechanisms and causal paths is discussed in the literature (Galster & Sharkey, 2017; Næss, 2016), though primarily at a conceptual level requiring empirical examination (see, e.g., Qu et al., 2024).

Structural equation modelling (SEM), despite its strengths in analysing interaction mechanisms and causal pathways (Hair, Risher, Sarstedt, & Ringle, 2019), has seen limited application in built environment studies. Those studies that have employed SEM focused primarily on outcomes such as social capital, physical activity (Ling et al., 2024; Mepparambath et al., 2024), mental health and a sense of community (Guo et al., 2021; Kan et al., 2022), physical functioning (Brown et al., 2008), and loneliness (Fu et al., 2024). Multidimensional poverty as an outcome remains understudied in the SEM approach. It is worth pointing out that although structural equation models have strengths in path analysis and the simultaneous interaction of variables, they have challenges in making causal claims (Pearl, 2000). However, we view them as helpful in exploring the complex conceptualisation of built environment effects on poverty, revealing important paths that can inform causality analysis.

2.4. Research gaps

The literature review reveals several significant gaps in our understanding of the relationship between the built environment and multidimensional poverty. Measurement gaps emerge in both built environment and poverty assessment. Despite the theoretical and practical merits of location-based accessibility measures, their application in analysing built environment effects on multidimensional poverty remains limited. Similarly, spatial opportunity measures in the built environment context struggle with conceptual distinction from social constructs, while analysis often relies on higher-level units such as census tracts rather than household-level data.

Conceptual gaps are identified where some studies relied on unidimensional measures of the built environment and poverty. This simplified approach has limited our understanding of the complex relationship between the built environment and multidimensional poverty. Most studies have addressed only select aspects of the built environment's relationship with poverty or well-being, without considering the comprehensive paths and mechanisms through which they interact.

Analytical gaps persist in the methods used to examine these relationships. The literature shows limited application of statistical approaches that can capture the simultaneous interaction of multiple variables and analyse mediating relationships. While some studies have employed sophisticated statistical methods, few have attempted to integrate multiple built environment components and poverty dimensions within a single analytical framework.

This study addresses these gaps by examining the association between multiple built environment variables and multidimensional poverty at the household level. Our analysis focuses particularly on understanding the paths and mechanisms involved in the interaction between accessibility and spatial opportunity, providing valuable insights for urban planning policies aimed at addressing multidimensional poverty through built environment interventions.

3. Methodology

3.1. Data

Household social and economic data was obtained from the State of Our Cities Survey 2013; Gulyani et al., 2017). The World Bank microdata website[1] contains the dataset and technical reports about the survey. Our analysis is based on 756 households in the capital city of Kenya, Nairobi. Data on land use and schools were obtained from the Centre for Sustainable Urban Development[2] (CSUD). Public transport data was obtained from the Digital Matatus website.[3] The Kenya Roads Board[4] (KRB) provided the road network dataset. Data on health facilities was obtained from Snow et al. (2019) [5].

3.2. Study area

This study focused on Nairobi, the capital of Kenya. The city was selected due to several factors, including the level of economic and infrastructure development and the poverty dynamics (United Nations Habitat, 2022). The availability of spatial data to undertake the research was also considered.

3.3. Conceptual framework

Our conceptual framework builds on Sen's capability approach, viewing functionings as empirically measurable end states of poverty or deprivation (see, for instance, Sen, 1993, 1995 and Day et al., 2016). These include deprivation in education, health, economic status and standard of living (Alkire et al., 2015). Moreover, we conceptualise

[1] https://microdata.worldbank.org/index.php/catalog/2796.
[2] https://csud.climate.columbia.edu/content/gis-maps.
[3] http://digitalmatatus.com/.
[4] https://maps.krb.go.ke/kenya-roads-board12769/maps.
[5] https://doi.org/10.6084/m9.figshare.7725374.v1

capabilities as spatial opportunities and accessibility, which can be measured through built environment characteristics like land use and transport systems (Galster & Sharkey, 2017; Geurs & Van Wee, 2004; Green, 2015; Qu et al., 2024).

In this framework, poverty represents the deprivation of spatial opportunity and freedom to achieve valued functionings. The built environment represents this spatial opportunity structure through land use system indicators of diversity and density. Accessibility, involving transport system indicators, works together with the land use system and people's characteristics to determine their capabilities. This conceptualisation leads to our central hypothesis that accessibility mediates the built environment's effect on poverty and inequality. We posit that accessibility affects multiple poverty dimensions both jointly and individually, mediating how components of the built environment create, attenuate, increase or decrease multidimensional poverty.

Five conceptualised plausible pathways and mechanisms are explored in this paper: (1) Spatial opportunity influences poverty both directly and indirectly through accessibility's mediation; (2) Built environment characteristics affect different dimensions of urban poverty to varying degrees; (3) Accessibility's influence on poverty is strongest when linked to spatial opportunity; (4) Factors determining spatial opportunity also determine accessibility; and (5) Both spatial opportunity and accessibility affect poverty.

3.4. Analytical framework

We used the SEM analytical approach to explore these complex mechanisms and pathways. SEM offers several advantages in empirically investigating the conceptual framework and explaining the relationships of the constructs identified as poverty, spatial opportunity, and accessibility. It enables the simultaneous examination of complex mediation relationships among constructs (Hair, Risher, Sarstedt, & Ringle, 2019; Hair et al., 2021). It also enables the analysis of linear and non-linear relationships (Kock, 2010), exploratory theory development, and theory testing (Hair, Risher, Sarstedt, & Ringle, 2019). Key steps from model specification to model modification followed the literature (Hair et al., 2021). We applied SEM to explore theoretical frameworks related to the built environment and poverty (Galster, 2012; Galster & Sharkey, 2017; Naess, 2016), specifically examining direct and indirect relationships and mediation pathways. We hypothesised that accessibility mediates the influence of spatial opportunity on multidimensional poverty (Fig. 1).

(Adapted from Gunzler et al. (2013))

The SEM equation for the pathway given in Fig. 1 of the ith subject $(1 \le i \le n)$ can be expressed as:

$$Z_i = \beta_0 + \beta_{xz} X_i + \varepsilon_{zi}, \tag{1}$$

$$Y_i = \gamma_0 + \gamma_{zy} Z_i + \gamma_{xy} X_i + \varepsilon_{yi} \tag{2}$$

Where the error terms $\varepsilon_{zi}, \varepsilon_{yi}$ are assumed to be uncorrelated and they have multivariate normality. The structural equations are linked for simultaneous inference. The direct effect is denoted by γ_{xy} representing the pathway between the exogenous variable X_i to the outcome Y_i, while controlling for the mediator Z_i. The indirect effect is given by the product of β_{xz} and γ_{zy} describing the pathway of the exogenous variable to the outcome through the mediator. The total effect is given by, $\gamma_{xy} + \beta_{xz}\gamma_{zy}$ which sums up the direct and indirect effects of X_i on Y_i (Gunzler et al., 2013). Through this framework, we examined the hypothesis that spatial opportunity and accessibility are key forces influencing multidimensional poverty, with accessibility mediating the influence of spatial opportunity.

SEM has two components: the measurement model and the structural model. The measurement model analyses the relationship between the observed (manifest) variables to define the unobserved (latent) constructs, while the structural model analyses the interrelationship between the latent constructs. The full SEM considers both models (Schumacker & Lomax, 2010; Hair et al., 2021).

In this study, spatial opportunity (Galster, 2012; Galster & Sharkey, 2017; Green, 2015) and accessibility (van Wee, 2022) were treated as latent constructs measured by observed built environment indicators. The measurement model included spatial opportunity (latent) measured through land use variables (observed) such as education, health, government services, and commercial land uses (Christian et al., 2017; Ewing & Cervero, 2010; Turrell et al., 2013). Accessibility (latent) was measured by observed transport-related variables such as destination accessibility (Ewing & Cervero, 2010; Liang et al., 2022; Wan et al., 2012). Multidimensional poverty (latent) was measured through dimensions and indicators such as health, education, economic status, and standard of living (Alkire et al., 2015).

We employed partial least squares SEM (PLS-SEM) due to the exploratory nature of this research. PLS-SEM is better suited for exploratory studies than covariance-based SEM (Hair, Risher, Sarstedt, & Ringle, 2019). We expected cross-loading of observed variables onto latent constructs, which is common in built environment studies (Ewing & Cervero, 2010). Furthermore, the complex and non-linear nature of the built environment and its plausible relationship to multidimensional poverty inclined this research towards PLS-SEM.

The structural model explored the relationship between spatial opportunity, accessibility and multidimensional poverty. We controlled for socio-demographic confounders (Ahmed et al., 2023; Brown et al., 2008; Sarkar et al., 2015) and evaluated the measurement and structural model following established PLS-SEM procedures (Hair, Risher, Sarstedt, & Ringle, 2019; Hair et al., 2021).

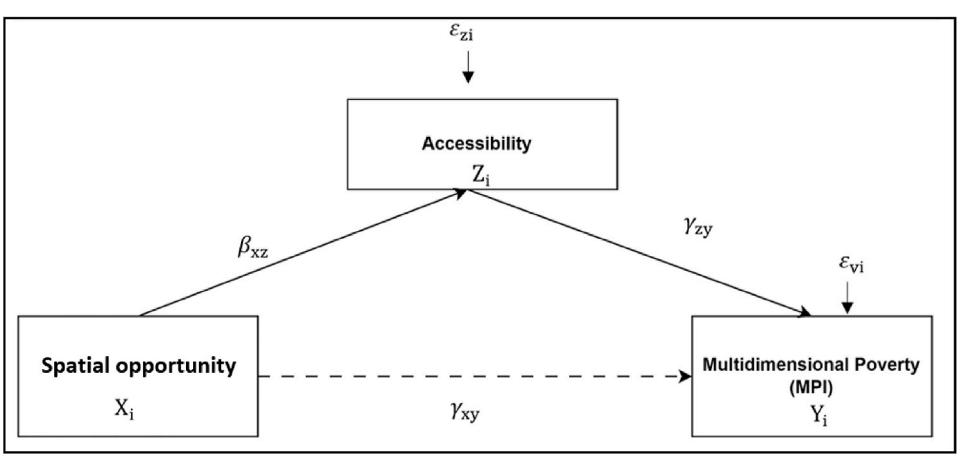

Fig. 1. Pathway of accessibility mediation on multidimensional poverty.

3.5. MPI poverty construct

This study used the multidimensional poverty index (MPI) based on the Alkire and Foster (AF) approach (Alkire & Foster, 2011). The approach involved calculating the number of deprivations in dimensions to identify the poor and compute the MPI. Dimensions of poverty were informed by normative judgment and policy context following Alkire et al. (2015). The capabilities theory (Sen, 1979, 1993, 1995) provided a theoretical framework for identifying the indicators that constitute dimensions. Indicators for the dimensions were measured from the data (Alkire et al., 2015).

The indicators used in constructing the MPI were derived from the State of Our Cities Survey 2013(Gulyani et al., 2017). We structure the MPI around four primary dimensions: health, education, economic status, and standard of living, as shown in Table 1. Each indicator within these dimensions is coded as a binary variable (0 = not deprived, 1 = deprived) based on carefully defined deprivation cutoffs (depicted in column 4 of Table 1). These cutoffs are established through a combination of normative criteria, policy contexts, and practical considerations of what constitutes meaningful deprivation in the urban Kenyan context. This binary coding allows for clear identification of deprivation while avoiding potentially arbitrary gradations of poverty intensity.

3.6. Built environment measures

Our measurement of the built environment encompasses both spatial opportunity and the conventional “5Ds” framework of built environment characteristics. For spatial opportunity, we employed a counting approach within a 1-km radius of each household, capturing the presence of various urban opportunities, including educational facilities, health services, government offices, commercial activities, institutional facilities, and other urban amenities. Due to data limitations, we adopted a simplified measure compared to composite indices in the literature (Galster & Sharkey, 2017; Kuzmyak et al., 2006; Kuzymak, 2012). Specifically, we omitted the desirability and size scores of the different opportunities, using 1 km to represent the walking distance of households to routine activities, aligning with the 15-min city concept (Abbiasov et al., 2022; Calafiore et al., 2022; Moreno et al., 2021). Our approach follows the neighbourhood institutional assets measurement discussed in the concept of opportunity in geography (Green, 2015), which aligns with conceptualizing the built environment as a physical phenomenon. Our measure departs from Green (2015) by using a broader range of opportunities and focusing the analysis at the household unit level.

Destination accessibility is measured using the three-step floating catchment area (3SFCA) method, which provides a sophisticated measure of accessibility that accounts for both supply and demand factors (Wan et al., 2012). This process begins with the generation of population demand points using WorldPop data, proceeds through the creation of detailed distance matrices between population points and opportunities (including schools, hospitals, and employment locations), and culminates in the calculation of accessibility ratios that reflect the complex interplay between service provision and population need. We modified the Python code provided by Zhang (2021) to perform 3SFCA.

The established “5Ds” framework measures the remaining characteristics of the built environment. Density is captured through building density measures derived from land use data. Diversity is quantified using the Land Use Entropy Index, which measures the mix of different land uses in an area (Kuzmyak, 2012). Design characteristics are measured using the Spatial Design Network Analysis (sDNA) tool, which provides metrics for network connectivity, efficiency, and betweenness centrality (Cooper, 2024). Distance to transit is measured as the straight-line distance to the nearest bus stop. Destination accessibility, as previously described, is measured through the 3SFCA method.

3.7. Confounders

Our analysis includes a carefully selected set of control variables to account for household characteristics that might confound the relationship between built environment characteristics and poverty outcomes. The key confounders we used were related to the number of adults and children in a household, the age of the household head, the place where the household lived (formal or informal settlement), and the gender of the household head. The selection of these control variables is guided by previous studies in the field (Ahmed et al., 2023; Sarkar et al., 2015) and aims to isolate the effects of built environment characteristics from other factors that might influence poverty outcomes.

4. Results and discussion

4.1. Descriptive analysis

The descriptive statistics **in** Table 2 **reveal considerable variation in** built environment features and poverty indicators across the study area. All variables have been **standardised** to facilitate comparison and interpretation, with means of zero and standard deviations of one.

The multidimensional poverty dimensions show varying levels of deprivation across the sample. Health deprivation appears most prevalent, with a mean score of 0.463, indicating that nearly half of households experience some form of health-related deprivation. Economic status deprivation follows with a mean of 0.285, while the standard of living deprivation affects about a quarter of households (0.259). Education shows the lowest level of deprivation (0.086), suggesting relatively good access to and participation in education among the sampled households.

Built environment characteristics display notable variation across the study area. The spatial opportunity measures reveal substantial differences in access to various urban amenities, with some areas having high concentrations of opportunities (maximum standardised values above 6 for government and commercial opportunities)**. In contrast,** others show significant deficits (minimum values below −2 for institutional opportunities). This variation suggests considerable spatial inequality in the distribution of urban amenities. Settlement characteristics show an almost even split between formal and informal settlements (49.3 % informal), providing a balanced perspective on different urban contexts.

4.2. Model evaluation

The measurement and structural models demonstrated acceptable reliability and validity, supporting the robustness of our findings. Factor loadings for most indicators exceeded the recommended threshold of 0.708,[8] and composite reliability measures (rho_c and rho_A) for the reflective multi-item constructs (e.g., accessibility and spatial

[8] Most indicators used to build the composite constructs are reliable and have acceptable factor loadings above the 0.708 threshold recommended in the literature (Hair, Risher, Sarstedt, & Ringle, 2019). However, some of the indicators are below the recommended threshold but are retained since they meet the minimum acceptable threshold. These indicators, such as health accessibility ratio (destination accessibility construct), education opportunities (spatial opportunity construct), and Two-Phase Destination (design construct), which have values of 0.68, 0.67 and 0.69, respectively, are also retained because they do not affect reliability. They are helpful for our exploratory analysis and conceptualisation of the relationship between the built environment and multidimensional poverty. None of the indicators used in our analysis are below the cutoff threshold of 0.40. A discussion on the retention or removal of indicators with a decimal point difference from benchmark thresholds and the minimum cut-off can be found in Hair et al., 2021. The full table of factor loadings is presented in **Supporting Material A.**

Table 1
Dimensions and indicators used in the MPI.

Dimension	Normative context/basis	Indicators	Household is considered deprived if … (cutoff)
1. Health	SDG3: enhance healthy lives and promote well-being for all at all ages. African Union (AU) Agenda 2063 Goal 3: Healthy and well-nourished citizens Kenya Vision (2030). Constitution of Kenya/Bill of Rights: right to health; equitable and affordable health care for a healthy working population; Universal Health Coverage	Morbidity	A household member has suffered from disease or injury in the past two weeks, preventing them from conducting regular activities [q6.1; q6.2; q6.5]
		Affordability of health	No member of the household is covered by health insurance [q6.11]
2. Education	SDG 4: Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all AU Agenda 2063 Goal 2: Well-educated citizens and skills revolution underpinned by science, technology and innovation. Kenya Vision (2030). Constitution of Kenya/Bill of Rights: right to education; universal access to education; Education and economic development	School achievement	Adult has not completed lower secondary school [q1.4F]
		Child school attendance	Any school-aged child is not attending school [q1.4d]
3. Economic status	SDG 8: Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all AU Agenda 2063 Goal 1: A high standard of living, quality of life and well-being for all citizens. Kenya Vision (2030). Constitution of Kenya/Bill of rights: high-quality jobs, right to fair labour practices	Employment status	The main activity has been helping without pay in household business, Sick/handicapped, unable to work, looking for work, not looking for work, and being a Homemaker.[q1.4g]
		Poverty line	The household's total expenditure, excluding rent in the previous month, was below the poverty line, i.e. poverty line = 5,567 Ksh per month for each adult 15 years and older in the household +3,619 Ksh per month for each child aged 5 to 14 in household +1,336 Ksh per month for each child under 5 years old in household. (Ksh 86.50 per USD in January 2013) [q4.1]
4. Standard of living	SDG 11: Make cities and human settlements inclusive, safe, resilient and sustainable; New Urban Agenda (NUA) AU Agenda 2063 Goal 1: A high standard of living, quality of life and well-being for all citizens. Kenya Vision 2030 and Constitution: right to decent and affordable housing and high standard of living	Housing roof material	The house roof is built from unconventional/rudimentary materials, e.g. Roof = grass, thatch or tin [10.2b]
		Housing wall material	The house walls are built from unconventional/rudimentary materials, e.g. Walls = , mud/Wood, Mud/Cement, wood only, tin [10.2a]
		Housing floor	The house floor is built from unconventional/rudimentary materials, e. g. Floor = earth clay [10.2c]
		Water quality	Water quality is poor [q5.11]
		Private water	There is no private water source in the dwelling [q5.1]
		Electricity source	Not connected to electricity [q5.34]
		Energy for cooking	Uses unclean sources of energy, e.g. dung, wood and charcoal, and kerosene to cook [q5.43]
		Energy for lighting	The primary lighting source is not clean, i.e. kerosene, firewood, Paraffin and other unclean sources [q5.45]
		Sanitation facilities	Households usually use no facility/flying toilet; public shared latrine or paid shared facility [q5.18]
		Shared toilets	More than two households share a toilet, i.e. more than one household and one other [q5.20a]
		Housing tenure	Does not own land or structure but is occupying the site or tenant not paying rent [q2.1; q2.15]
		Housing space/ crowding	Overcrowding is defined as three or more people per habitable room (minimum of 4 square meters of space) [q1.3a,b,c; and q3.4]

Note: All indicators are derived from the State of Our Cities Survey 2013 dataset (Gulyani et al., 2017). The square brackets [q#.#] after each indicator refer to the corresponding question numbers in the survey questionnaire. For example, [q6.1] refers to question 6.1 in the survey. AU Agenda 2063 is Africa's blueprint for sustainable development. Kenya is a member of AU and aligns to this agenda.[61] Kenya Vision 2030 is the development blueprint adopted to transform the country into a middle-income nation by 2030.[72] AU Agenda 2063; Kenya Vision 2030 provide the development policy normative context for multidimensional poverty analysis.
Source: Authors' adaptation from Robeyns (2003), Alkire and Foster (2011), Alkire et al. (2015), Rippin (2016), Espinoza-Delgado and Klasen (2018), UNDP (2018), and Gachanja et al. (2025).

opportunity) were above 0.70 and 0.60, respectively, indicating internal consistency. Average Variance Extracted (AVE) values were above 0.50, confirming convergent validity.

The formative measurement model for MPI poverty also showed strong convergent validity, with a high correlation ($R^2 = 0.98$) between the formative construct and the single-term poverty measure. Variance Inflation Factors (VIFs) for the formative indicators were below 3, indicating no significant collinearity issues (Hair et al., 2021). Among the four poverty indicators, only health score and standard of living show statistical significance in the formative model.

Overall, these model evaluation results provide confidence in the validity and reliability of the constructs and relationships examined in this study. Detailed results of the model evaluation, including factor loadings, HTMT ratios, bootstrapped weights, structural model collinearity diagnostics, and out-of-sample prediction errors are available in the **Supplementary Materials A-C**.

4.3. *Mediation analysis*

The structural relationships between the constructs of interest in this paper are significant,[9] as depicted in Table 3. The path between spatial opportunity and accessibility exhibits the strongest association based on the original estimate; it is also highly significant and positive. The path between accessibility and multidimensional poverty (MPIpoverty) is negative and significant, indicating that improved accessibility is associated with reduced poverty. Conversely, and somewhat counterintuitively, the path between spatial opportunity and multidimensional poverty is positive and significant. This suggests that simply increasing the number of opportunities in an area without also addressing accessibility may not lead to poverty reduction and could even be associated with higher levels of deprivation. This seemingly paradoxical finding may be explained by the "urban paradox," where lower-income

[9] Significance is established where the *t*-test value is greater than 1.96 and the value 0 does not fall into the 95 % Confidence Interval (CI).

Table 2
Descriptive statistics.

Variable	Description	Obs	Mean	Std. Dev.	Min	Max
Socio-Economic Outcomes						
MPI Poverty						
EconStat	Economic status dimension of MPI (1 = poor; 0 = not deprived)	750	0.285	0.301	0.000	1.000
HealthScore	Health dimension of MPI (1 = deprived; 0 = not deprived)	750	0.463	0.289	0.000	1.000
EducationScore	Education dimension of MPI (1 = deprived; 0 = not deprived)	750	0.086	0.204	0.000	1.000
STDofLiving	Standard of living dimension of MPI (1 = deprived; 0 = not deprived)	678	0.259	0.168	0.000	0.714
Built Environment 5 Ds						
Destination Accessibility						
std_HlthAccRatio	Health accessibility ratio (3SFCA)	741	0.000	1.000	−0.339	16.382
std_SchlAccessRatioJuly	School accessibility ratio (3SFCA)	756	0.000	1.000	−0.427	6.115
std_jobacratio	Job accessibility ratio (3SFCA)	756	0.000	1.000	−1.356	2.348
Design						
std__15jnc1500	Connectivity: number of junctions between road network links (sDNA)	756	0.000	1.000	−1.764	2.607
std__1khullr10	Efficiency: convex hull max radius-Furthest extent of the convex hull	756	0.000	1.000	−2.380	2.576
std__15tpd1500	Betweenness centrality: Proportion of origin weight received by each destination/competitive accessibility	756	0.000	1.000	−1.553	3.019
Distance to public transport						
std_Distance2PublicTrnspt	Distance to nearest public transport stop from household	756	0.000	1.000	−1.419	2.821
Diversity						
std_LandUseEntropy	Land use entropy	756	0.000	1.000	−2.341	2.052
Density						
std_BuidlingDensity	Building density	756	0.000	1.000	−1.108	3.984
Spatial opportunity						
std_GovtOPP	Number of government-related opportunities within 1 km of the house	756	0.000	1.000	−1.136	6.707
std_CommOpp	Number of commercial opportunities within 1 km of the house	756	0.000	1.000	−1.024	6.760
std_EducOPP	Number of education opportunities within 1 km of the house	756	0.000	1.000	−1.474	4.705
std_InstituOPP	Number of institutional opportunities within 1 km of the house	756	0.000	1.000	−2.127	2.412
std_HealthOPP	Number health opportunities within 1 km of the house	756	0.000	1.000	−0.878	3.989
std_OtherOPP	Number of other opportunities within 1 km of the house	756	0.000	1.000	−1.854	2.771
Controls						
FemaleHHHead	Female-headed household = , male household = 0	732	0.236	0.425	0.000	1.000
std_agehhhead	Age of household head	718	0.000	1.000	−1.585	4.787
std_numchild5to14	Number of children between the age of 5 and 14 years	756	0.000	1.000	−0.602	4.892
std_numchildunder5	Number of children under the age of 5 years	756	0.000	1.000	−0.698	4.026
std_numadults	Number of adults	756	0.000	1.000	−1.013	5.446
situation_TRUE	Situation 1 = informal settlement; 0 = formal settlement	756	0.493	0.500	0.000	1.000

Table 3
Significance of structural relationships: bootstrapped direct paths.

Paths	Original Est.	Bootstrap Mean	Bootstrap SD	T Stat.	5 % CI	95 % CI
DestAccessibility - > MPIpoverty	−0.231	−0.229	0.044	−5.282	−0.300	−0.156
Spatial opportunity - > DestAccessibility	0.730	0.730	0.022	32.795	0.692	0.766
Spatial opportunity - > MPIpoverty	0.232	0.231	0.048	4.811	0.151	0.310
NumAdults - > MPIpoverty	−0.107	−0.109	0.049	−2.187	−0.188	−0.029
Informal - > MPIpoverty	0.371	0.372	0.036	10.387	0.313	0.430
AgeHHHead - > MPIpoverty	−0.041	−0.040	0.043	−0.960	−0.110	0.032
NumChild5to14 - > MPIpoverty	0.054	0.054	0.038	1.421	−0.008	0.116
NumChildUnd5 - > MPIpoverty	0.052	0.052	0.035	1.469	−0.006	0.110
FemaleHHHead - > MPIpoverty	0.013	0.012	0.035	0.356	−0.045	0.070
Density - > MPIpoverty	0.156	0.154	0.034	4.637	0.098	0.209
Diversity - > MPIpoverty	−0.073	−0.073	0.034	−2.154	−0.129	−0.017
DistancePT - > MPIpoverty	0.152	0.152	0.041	3.688	0.083	0.219
Design - > MPIpoverty	−0.019	−0.022	0.037	−0.520	−0.083	0.038

Note: Structural relationships showing statistical significance are shown in bold.

neighbourhoods often have a higher density of services but poorer overall socio-economic outcomes. It may also reflect limitations in our measure of spatial opportunity, which did not account for the quality, desirability or size of those opportunities.

[6] https://au.int/en/agenda2063/overview.
[7] https://vision2030.go.ke.

We then specifically explored the mediation mechanism of accessibility in the relationship between spatial opportunities and multidimensional poverty. The analysis revealed a significant total indirect effect (mediation effect) of spatial opportunity on multidimensional poverty through accessibility, quantified as −0.169 (t = −4.844), 95 % CI [−0.239; −0.101]. This negative mediation effect indicates that increased accessibility, driven by spatial opportunity, is associated with a reduction in multidimensional poverty.

As noted, the direct effect of spatial opportunity on multidimensional poverty remains significant and positive (0.232, see Table 3). This indicates that *DestAccessibility* partially mediates the effect of *Spatial opportunity* on *MPIpoverty*. The product of paths is negative (−0.039), further supporting the presence of a mediating effect.

Fig. 2 illustrates the simplified model of the direct and indirect paths in the relationship between spatial opportunity, accessibility and multidimensional poverty. The paths are summarised as follows:

- Direct effect: The direct pathway from spatial opportunity to multidimensional poverty, holding accessibility constant, has a positive coefficient of 0.232.
- Indirect effect: The mediation effect through accessibility, quantified as −0.169, demonstrates how accessibility influences the relationship between spatial opportunity and multidimensional poverty.

Fig. 3 presents the full model with path diagrams for all constructs and confounders used in the analysis. Among the built environment indicators, higher population density is linked to increased poverty, potentially due to overcrowding and strain on resources, particularly in a developing country's context. Similar observations apply to distance to public transport; increased distance to public transport is associated with higher poverty, likely because it limits access to employment opportunities, essential services, and broader social networks.

Land use diversity has a significant negative association with multidimensional poverty. This suggests that areas with a mix of residential, commercial and institutional land uses may offer residents more diverse economic opportunities, better access to services and stronger social networks, thereby reducing poverty. The path between design and multidimensional poverty is not significant, suggesting that urban design, as measured in this study, does not have a direct impact on poverty levels.

Among the confounders, living in an informal settlement is strongly associated with increased poverty, reflecting the lack of basic services, poor living conditions, and limited access to formal employment in these areas. An increase in the number of adults (NumAdults) in a household is associated with a significant decrease in MPI poverty. This is also an expected result, as more adults in a household typically mean more potential income earners and a greater ability to share resources and responsibilities.

4.4. Discussion

We hypothesised that spatial opportunity influences urban poverty directly and indirectly through accessibility. Our results support the mediating role of accessibility: increased spatial opportunity enhances accessibility, which, in turn, reduces multidimensional poverty (MPI-poverty). This suggests that accessibility is crucial for translating spatial opportunities into improved socio-economic outcomes, partially contradicting the notion that spatial opportunity alone guarantees better outcomes (Green, 2015).

Surprisingly, we found a direct association between increased spatial opportunity and increased poverty. This counterintuitive finding may be explained by the higher density of lower-income neighbourhoods, where a greater number of opportunities per unit area may not equate to better socio-economic outcomes. This aligns with the "urban paradox," where high-poverty areas often contain numerous neighbourhood assets (Green, 2015; Campbell, Rising, Klopp, & Mbilo, 2019). Technically, this could also be due to our measure of opportunity lacking quality, desirability and size criteria (Kuzmyak et al., 2006). Further research is needed to explore the spatial heterogeneity of spatial opportunity and poverty.

Our results highlight the capability-enhancing role of accessibility if we consider the capability approach (Sen, 1979). It suggests that accessibility enables people to convert opportunities to "functionings". In our analysis, the structural model is a good predictor of health. Accessibility could be considered a mechanism for converting opportunities into improved health status. Our findings support this line of thought in the accessibility literature (Cascetta et al., 2013; Geurs & Van Wee, 2004; Hansen, 1959; Levinson & Wu, 2020; van Wee, 2022).

The intertwined relationship between spatial opportunity and accessibility is important. Accessibility literature often emphasizes the link between land use systems (activities distributed across space) and transport systems (connecting people to those activities) (Cascetta et al., 2013; Qu et al., 2024). While street network design is not significantly associated with multidimensional poverty, distance to public transport is (Venerandi, 2018; Benita, 2022). This suggests that transport services may be more influential than transport infrastructure alone. Exploring factors of land use and transport systems relevant to well-being is crucial.

Our hypothesis that factors determining spatial opportunity are also determinants of accessibility also drives us to consider the interrelationship between spatial opportunity and accessibility. The model evaluation results suggest that spatial opportunity and destination accessibility constructs are empirically different. However, closer inspection reveals high cross-loadings between indicators of spatial

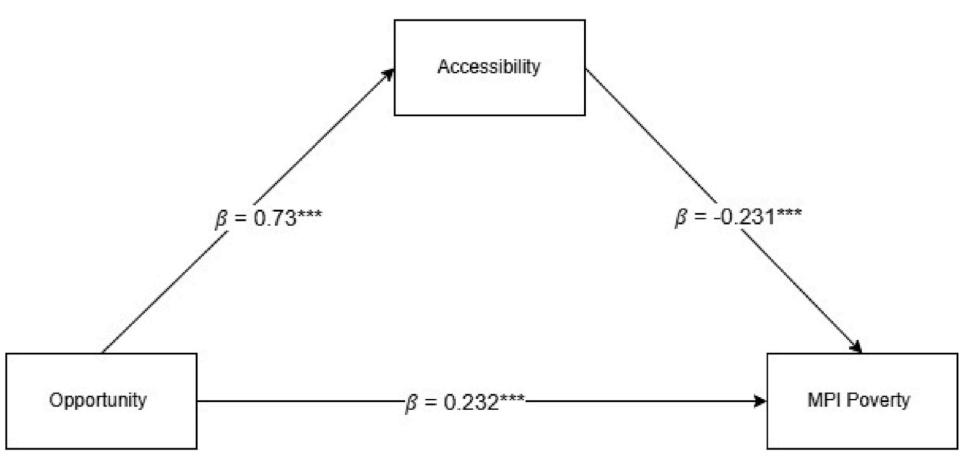

Fig. 2. Direct and indirect paths.

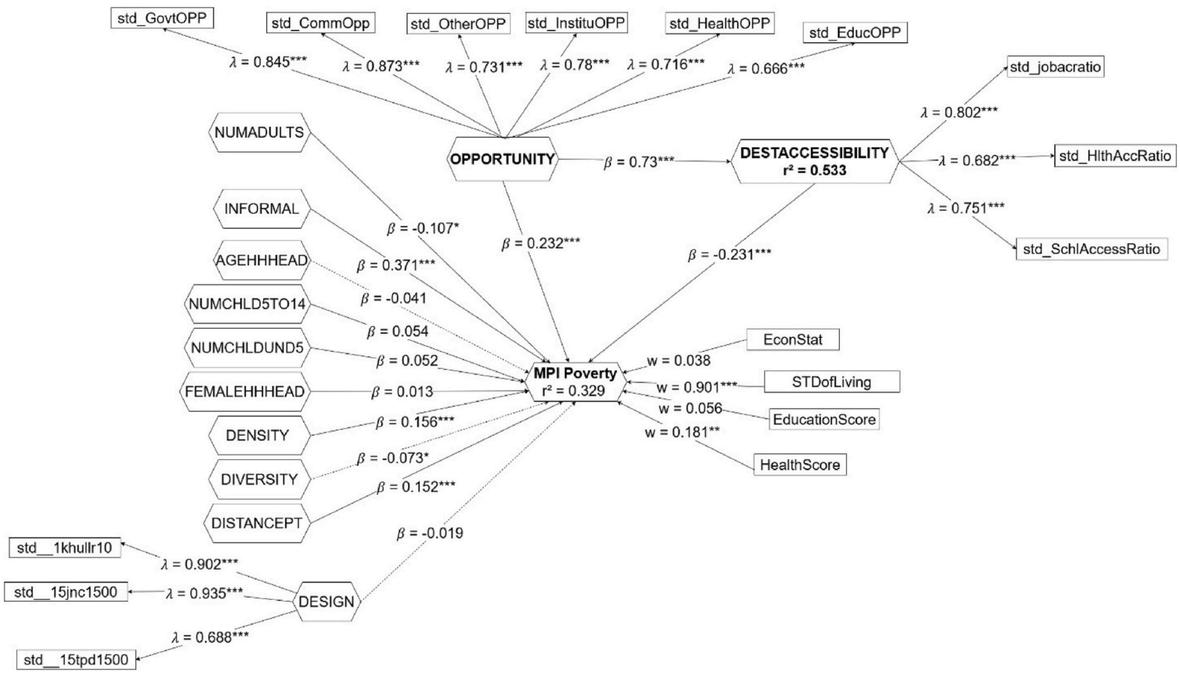

Fig. 3. Full structural equation model.

opportunity and destination accessibility, corroborating accessibility literature (Geurs & Van Wee, 2004; van Wee, 2022).

A hypothesis was also advanced that the built environment would affect some dimensions of urban poverty more than others. We argued that the dimensions and indicators contributing more to overall poverty also have a stronger association with the built environment. Our findings suggest that economic status and health deprivation are the most significant and relevant multidimensional poverty indicators. The model also predicts health deprivation better than education and standard of living. These findings corroborate the literature on health and the built environment (Rice, 2008; Turrell et al., al 2013; Dendup et al., 2021; Collyer et al., 2022; Zheng et al., 2022). They also support the literature on economic outcomes and built environment (Liang et al., 2022; Zhu et al., 2022).

4.5. Limitations and future research

We acknowledge that this study has limitations stemming from empirical measurement, conceptual considerations and analytical choices. A key limitation is the moderate explanatory power of our structural model, which explains 33 % ($R^2 = 0.329$) of the variance in poverty. However, lower R^2 thresholds are generally acceptable in social sciences, and interpretation depends on the study's context (Hair et al., 2021; Hair & Alamer, 2022). The relatively lower R^2 value in our study likely arises from the complex nature of the model, which involves multiple constructs formed from indicators derived from different sources and samples. For instance, built environment indicators were derived from spatial data sources (land use data, spatial network design and public transport networks), while multidimensional poverty indicators were derived from a household survey. The model's complexity, with multiple constructs and indicators, also contributes to the R^2 value (Hair et al., 2021). Notably, some studies using PLS-SEM have considered R^2 values as low as 0.1 to be satisfactory (Raithel et al., 2012). Despite this moderate explanatory power, our model provides valuable insights into the pathways and mechanisms through which built environment indicators and constructs are associated with multidimensional poverty.

While we aimed to capture key aspects of the built environment using the 5Ds framework, data constraints limited the comprehensiveness of some constructs. For instance, density and diversity were based on single indicators. Future research should aim to develop these constructs with a greater number of indicators to provide a more nuanced representation of these complex urban characteristics. Furthermore, our measure of spatial opportunity captures the quantity of opportunities but not their quality, desirability, size or other detailed characteristics. Opportunity measures incorporating these qualitative aspects could provide a more accurate reflection of lived experiences, as low-quality opportunities may not translate into tangible benefits for residents.

Conceptually, while we controlled for individual and family attributes to mitigate confounding effects (as is common in poverty studies), we acknowledge that we did not incorporate all aspects of comprehensive models of poverty, such as individual life decisions and parental influences (Galster & Sharkey, 2017). Future research could explore these individual-level factors in greater detail to provide a more holistic understanding of poverty dynamics.

Analytically, the cross-sectional nature of our data limits our ability to infer causal relationships and capture time-variant effects. Longitudinal studies are needed to investigate causal relationships and understand how the effects of the built environment on social phenomena unfold over time. In addition, future research could also investigate context-specific variations in these relationships and explore potential threshold effects, such as whether there are minimum levels of accessibility needed to significantly impact poverty outcomes. These extensions would further strengthen the evidence base for urban planning interventions aimed at poverty reduction.

5. Conclusion

In this study, we investigated the association between the built environment and multidimensional poverty, with particular emphasis on how accessibility mediates these relationships. Using Partial Least Squares Structural Equation Modelling (PLS-SEM) and integrating household survey data with detailed spatial analysis, we provide novel insights into the mechanisms through which the built environment influences poverty outcomes. Theoretically, this study advances our understanding of urban poverty by demonstrating how built environment characteristics operate through both direct and indirect pathways to influence different dimensions of poverty. This contribution extends beyond traditional single-dimensional poverty analyses and provides a more comprehensive framework for understanding the spatial dynamics of urban poverty.

Our findings reveal that the relationship between built environment and poverty operates through complex, interrelated pathways. The mediation analysis demonstrated that accessibility plays a crucial role between spatial opportunity and poverty outcomes. This suggests that the effectiveness of urban amenities and opportunities depends significantly on how accessible they are to residents. The analysis of different built environment characteristics revealed varying impacts across poverty dimensions, with particularly strong relationships in health outcomes and economic status. Land use diversity emerged as a particularly important factor, showing consistent poverty-reducing effects across multiple dimensions.

These findings have several important implications for urban policy and planning. First, urban poverty reduction strategies should prioritise enhancing accessibility to both existing and new spatial opportunities, with a particular focus on public transit. The substantial mediating role of accessibility identified in this research suggests that improving transport connectivity and accessibility should be a primary intervention focus. Second, the strong negative relationship between land use diversity and multidimensional poverty suggests that promoting mixed-use developments could be an effective strategy for poverty reduction. Policies that encourage a mix of residential, commercial and recreational uses within neighbourhoods may foster economic opportunities, social interaction and access to essential services, ultimately contributing to lower poverty rates. Third, our analysis reveals varying impacts of built environment characteristics across different poverty dimensions, with particularly strong relationships observed in health and economic outcomes. This suggests that urban interventions should carefully consider their differential effects on various aspects of poverty, rather than assuming uniform impacts across all poverty dimensions.

While our model demonstrates moderate explanatory power due to the measurement and analytical limitations discussed earlier, its primary contribution lies in illuminating the pathways through which built environment characteristics influence multidimensional poverty. This research advances our understanding by empirically demonstrating how accessibility mediates the relationship between spatial opportunity and poverty outcomes, providing a comprehensive framework for analysing urban poverty dynamics. Future research directions include investigating causal relationships through longitudinal studies, examining context-specific variations in these relationships, and exploring potential threshold effects in accessibility-poverty relationships. These extensions would further strengthen the evidence base for urban planning interventions aimed at poverty reduction.

CRediT authorship contribution statement

James Gachanja: Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Formal analysis, Data curation. **Tianren Yang:** Writing – review & editing, Writing – original draft, Validation, Supervision, Project administration, Funding acquisition, Formal analysis.

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Declaration of competing interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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Appendix A. Supplementary data

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