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Land use mix and walking: a systematic review of the empirical evidence

Diversidade de uso do solo e caminhada: uma revisão sistemática das evidências empíricas

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Abstract

This study examines the association between land use mix (LUM) and utilitarian, leisure, and total walking. Existing reviews usually include several built environment components at once, thus failing to properly explore the nuances of LUM's operational definitions and associations with walking. We systematically reviewed 61 studies that met our inclusion criteria according to data source, land use categories, spatial units, sample sizes, dependent and independent measures, and presence and direction of associations. The results showed five types of LUM measures: evenness, richness, proxy, synergy and factor-based measures. Overall, LUM was positively associated with total and utilitarian walking, while evidence for leisure walking was more equivocal. Entropy and NEWS land use mix measures were the most consistently able to capture associations with walking.

Keywords: Entropy. Land use mix. Street life. Urban vitality. Walking.

Resumo

Este estudo examina a associação entre a mistura de uso do solo (LUM, na sigla em inglês) e caminhadas utilitárias, de lazer e total. As revisões existentes geralmente incluem vários componentes do ambiente construído de uma vez, e, assim, falham em explorar adequadamente as nuances das definições operacionais da LUM e suas associações com a caminhada. Revisamos 61 estudos de acordo com a fonte de dados, categorias de uso do solo, unidades espaciais, tamanhos de amostra, medidas dependentes e independentes, e presença e direção das associações. Os resultados mostram cinco tipos de medidas de LUM: uniformidade, riqueza, proxy, sinergia e medidas baseadas em fatores. No geral, a diversidade foi positivamente associada à caminhada total e utilitária, enquanto as evidências para a caminhada de lazer foram mais ambíguas. As medidas de Entropia e a de diversidade de usos do solo do protocolo NEWS foram as que melhor conseguiram captar associações com a caminhada.

Palavras-chave: *Entropia. Mistura de uso do solo. Vida urbana. Vitalidade urbana. Caminhada.*

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Introduction

Land use mix (LUM) is widely considered as an important factor in promoting intense and continued use of public spaces. Besides contributing to social interactions, it also enhances physical health by reducing the need for motor vehicle trips and encouraging walking, providing a greater and more varied number of accessible destinations (Gehrke; Clifton, 2019; Song; Merlin; Rodriguez, 2013). UN-Habitat regards it as one of the five key principles for sustainable neighborhoods (UN-Habitat, 2014), and several governmental and non-governmental agencies at various levels have included mixed-use in their guidelines for urban planning and design (Schmitz; Scully, 2006; Transportation and Growth Management Program, 2001; Urban Task Force, 2004).

Not surprisingly, this subject has gathered a great deal of scrutiny in the last decades. After the seminal work of Jacobs (1992), highly influential to this day, other fields turned their attention to the hypothetical effects of land use mix on specific aspects of urban vitality, particularly in transport and health-related studies. The first is mainly interested in its potential to change people's decisions in favor of more sustainable modes of transportation such as walking, cycling and using public transit, as opposed to private motorized vehicles (Boulange *et al*., 2017; Cervero, 1996). The latter examines the effects of LUM on walking and cycling from the perspective of the increase in physical activity that they could help stimulate (Frank *et al*., 2005; Van Dyck *et al*., 2012).

Existing systematic reviews and meta-analyses provide a good overview of the association of built environment attributes with some of these specific outcomes. Overall, they provide support for the notion that land use mix is indeed associated with walking for transport (Cerin *et al*., 2017b; Ding *et al*., 2011; Ewing; Cervero, 2010; Kärmeniemi *et al*., 2018; Saelens; Handy, 2008), whereas evidence for leisure walking is less convincing (Kärmeniemi *et al*., 2018; McCormack; Shiell, 2011; Saelens; Handy, 2008).

However, these reviews examine multiple aspects of the built environment simultaneously, hence limiting their capacity to analyze more critically the role of land use mix and how exactly this construct was operationalized. As a result, in some cases it is conflated with other aspects as part of broader measures such as accessibility (Kärmeniemi *et al*., 2018) or walkability (Hajna *et al*., 2015), or just as part of a general built environment construct (Adkins *et al*., 2017). In others, associations of land use mix are available only for a small fraction of the included studies (Ding *et al*., 2011; McCormack; Shiell, 2011), undermining the robustness of the findings. In addition, some aspects of the reported associations are not clear, especially those related to the operational definition of LUM, an aspect that has repeatedly been highlighted as worthy of special attention (Brownson *et al*., 2009; Cerin *et al*., 2018; Duncan *et al*., 2010). For instance, in some cases it is difficult to ascertain what is the distinction between "land use mix" and "distance to non-residential destinations" (Cerin *et al*., 2017a; Saelens; Handy, 2008) and, consequently, exactly what aspects of land use diversity are being captured by the construct and being tested against the dependent variables.

In this article, we reviewed and synthesized 61 studies that examined the association between at least one measure of land use mix and walking for transport and for leisure, as well as total walking. Following Xiao and Watson's (2017) typology of literature reviews, we developed a "textual narrative synthesis" focusing specifically on land use mix as the independent variable. In doing so, we could explore in more detail not only the many ways by which the construct is operationalized, but also the performance of different LUM measures in capturing the associations with walking for different purposes.

More in-depth knowledge of how land use mix has been studied and what results have been obtained in terms of association with walking may help in several ways. First, knowing the usual ways by which authors have operationalized the construct may be used to prevent avoidable mistakes, maximize comparability with other studies, and serve as steppingstones to further improvements in methodological decisions. An overview and synthesis of aspects such as the most common land use classifications, spatial units, buffer radii, and analytical techniques, such as the one presented here, is largely absent from the literature. Second, and more importantly, a better grasp of the potential effects of land use mix in the promotion of walking and sustainment of lively urban areas can inform and support public policies in creating places that more fully realize the city's potential to put people in contact with each other and create vibrant and enriching environments for daily life. Finally, being able to ascertain the efficacy of different LUM measures in revealing associations with walking may help a more critical evaluation of the quality of existing empirical studies, as well as guide future endeavors both in academic research and in planning practice.

Methods

Search strategy

We searched for relevant studies published in English in the form of articles in peer-reviewed journals. Books, book chapters, or unpublished works such as thesis or technical reports were not considered for inclusion. No limitations were imposed on the country of origin of the journal, authors, or case study, nor did we establish any temporal constraint. Two databases were used for the search: Web of Science (WoS) and Scopus. Both are widely respected curated databases of scientific content that set high standards of publishing practice for the inclusion of journals from several disciplines.

The search query was divided into two parts: the first included the concept of land use mix and its variants, while the second encompassed different terms related to walking, street life and urban vitality. The latter were included because walking is often used as a proxy for them in experimental studies (Im; Choi, 2020). Several tests were performed before the final query; the keywords and titles of these preliminary results were examined in order to adjust the search query and maximize comprehensiveness without losing specificity. The final query was: ("mixed-use" OR "land use diversity" OR "mixed land use" OR "land use mix") AND ("walking" OR "walkability" OR "pedestrian movement" OR "urbanity" OR "vitality" OR "street life"). It was applied to titles, keywords and abstracts to form the initial set of candidates for inclusion.

Screening and eligibility criteria

The query yielded 549 results from WoS and 533 from Scopus. These references were imported into a reference manager that helped in gathering citation data from online databases, importing metadata, and grouping them in various ways. It also assisted in checking the results for duplicates (386 articles) and merging records when necessary (Figure 1). Once the list was composed of unique studies (698 articles), two more filters were applied. The first removed those studies obviously out of the scope of the review as assessed by reading the title and, if necessary, the abstract and keywords. We also constrained the included articles to those that analyzed the relationships between the dependent and independent variables in a quantitative manner. Qualitative and/or purely theoretical studies were excluded. At this stage, 471 studies were eliminated.

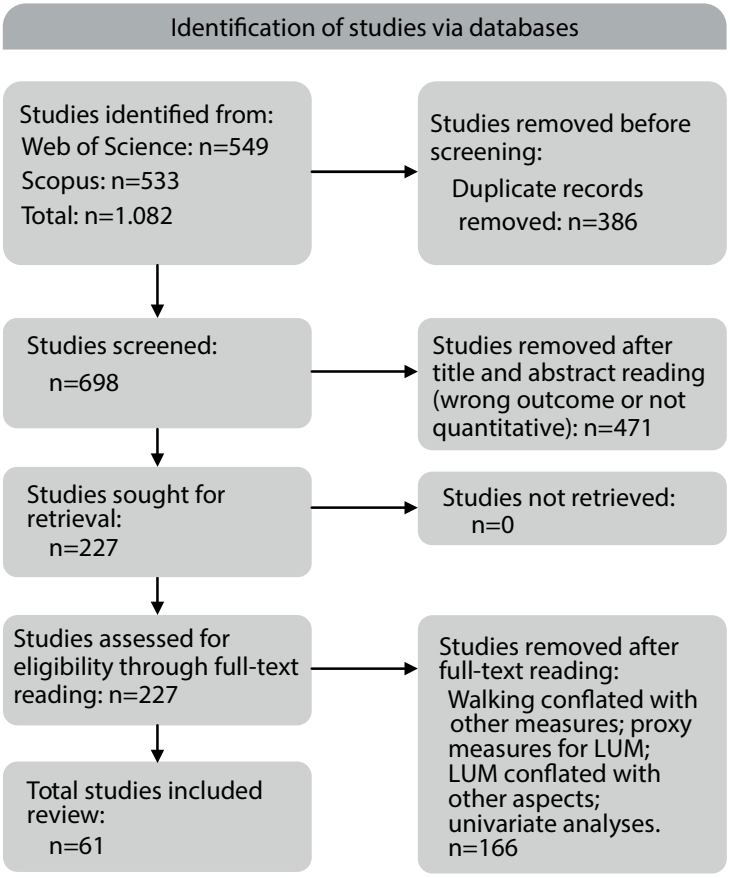


Figure 1 – Flow diagram for the search and screening of included studies.
Source: Adapted from Page *et al*. (2021).

Finally, the remaining 227 articles were selected for full-text reading. We were able to access all studies, and they went through a final filter, according to which the following conditions should be met:

• The dependent variable should include at least one individual measure of walking (as opposed, for instance, to being inside a broader measure of physical activity);

• The dependent variable should not be generated by simulation (*e.g.* Monte Carlo techniques);

• Measures of land use diversity should be either objectively measured or estimated through directly consulting participants, as opposed to employing some kind of proxy measure to represent LUM (*e.g.*, zoning classifications);

• Land use mix measures should be independently tested for associations with the dependent variable(s), as opposed to being conflated with other aspects as part of composite indexes summarizing more comprehensive features of the built environment (*e.g.*, walkability indexes);

• Due to the ubiquity of confounding factors involved in the relation between LUM and walking (Cerin *et al*., 2017a), studies should employ statistical tools able to take them into account, such as various kinds of multivariable regression analyses (as opposed, for instance, to simple correlation measures).

We established no exclusion criteria for the participants' age and included works that studied not only objective but also subjective measures of land use diversity, reasoning that the latter is

probably a mediator to walking: land use mix, if it exists "objectively" and influences behavior, must somehow be perceived by the person who decides to walk.

Another decision was whether to include studies that adopted land use measures that accounted only for the intensity or proportion of non-residential uses. Strictly speaking, these are not measures of diversity, since places with 100% of one type of commercial use, for instance, would have the highest score albeit having no diversity. We opted to include them for two main reasons: first, they are quite common, being used in 15 of the 61 studies analyzed here and in other works as well. For instance, Song, Merlin and Rodriguez (2013) and Gehrke and Clifton (2016) consider percentages of specific land uses as one type of LUM measure, and the UN-Habitat guideline for sustainable neighborhoods states that "At least 40 percent of floor space should be allocated for economic use in any neighbourhood" (UN-Habitat, 2014, p. 1). Second, given the prevalence of residential uses in cities, higher proportions and/or intensities of non-residential uses are usually associated with higher land use diversity (Saboya *et al.*, 2021). This is true especially when we consider broad patterns in large samples, such as is the case of the studies included here, even if individual zones or segments may violate this general tendency. Therefore, measures based on intensity or proportion of non-residential uses may be considered as proxies for land use mix. Based on this, we reasoned that knowing its potential effects on the components of street life would also be a valuable contribution to the community of researchers and practitioners.

Data analysis

Coding procedures

The 61 studies that remained after all filters were applied were read and coded independently by the authors. The codes were refined throughout the process and the final version is discussed below. Interpretations were compared and inconsistencies were discussed and agreed upon between the authors.

Dependent variables were classified as one of the three types of walking: utilitarian, leisure and total walking. When data about walking was derived from transport surveys, it was considered as utilitarian walking, unless stated otherwise. Operational aspects were coded according to the size of the sample, the spatial unit, the sources of data (for land use only), the quantity and type of LUM measures, and the land use categories. The size of the sample considered both the dependent variables (*e.g.*, the number of participants whose walking was being measured) and the number of spatial units used to measure LUM (*e.g.*, zones or buffers). Accordingly, the spatial unit was determined only for the areas used as reference for the measurement of LUM. For the number of LUM measures, each "algorithm", understood as a formula, equation or other type of description of the steps and components needed to calculate it (*e.g.*, Shannon's entropy; distance to non-residential destinations, *etc*.), was counted as one measure. Thus, different radii or combinations of land use categories for the same algorithm did not count as additional measures. Land use categories were classified in "general" and "detailed" when amounting up to six or more than six categories, respectively. We also took note of cases in which existing categories were excluded from consideration in the measures.

The associations between LUM and the dependent variables were classified by their direction (positive, negative, neutral/insignificant and inconsistent). They were coded as positive (negative) if an increase in land use mix corresponded to a statistically significant increase (decrease) in the dependent variable. Cases in which there was no statistically significant association (p>0.05) were

coded as neutral/insignificant. When results involved subgroups such as men/women or different cities, they were summarized, as much as possible, according to the results of the complete sample.

The association was coded as "inconsistent" when positive and negative associations were found for the same dependent variable and LUM measure, or if two LUM measures yielded contrasting directions of association to the same dependent variable, unless they were related to two different samples (for instance, buffer around home and buffer around work).

Data Synthesis

After several rounds of coding and refining, final tables with the consensual interpretation and tabulation of results were generated. It allowed the summarization of several coded segments in a brief paragraph for each article. This matrix was then further processed to generate descriptive data and comparative tables. Due to the difficulties in comparing studies caused by the great variety of measures, sample types and research designs in general (Saelens; Handy, 2008), we used narrative synthesis (Xiao; Watson, 2017) to report and discuss the results.

Results

Sample general description

Figure 2 shows a quantitative summary of the studies by year and gives a visual idea of the distribution among fields of study. Due to the considerable overlap in aims and variables of interest, studies were classified in the different fields according to the journal in which they were published, as a proxy indicator of the intended audience. The earlier studies included in our sample investigated the association of built environment characteristics – including LUM – with walking, mainly from a health standpoint. More recently, the urban planning and design fields have been devoting renewed attention to LUM and its potential effects (Gehrke; Clifton, 2019; Im; Choi, 2020). The last decade saw a significant increase in the number of articles on this topic, with 2020 being the year with the highest number (14). Most studies were carried out in the U.S. (24.36%), China (15.38%), and Australia (11.54%) (Figure 3).

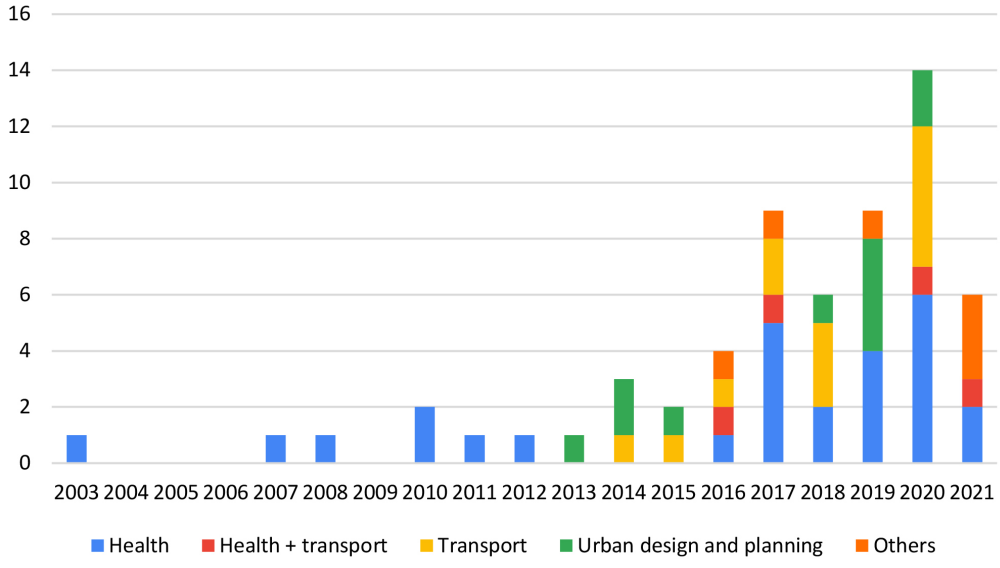


Figure 2 – Number and field of study of published articles per year.



Figure 3 – Percentage of studies per country.

Measuring the dependent variables

Measures used to quantify the dependent variables are summarized in Table S1 (Appendix C – https://zenodo.org/records/16793883). The most common is total time spent walking, usually recorded in minutes per day or week. The next two most common measures were the number of walking trips in a specified amount of time and a dummy variable representing whether the participant chose walking as a transportation mode instead of other modes in the last X days.

Measuring Land Use Mix

Data Sources

Most studies (39.7%) relied on data from official agencies such as Census Bureaus and municipal parcel databases to calculate land use measures, followed by questionnaires (30.9%), more specifically some version of the Neighborhood Environment Walkability Scale (NEWS) protocol (Cerin *et al*., 2006). Other sources were field surveys (23.5%), private agencies (2.9%), previous existing studies (1.5%) and Google Street View (1.5%). Five studies (7.4%) did not report the data source for land use mix measures (Table S2 in Appendix C – https://zenodo.org/records/16793883)

Land Use Categories

Overall, 33 studies (54.1%) classified land use in general categories (equal or less than six types). We list all classifications up to 6 land uses in Table S3 in Appendix C (https://zenodo.org/records/16793883). Of these, the three-land-use type was the most widely adopted (19.7% of the total number of studies), albeit with different land use combinations, followed closely by four land uses, with 18.0%. The most adopted specific combinations of land uses were residential and nonresidential; commercial, residential and office; and residential, commercial, office and others. In addition, some studies excluded one or more land use categories from the land use mix measure, reasoning that they were not attractive destinations for walking trips. Some of the excluded categories were industrial (Duncan *et al*., 2010; Steinmetz-Wood; Kestens, 2015; Winters *et al*., 2010), vacant (Winters *et al*., 2010) and recreational (Duncan *et al*., 2010).

Some studies grouped different activities in an ad-hoc manner, depending on their objectives and theoretical framework. For instance, McConville *et al*. (2011) used three categories defined as night uses (restaurants, bars, theaters, sports arenas), physical activity uses (parks, playgrounds, athletic properties) and social uses (religious and cultural areas, playgrounds, athletic properties). Similarly, Sung and Lee (2015) classified uses in "daily-activity neighborhood use", "non-daily commercial use" and office use.

For the detailed classifications, most were used as part of the NEWS protocol, in which respondents were asked about the estimated time to reach a number (from 9 to 43) of non-residential uses, as we discuss in more detail below.

Spatial units and sample sizes

Three main spatial units were used to aggregate land use data and transform it into measures of land use mix: areas around survey participants' homes, census zones or other types of administrative boundaries, and areas around origins, destinations and routes of trips (Table S4 of Appendix C (https://zenodo.org/records/16793883). The first type was the most common (57.1% of the studies) and usually consisted of a buffer around the homes of the respondents of a survey that gathered data about their trips and/or physical activity. The radii sizes ranged from 50m to 8000m, but most (67.6%) were concentrated between 400m and 1600m (Appendix B (https://zenodo.org/records/16793883). In terms of specific radii, 500m and 1000m were the most used (13 times each), followed by 400m and 800m (8 times each). Three methods were used to determine the buffer polygon: network distances (39.2%), aerial distances (37.8%) and undefined (23.0%).

In some cases, time-based radii were used. The NEWS protocol, for instance, uses two definitions: the first (land-use diversity) asks participants the estimated time to go to a number of destinations, with the last option defined as more than 30 minutes of walking. Therefore, it does not actually specify a fixed radius, even though it may be considered as a (time) radius-based spatial unit. The other (land-use access) takes into account the area within a 10- to 15-minute walk from participants' homes.

When we compared the proportion of each type of buffer until 2016 and from 2017 onwards, the most noticeable trends were a decline in aerial buffers, from 35.7% to 23.1%, and an increase in the adoption of time-based radii, going from 7.1% to 15.4%. Network-based radii remained relatively stable going from 35.7% to 30.8%.

Zone-based units were usually census tracts or similar administrative units for which there was previously available land use data. In some cases, data about the dependent variable were also available at this unit; in others, it was aggregated from disaggregated data (*e.g.*, participants' data aggregated by housing estates, as in Lu *et al*., 2018). Finally, a third type consisted of network buffers around origins, destinations, and, less frequently, routes of trips. Other types of spatial units were used only sparingly, such as specific locations where counts of pedestrian traffic were carried out (Kim; Sohn; Choo, 2017) and the surroundings of transit stations, where information about trips was gathered from people leaving the public transport (Wang; Cao, 2017).

Since the samples were diverse in types and spatial units, it was not possible to directly compare their sizes. The distribution of sample sizes for the most common type (participant-based studies, comprising NEWS-based questionnaires and transport-related travel surveys) ranged from 99 to 93,812. Only a few of them included more than one city or cities in more than one country. Notable exceptions are Christiansen *et al*. (2016) and Kerr *et al*. (2016), which analyzed data from 14 cities in 10 countries and 17 cities in 12 countries, respectively.

Measures

Overall, we identified five types of measures, summarized in Table S5 of Appendix C (https://zenodo.org/records/16793883): evenness-, richness-, proxy-, synergy- and factor-based measures. Evenness measures emphasize the proportionality among land uses. Areas with similar proportions of all land uses have the highest scores. Entropy-based measures of land use diversity were by far the most used, comprising 38 of the 61 studies (62.3%). The most adopted version was the one put forward by Cervero (1989) and popularized by Frank and Pivo (1994). Frank *et al*. (2005) later adapted it by dividing the original index by the natural logarithm of the total number of uses, as shown in Appendix D (https://zenodo.org/records/16793883). This modification constrains its range to values between 0 (only one use) and 1 (all uses equally distributed), and, as a result, is sensitive solely to the evenness of the proportions of different land uses in an area, assigning no weight to the total number of different uses.

The other evenness measures were much less popular. Most of them were employed by Gehrke and Clifton (2014) as part of their comparison among LUM measures, with Bhat and Gossen's evenness index also adopted by Manoj and Verma (2016) and Gehrke and Wang (2020). The latter also used a measure introduced earlier by Gehrke and Clifton (2019) called activity-related complementarity. Despite its name, it is a measure of evenness more than it is a measure of synergy. It considers the potential of attraction of trips of each land use and compares them to their actual proportions in the area. As a result, "A score of zero indicates a landscape dominated by a single land use type; whereas a score of one indicates a landscape where the spatial allocation of all land use types perfectly matches the observed attraction for activities" (Gehrke; Clifton, 2019, p. 16).

The second type of measure included those that emphasize richness, *i.e.*, the total number of land uses in an area. Most of them were derived from the use of some version of the NEWS protocol, that asks participants: "About how long would it take to get from your home to the nearest businesses or facilities listed below if you walked to them?" (Saelens *et al*., 2003, p. 1554). This results in an index of richness weighted by the proximity to a reference point (usually the residence) as measured by the time walking to access several non-residential destinations. The types of destinations varied depending on the version of the protocol chosen by authors as well as on ad-hoc adaptations and ranged from seven (Carlson *et al*., 2018) to 43 (Adlakha *et al*., 2017). Responses are coded in time intervals in such a way that smaller numbers are assigned to longer time estimates, thus correcting the direction of the measure (higher numbers representing higher proximities). The numeric values of the codes for all types of destinations are then averaged to compose the final measure. Since the last range refers to "more than 30 minutes", there is not a maximum radius specified for the measure.

Boulange *et al*. (2017) and McConville *et al*. (2011) adopted simple richness measures that count the number of different land use types in the area of reference.

The third group consists of proxy measures of different kinds. As stated earlier, they are not land use mix measures per se, but are supposedly correlated with it and thus used by the authors to capture LUM. The most used (10 studies) was another measure derived from the NEWS protocol, "Land Use Diversity – Access", that asks participants how much they agree or disagree with statements such as "I can do most of my shopping at local stores" (Saelens *et al*., 2003, p. 1554).

A measure of non-residential density was the next most frequent proxy measure (nine studies). They quantified the intensity (usually in terms of total land area) of different types of uses

in relation to the total area of the spatial unit under consideration (typically zones or the buffers around participants' homes).

Synergy measures try to capture complementarities or other types of relationships between land uses. In spite of being a supposedly central component of land use mix (Jacobs, 1992; Song; Merlin; Rodriguez, 2013), only one study attempted to capture synergy in its measure (not including Gehrke; Clifton, 2019, as explained above): Manaugh and Kreider (2013) took into account the adjacency of different land uses in each area as a way to capture the (potential for) interaction among them.

Finally, factorial measures refer to the combinations of different measures in a single composite index. Gehrke and Clifton (2019, p. 17), for instance, used factorial analysis to derive a "latent construct reflective of the paired pattern aspects of composition and configuration."

Number of LUM measures

Most studies used only one or two measures. Thirty-six articles used only one measure of LUM, of which 27 chose entropy as the sole measure. A few of the studies adopted several measures of land use mix to try to capture as many of its aspects as possible, or with the explicit intention of testing the performance of different measures (Gehrke; Clifton, 2014; Gehrke; Wang, 2020).

Associations of land use mix and the dependent variables

Figure 4 summarizes the associations found for the dependent variables. The results show two clear patterns: the first is that both utilitarian and total walking have higher numbers of positive associations compared to the negative ones (25 vs 2 and 22 vs 5, respectively), although these proportions go considerably down if we contrast positive vs non-positive results (25 vs 16 and 22 vs 17). The second is that the evidence of the association between LUM and leisure walking is much less compelling, both because of the low number of studies (13 in total) and of its relatively even distribution across the range of positive and non-positive associations, including three studies that found negative ones. Overall, there were five studies with positive and eight with non-positive results.

A closer look at the two studies with negative association between LUM and utilitarian walking, however, reveals some important points that may explain these results. Lu *et al*. (2018) used the number of retail shops as one of the variables representing the built environment and stated that "All built environment variables were entered the models simultaneously" (Lu *et al*., 2018, p. 8). This is problematic because the number of retail shops is very likely to be highly correlated with land use mix (in this case, an Entropy score with four land use categories). Being mostly composed of

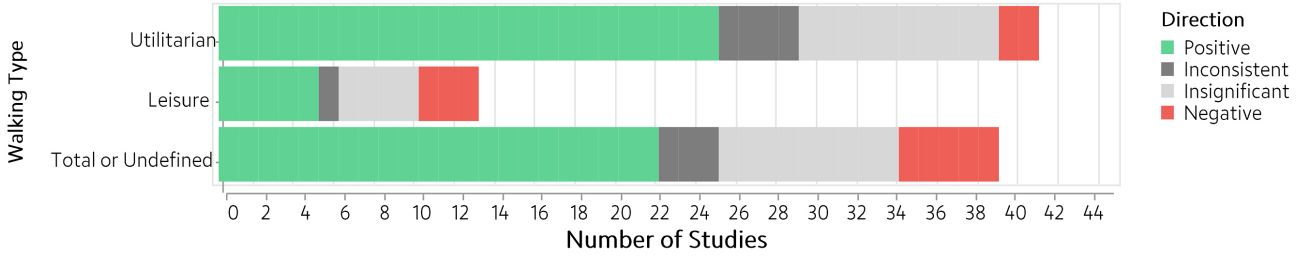


Figure 4 – Direction and intensity of associations of LUM measures and the outcomes included in this study.

Note. A table version of this graph is available in Appendix C (Table S6) and an interactive version where the user can find information about the studies by hovering over the colored bars can be found at https://urbanidades.ufsc.br/saboya-kretzer-calvetti-2025-land-use-mix-and-walking-a-systematic-review/

residential uses, areas with a high presence of retail have, in all but a few cases, higher diversity than the average. This introduces collinearity in the regression model, which may explain the negative sign as a spurious result.

Larrañaga and Cybis's (2014) study presents a similar issue, as it includes the number of shops and services directly in the regression model. Complicating matters further, their representation of land use mix (LUM) classifies areas with a high concentration of jobs as non-mixed (see Table S5, Study ID 30, in Appendix C – https://zenodo.org/records/16793883). However, such areas likely attract substantial volumes of movement – both pedestrian and otherwise – compared to other areas that, while classified as mixed, may in fact contain far fewer non-residential uses.

Associations of specific LUM measures and the dependent variables

Figure 5 shows the combinations of associations between the four most used LUM measures and the dependent variables. Overall, the measures have shown similar performances in capturing associations. Despite all the criticism towards Entropy as a LUM measure (Brown *et al.*, 2009; Manaugh; Kreider, 2013), it showed robust capacity to explain (or at least be associated with) utilitarian and total walking.

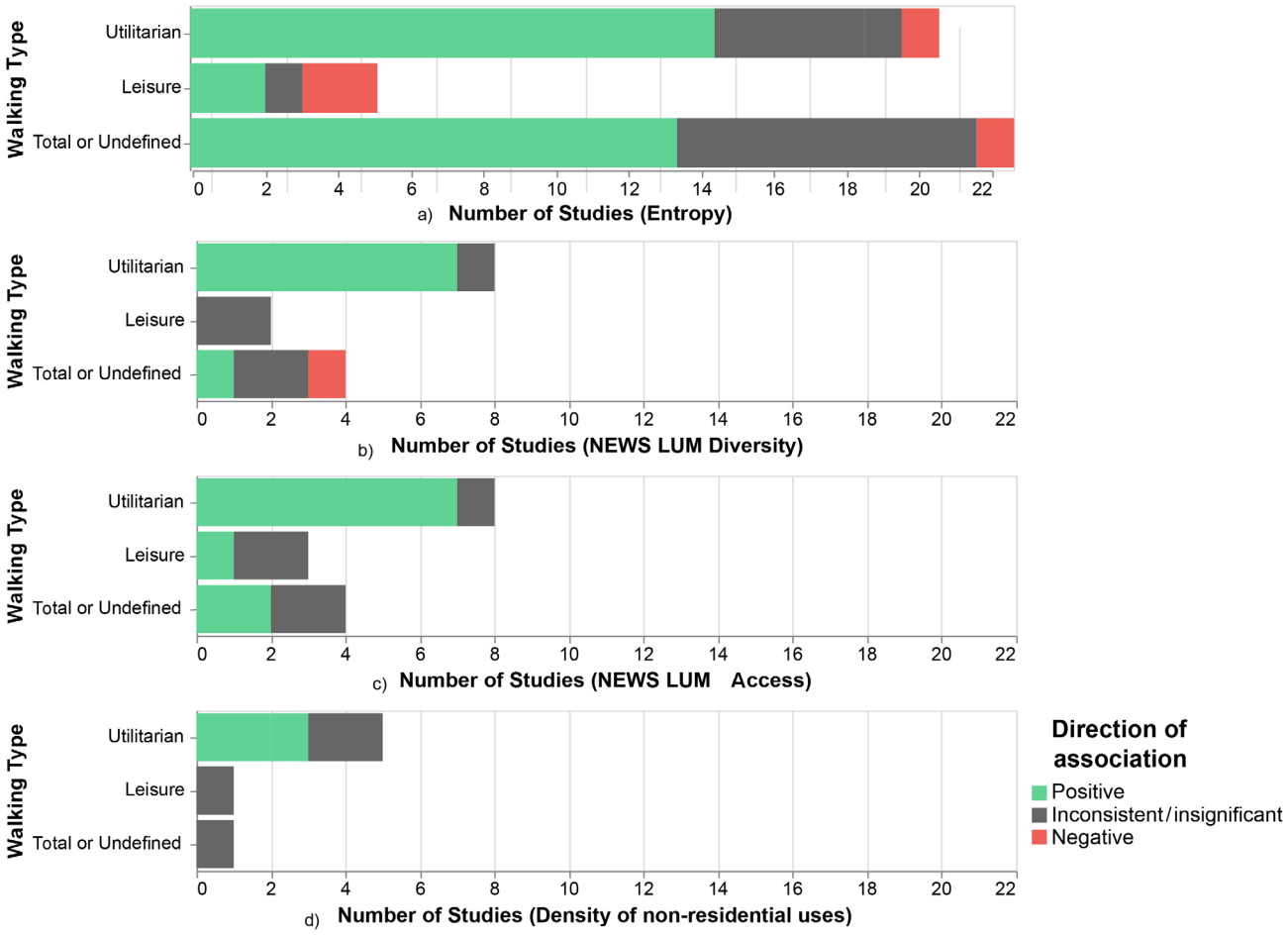


Figure 5 – Associations of LUM and the dependent variables for the four most adopted LUM measures.

Note. Entropy includes weighted entropy; Density of non-residential uses includes retail density (He et al., 2020). A table version of this graph is available in Appendix C (Table S7) and an interactive version where the user can find information about the studies by hovering over the colored bars can be found at https://urbanidades.ufsc.br/saboya-kretzer-calvetti-2025-land-use-mix-and-walking-a-systematic-review/

Gehrke and Clifton's (2014) study is the only one in this review whose main objective was to test and compare LUM measures. Their results showed that for the land use classification with four uses measured at the origin of trips, the Smith-Wilson evenness index in the 2-mile buffer was the most significant in predicting utilitarian walking, albeit with a negative (and counter intuitive) direction. On the other hand, for the land use classification that considered only residential vs non-residential uses, the Smith-Wilson index was again the best predictor, this time with the expected positive sign.

Moudon *et al*. (2007, p. 455) used three different types of LUM measures and concluded that "Measures of distance to destination dominated the model results. In the network models, all but two significant variables were distance measures." However, they did not include entropy in their characterization of LUM.

Final thoughts

This review examined studies that tested the association of land use mix and walking. In addition, it explored in detail the operational aspects involved in capturing and measuring LUM, a challenge that has been eluding researchers for some time.

Associations of LUM and walking

Overall, the patterns of association of LUM and walking were robust for utilitarian and total walking, especially considering that the few negative associations may be due to the inclusion of collinear variables in the regression models, as discussed above. Leisure walking, on the other hand, yielded more non-positive than positive associations. This could be explained, of course, by a lack of association between these phenomena. However, it may also be the case that the land use categories used to measure diversity are not appropriate to explain this type of walking. Table S3 in Appendix C shows that most land use categories refer to generic uses such as residential, commercial, offices, *etc*. A more fine-tuned list of land use categories could help reveal associations to leisure walking. Wang *et al*. (2021), for instance, used "recreative" as one of their categories and found positive associations.

Regarding the measures employed, despite being widely considered as lacking a solid theoretical basis, Entropy showed a good capacity to reveal associations with utilitarian and total walking.

Distance to non-residential destinations also performed well and has the advantage of a more solid justification in terms of its theoretical basis, displaying some interesting characteristics. First, by considering the time to reach non-residential destinations it can differentiate those that are closer from the ones farther away, something that buffer- and zone-based measures usually cannot. Therefore, it overcomes the binary logic of most traditional measures of LUM that rely solely on the presence or absence of each land use in the spatial unit. Second, it also captures aspects of richness, since uses that are not in the vicinity of the respondent's residence (represented by more than 30 minutes of walking) penalize its score. The combination of these two aspects provides an integrated picture of the number and closeness of different uses simultaneously, two fundamental aspects of the concept of land use mix (Song; Merlin; Rodriguez, 2013). Finally, it is increasingly easier to produce objective versions of this measure, given the computational tools and data sources available.

The good performance of distance-based measures seems to be true for both subjective and objective measures of distance and is in line with Ewing and Cervero's (2010) meta-analysis, in which distance to stores had higher associations with walking than Entropy. Unfortunately, Gehrke and Clifton (2014) did not include measures based on distances to non-residential destinations in their comparative study. Thus, more systematic scrutiny focusing specifically on the differences in performance between these two kinds of measures would be welcome.

Limitations

This review has several limitations. First, the search for candidate studies was carried out in only two databases. Although the ones selected are among the most important and cover a wide range of curated journals (Web of Science alone has more than 14,000 journals), further searches in other sources could have yielded a higher number of articles able to meet the criteria for inclusion. The same logic holds for the decision to consider only those articles written in English.

Second, as our analysis showed, the cases are heavily concentrated in developed countries and, more specifically, in English-speaking countries. Studies that examine more cities in Africa, Eastern Europe, Asia, and Latin America could paint a more precise and robust picture of the relation between LUM and the outcomes of interest across the world.

A final consideration relates to the growing tendency to favor the acceptance of positive results for publication (Fanelli, 2012), a factor that should be taken into consideration when interpreting the results presented here.

Further research

Based on the trends observed in the studies covered by this review, their results, and their limitations, we suggest that future studies examining the associations of land use mix and walking should:

- Adopt multiple measures of land use mix to capture different aspects of the construct;
- Base the analysis on network buffers or other spatial units that more closely capture the actual cost of accessing diverse destinations (as opposed to aerial buffers or administrative zones);
- Use land use categories that make sense for the kind of outcome being examined;
- Be mindful of variables and confounders added to the regression models and their potential impact on the resulting coefficients and/or odds ratios, especially those that tend to have high correlation/collinearity with LUM measures;
- Control for the position in the urban system to minimize its potential confounding effect on the associations between land use mix and the dependent variables.

Regarding this last point, none of the studies controlled for the position of the areas in the larger urban context. Many controlled for connectivity, but this is a local measure, while the position in the urban grid considers its relation to the system as a whole. This can be an important issue because the position in the urban grid has been shown to be associated with both the density of commercial and retail uses (Berhie; Haq, 2017) and pedestrian movement (Hillier *et al.*, 1993; Hillier; Iida, 2005), thus potentially confounding the relation of land use mix and walking (Saboya; D'Orsi; Keivani, 2024).

Implications for practice

The results suggest that actions to increase land use mix are indeed effective to foster more utilitarian (and thus total) walking, and therefore should continue to be used in urban public policies in combination with other strategies such as density, compactness, and street grid accessibility, among others. However, for leisure walking, a mix of land uses pertaining to general categories does not seem to be sufficient. Other strategies could be employed, such as the presence and number of parks in the neighborhood (Schipperijn *et al*., 2017), street connectivity, and safety improvements (Kärmeniemi *et al*., 2018).

Furthermore, the positive associations between walking and different LUM measures that focus on different aspects of the phenomenon show that there are several ways to foster land use mix. The evenness in the distribution of land uses, as well as the density and proximity of different land uses may be seen as complementary or alternative strategies, according to each specific situation. They all should be considered when promoting walking, a crucial part of the "intricate pools of fluid street use" (Jacobs, 1992, p. 184) that characterize vibrant and lively urban areas.

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