Received: 24 June 2020 | Accepted: 25 June 2020
DOI: 10.1111/obr.13098

SUPPLEMENT ARTICLE

OBESITY Reviews WILEY

Land use mix in the neighbourhood and childhood obesity

Peng Jia[1,2,3] | **Xiongfeng Pan**[4,3] | **Fangchao Liu**[5] | **Pan He**[6] | **Weiwei Zhang**[7] | **Li Liu**[8] | **Yuxuan Zou**[3,9] | **Liding Chen**[10]

[1]Faculty of Geo-information Science and Earth Observation, University of Twente, Enschede, The Netherlands

[2]Department of Land Surveying and Geo-Informatics, The Hong Kong Polytechnic University, Hong Kong, China

[3]International Institute of Spatial Lifecourse Epidemiology (ISLE), Hong Kong, China

[4]Xiangya School of Public Health, Central South University, Changsha, China

[5]Department of Epidemiology, Fuwai Hospital, National Center for Cardiovascular Diseases, Chinese Academy of Medical Sciences and Peking Union Medical College, Beijing, China

[6]Department of Earth System Science, Tsinghua University, Beijing, China

[7]School of Environmental Science and Engineering, Suzhou University of Science and Technology, Suzhou, China

[8]Aerospace Information Research Institute, Chinese Academy of Sciences, Beijing, China

[9]School of Geographical Sciences, Guangzhou University, Guangzhou, China

[10]State Key Laboratory of Urban and Regional Ecology, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing, China

Correspondence
Liding Chen, PhD, State Key Laboratory of Urban and Regional Ecology, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing 100085, China.
Email: liding@rcees.ac.cn

Peng Jia, PhD, Director, International Institute of Spatial Lifecourse Epidemiology (ISLE); Faculty of Geoinformation, Science and Earth Observation, University of Twente, Enschede 7500, Netherlands.
Email: p.jia@utwente.nl; jiapengff@hotmail.com

Summary

Land use mix (LUM) in the neighbourhood is an important aspect for promoting healthier lifestyles and consequently reducing the risk for childhood obesity. However, findings of the association between LUM and childhood obesity remain controversial. A literature search was conducted on Cochrane Library, PubMed and Web of Science for articles published before 1 January 2019. In total, 25 cross-sectional and two longitudinal studies were identified. Among them, Geographic Information Systems were used to measure LUM in 15 studies, and perceived LUM was measured in 12 studies. Generally, most studies revealed an association between a higher LUM and higher PA levels and lower obesity rates, although some studies also reported null or negative associations. The various exposure and outcome assessment have limited the synthesis to obtain pooled estimates. The evidence remains scare on the association between LUM and children's weight status, and more longitudinal studies are needed to examine the independent pathways and causality between LUM and weight-related behaviours/outcomes.

KEYWORDS
built environment, child, land use mix, obesity

Peng Jia and Xiongfeng Pan contributed equally to this work.

Funding information
State Key Laboratory of Urban and Regional Ecology of China, Grant/Award Number: SKLURE2018-2-5

1 | INTRODUCTION

Childhood obesity is widely accepted as a risk factor for many diseases in children and adolescents and in adults who had overweight or obesity during childhood.[1] The overweight/obesity prevalence among children and adolescents has increased dramatically over the recent decades.[2,3] It is widely accepted that overweight/obesity in children has now become a major public health issue, not only due to its negative impact on children's health but also because obesity during childhood and adolescence has been found to increase mortality rates during adulthood.[4] In addition, overweight/obesity represents a heavy burden on the health care system and society overall. In order to develop more successful interventions aimed at reducing obesity during childhood and adolescence, more research is needed focusing on its causes.[5]

The etiology of obesity during childhood and adolescence is complex and influenced by numerous behavioural, psychosocial, genetic and environmental determinants.[6–9] Neighbourhood environment, where children and teenagers spend most of their free time, is a well-recognized public health determinant,[10,11] and thus plays an important role in children's and teenagers' development, behaviours and weight status.[12] Land use mix (LUM) is an important indicator for neighbourhood walkability, usually represented by an entropy index that measures the extent of mix in the distribution of land uses (e.g., office, residential, retail, entertainment, sporting infrastructure and education) within a given area, with a higher value indicating a greater land use heterogeneity.[13] The association between LUM and obesity remains equivocal. Although some studies have suggested that a higher LUM is associated with a higher level of physical activity (PA), others have demonstrated null associations.[14,15] Also, some study results have shown that living in areas with a lower LUM might increase the risk for childhood and adolescence obesity, whereas other studies have found no associations.[16,17] However, there has been no comprehensive review yet that was specifically targeted at the association between LUM and children's behaviours and weight status, although some previous studies have included LUM in subgroup analyses. For example, a previous review found an association between LUM and PA among children and adolescents, which, however, included only four studies.[18] Another review including five studies about LUM and PA found that the most supported correlates for adolescents PA were LUM and residential density.[12] It is necessary to conduct a systematic review of globally conducted studies examining the association between LUM and PA and childhood obesity.

This study aimed to systematically review the association between LUM and weight-related behaviours/outcomes among children and adolescents. Characteristics of the relevant studies have been summarized and analysed, such as study design and area, measures of LUM (subjectively reported or objectively measured) and weight-related behaviours and outcomes (e.g., diet, PA and sedentary behaviour), in order to demonstrate the strengths and weaknesses of the current evidence. Findings from this study may provide important suggestions for urban planning practitioners and policy-makers on designing urban and community environments to curb obesity.

2 | METHODS

This systematic review followed the Cochrane handbook version 5.1.0, and results of this study were reported by following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) checklist.[19]

2.1 | Study selection criteria

Studies that met all of the following criteria were included in the review: (a) study design: longitudinal (prospective and retrospective cohort studies), cross-sectional, case-control, ecological and intervention studies; (b) study subject: children and adolescents aged under 18 years; (c) exposure of interest: LUM in the neighbourhood; (d) study outcome: weight-related behaviours (e.g., diet, PA and sedentary behaviour) and/or outcomes (e.g., body mass index [BMI, kg/m^2], overweight and obesity measured by BMI, waist circumference, waist-to-hip ratio and body fat); (e) article type: peer-reviewed original research; (f) time of publication: from the inception of the electronic bibliographic database to 1 January 2019 and (g) language: English.

2.2 | Search strategy

A keyword search was performed for relevant studies published by 1 January 2019 on three electronic bibliographic databases: PubMed, Cochrane Library and Web of Science. The search strategy included all possible combinations of the keywords in three groups (LUM, child and weight-related behaviours/outcomes) in the title or abstract field (Appendix S1).

Titles and abstracts of the articles identified through the keyword search were screened against the study selection criteria.[20] Potentially relevant articles were retrieved for an evaluation of the full text. Two reviewers independently screened the titles and abstracts to identify potentially relevant articles for the full-text review. In case of disagreements, the final decision was made by consultation with a third reviewer. Three reviewers jointly determined the list of articles for the full-text review through a discussion. Then, two reviewers independently reviewed the full texts of all articles on the list and determined the final pool of articles to be included in the review.

2.3 | Data extraction

A standardized data extraction form was used to collect information from each selected study, including authors, year of publication, study design, area and scale, sample size and age (at baseline for longitudinal studies), statistical models used, measures of LUM, weight-related behaviours and body-weight status and key findings on the association between LUM and weight-related behaviours/outcomes.

2.4 | Study quality assessment

We used the National Institutes of Health's Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies to assess the quality of each included study.[21] This assessment tool rates each study based on 14 criteria (Appendix S2). For each criterion, a score of one was assigned if 'yes' was the response, whereas a score of zero was assigned otherwise (i.e., an answer of 'no', 'not applicable', 'not reported' or 'cannot determine'). A study-specific global score ranging from 0 to 14 was calculated by summing up the scores of all criteria. The study quality assessment helped measure the strength of the scientific evidence but was not used to determine the inclusion of studies.

3 | RESULTS

3.1 | Study characteristics

We identified a total of 170 articles through the keyword search. After title and abstract screening, 35 articles were excluded. The full texts of the remaining 135 articles were reviewed on the basis of study selection criteria, and 108 of them were further excluded (Figure 1). Included in this study were the remaining 27 studies that examined the association between LUM and weight-related behaviours and/or outcomes among children and adolescents, 25 cross-sectional and two prospective cohort studies with sample sizes ranging from 98 to 22 117 (Table 1). The majority of these studies were conducted in the United States (n = 9), followed by in Belgium (n = 7), the United Kingdom (n = 3) and Canada (n = 4), and one study each was conducted in Australia, Germany, Malaysia and New Zealand. Scores for the study quality assessment were 12 and 13 for two cohort studies and ranged from 8 to 11 for 25 cross-sectional studies (Table S1).

3.2 | Measures of LUM

LUM was objectively measured in 14 studies, all in Geographic Information Systems (GIS) environment, as a dissimilarity index for the degree to which different land uses existed within buffer zones, with varying radii from 0.25 to 1.6 km, centred on individual addresses or schools (Table 2). Values of the dissimilarity index range from zero to one: A value of zero represents the dominance of a single land use type, and a value of one represents an equal balance among all land uses within the area.

Two survey instruments, the Neighborhood Environment Walkability Scale (NEWS) (Appendix S3) and the Neighborhood Environment Walkability Scale for Youth (NEWS-Y) (Appendix S4), were used to capture participants' perception of their neighbourhood environment in 13 studies, including LUM diversity and accessibility.[22] The LUM diversity subscale measures perceived walking proximity from their home to the nearest business or facilities of 13 various types. The response is on a five-point scale from 1 (more than 30 min) to 5 (1–5 min) with a higher total score

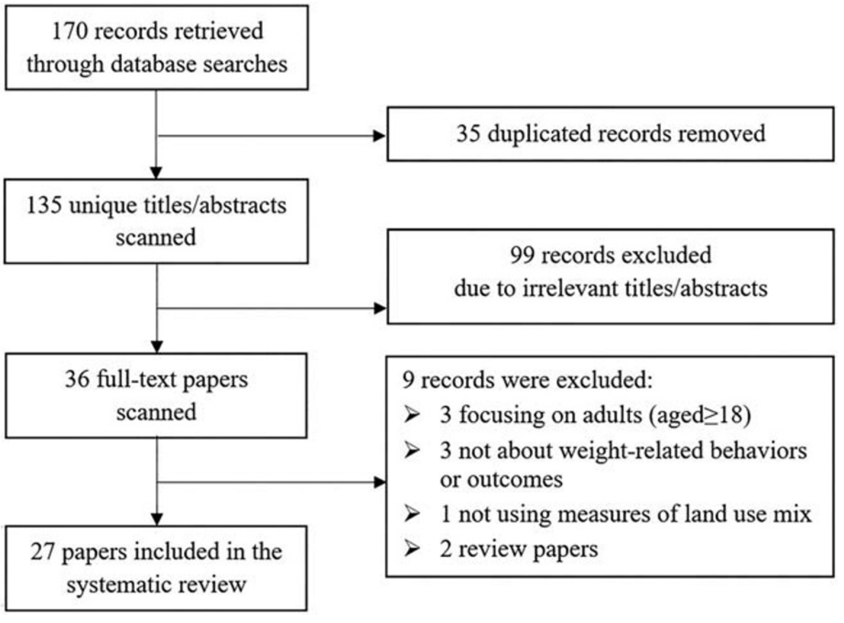

FIGURE 1 Study exclusion and inclusion flowchart

TABLE 1 Basic characteristics of the included studies

First author (year)	Study design[a]	Study area, country (scale)[b]	Sample size	Sample age (years, range and/or mean ± SD)	Statistical model
Buck (2015)[22]	C	Delmenhorst, Lower Saxony, Germany (C)	400	6.7 ± 1.7 in 2007 and 2008	Basic log-gamma regression
Carver (2014)[23]	L	Norfolk, UK (C)	1121	9 and 10 in 2007 and 2008	Multivariable regression
Deforche (2010)[24]	C	East-and West-Flanders, Belgium (S2)	1445	17.4 ± 0.6 in 2008	Moderated multilevel regression
De meester (2013)[25]	C	Ghent, Belgium (C)	637	14.5 ± 0.9 in 2008 and 2009	Stepwise linear regression
De meester (2014)[26]	C	East-and West-Flanders, Belgium (S2)	736	11.2 ± 0.5 in 2010 and 2011	Stepwise linear regression
D'Haese (2015)[27]	C	Ghent, Belgium (C)	606	9–12 in 2011–2013	Multilevel logistic regression
Dwicaksono (2017)[17]	C	New York State, USA (S)	1246	Not available	Ordinary least squares linear regression
Frank (2007)[14]	C	Atlanta, Georgia, USA (C)	3161	12–15 in 2001 and 2002	Logistic regression
Hinckson (2017)[28]	C	Auckland and Wellington, New Zealand (C2)	524	15.8 ± 1.6 in 2013 and 2014	Moderated multilevel regression
Hobin (2012)[29]	C	Ontario, Canada, (S)	22 117	9–12 in 2005 and 2006	Multilevel linear regression
Ito (2017)[30]	C	Massachusetts, USA (S)	18 713	9–12 in 2011–2015	Multilevel linear regression
Kerr (2007)[31]	C	Atlanta, USA (C)	3161	5–18 in 2001 and 2002	Stratified logistic regression
Kligerman (2007)[32]	C	San Diego County, California, USA (C)	98	14.6–17.6 in mid 1980s	Linear regression
Larsen (2009)[33]	C	London, Ontario, Canada (C)	614	11–13 in 2006 and 2007	Stepwise logistic regression
Lovasi (2011)[34]	C	New York, NY, USA (C)	428	2–15 in 2003–2005	Generalized estimating equations regression
Nelson (2010)[35]	C	Ireland (N)	2159	16.0 ± 0.7 in 2010	Bivariate logistic regression
Noonan (2017)[36]	C	Liverpool, England, UK (C)	194	9–10 in 2014	Multilevel linear regression
Oreskovic (2014)[37]	C	Houston, USA (C)	NA	Not available	Linear regression
Rosenberg (2009)[38]	C	Boston, Cincinnati and San Diego, USA (C3)	458	5–18 in 2005	Linear regression
Spence (2008)[16]	C	Edmonton, Canada (C)	501	5.0 ± 0.4 in 2004	Logistic regression
Su (2013)[39]	L	Los Angeles, California, USA (C)	4338	5–7 in 2002 and 2003	Multilevel linear regression
Timperio (2017)[40]	C	Melbourne and Geelong, Victoria, Australia (C2)	788	5–12 in 2002–2006	Linear regression
Tung (2016)[41]	C	Klang, Selangor, Malaysia (C)	250	9–12 in 2016	Multilevel linear regression
Van dyck (2013)[42]	C	Ghent, Belgium (C)	477	13–15 in 2013	Moderated regression
Vanwolleghem (2016)[43]	C	East- and West-Flanders, Belgium (S2)	126	10–12 in 2013	Generalized linear regression
Verhoeven (2016)[15]	C	Flanders, Belgium (S)	562	17–18 in 2013	Zero-inflated negative binomial regression
Voorhees (2011)[44]	C	Baltimore, Maryland, USA (C)	350	9–12 in 2006	Linear regression

[a]Study design: C—cross-sectional; L—longitudinal.
[b]Study scale: (N) —National; (S) —State (e.g., in the United States) or equivalent unit (e.g., province in China and Canada); (S*n*)—*n* states or equivalent units; (CT)—County or equivalent unit; (CT*n*)—*n* counties or equivalent units; (C) —City; (C*n*)—*n* cities.

indicating a larger LUM diversity. The LUM accessibility subscale measures perceived accessibility to neighbourhood services (e.g., ease of walking to public transport and possibilities to do shopping in local areas), which is rated on a four-point scale from 1 (strongly disagree) to 4 (strongly agree), with a higher total score indicating a higher LUM accessibility.

TABLE 2 Measures of land use mix, weight-related behaviours and body-weight status in the included studies

First author (year)	Measures of land use mix (LUM)	Measures of weight-related behaviour	Measures of weight-related outcomes	Results about weight-related behaviour	Results about weight-related outcomes
Buck (2015)[22]	The entropy index of 5 land use types in a 1-km school road-network buffer (playground, green space, residential, institutional and park)	MVPA	NA	LUM was negatively associated with MVPA.	NA
Carver (2014)[23]	The entropy index of 17 land use types in a 1.6-km school road-network buffer (farmland, woodland, grassland, uncultivated land, other urban, beach, marshland, sea, small settlement, private garden, park, residential, commercial, building, multiple-use building, other buildings, road and unclassified)	Walking/cycling independently to school	NA	LUM was associated with walking/cycling independently to school in girls.	NA
Deforche (2010)[24]	Perceived LUM around children's homes by NEWS	Active transportation index (sum of active transport to school and in leisure-time)	NA	LUM diversity was negatively associated with active transportation.	NA
De meester (2013)[25]	Perceived LUM around children's homes by NEWS	Flemish physical activity questionnaire and the Dutch version of the NEWS	NA	A lower degree of LUM diversity is associated with more min/day active transport to and from school.	NA
De meester (2014)[26]	Perceived LUM around children's homes by NEWS-Y	Activity monitor and to fill in a survey questioning demographic factors and the Flemish physical activity questionnaire	NA	More active transport was reported when parents perceived more LUM diversity and good land use mix.	NA
D'Haese (2015)[27]	Perceived LUM around children's homes by NEWS-Y	Actigraph accelerometer for children's PA	NA	The higher LUM was associated with more PA in public recreation space.	NA
Dwicaksono (2017)[17]	The entropy index of 4 land use types in a 1-km school road-network buffer (farmers' market, supermarket, fast-food	NA	Students whose body mass index are at or above the 95th percentile of the sex- and age-specific values are considered obese	NA	Higher land use mix was only significantly associated with lower obesity rates among middle/high school students.

(Continues)

TABLE 2 (Continued)

First author (year)	Measures of land use mix (LUM)	Measures of weight-related behaviour	Measures of weight-related outcomes	Results about weight-related behaviour	Results about weight-related outcomes
	restaurant and intersection)				
Frank (2007)[14]	The entropy index of 3 land use types in a 1-km school road-network buffer (commercial, recreation and open space)	Walked at least once over 2 days	NA	LUM was all significantly related to walking.	NA
Hinckson (2017)[28]	The entropy index of 3 land use types in 0.25-, 0.5-, 1-, 2-km school road-network buffers (residential, park and shopping area)	Perceived attributes related to walking, PA and sedentary behaviour	NA	The higher LUM was associated with more PA in public recreation space.	NA
Hobin (2012)[29]	The entropy index of 3 land use types in a 1-km school road-network buffer (commercial, residential and office)	Students' time spent in PA	NA	A negative association between LUM diversity and students' time spent in PA.	NA
Ito (2017)[30]	The entropy index of 4 land use types in a 0.8-km school road-network buffer (residential, commercial, recreational and institutional)	Walk to school	NA	LUM was associated with the increased odds of children walking to school.	NA
Kerr (2007)[31]	The entropy index of 4 land use types in a 1-km school road-network buffer (residential, commercial, open space and institutional)	Walking	NA	LUM was positively associated with walking.	NA
Kligerman (2007)[32]	The entropy index of 5 land use types in 0.4-, 0.8-, 1.6-km school road-network buffers (residential, recreational, retail, park and institutional)	Accelerometer	NA	LUM was positively associated with MVPA.	NA
Larsen (2009)[33]	The entropy index of 6 land use types in a 1-km school road-network buffer (recreational, agricultural, residential, institutional,	Children's mode of travel to and from school	NA	LUM may contribute to a more appealing walking environment for youths.	NA

TABLE 2 (Continued)

First author (year)	Measures of land use mix (LUM)	Measures of weight-related behaviour	Measures of weight-related outcomes	Results about weight-related behaviour	Results about weight-related outcomes
	industrial and commercial)				
Lovasi (2011)[34]	The entropy index of 5 land use types in a 0.5-km school road-network buffer (subway, bus stop, park, residential and playground)	Accelerometer	BMI z-score	LUM density were positively associated with PA.	LUM density were associated with adiposity
Nelson (2010)[35]	Perceived LUM around children's homes by NEWS	Participants' self-reported active	NA	The positive perception of places for walking/cycling, LUM diversity increased the odds of active commuting to school	NA
Noonan (2017)[36]	Perceived LUM around children's schools by NEWS-Y		NA	LUM diversity was positively associated with active school commuting.	NA
Oreskovic (2014)[37]	The entropy index of 3 land use types in a 1-km school road-network buffer (bicycle path, major road and park)	Accelerometer-determined MVPA	NA	LUM was positively associated with daily MVPA.	NA
Rosenberg (2009)[38]	Perceived LUM around children's homes by NEWS-Y	NA	NA	LUM density was positively associated with PA.	NA
Spence (2008)[16]	The entropy index of 4 land use types in a 1.5-km school road-network buffer (institutional, maintenance, dining and leisure)	NA	Risk of overweight	NA	No significant associations were observed for overweight or obese and LUM
Su (2013)[39]	Fragstats: % of landscape in a particular use, Simpson's diversity index and contagion and interspersion in a 0.5-km home/school road-network buffer	Walking to school	NA	LUM was positively associated with walking to school	NA
Timperio (2017)[40]	The entropy index of 4 land use types in a 0.8-km school road-network buffer (residential, agricultural,	Accelerometer-determined MVPA	NA	LUM was positively associated with MVPA.	NA

(Continues)

TABLE 2 (Continued)

First author (year)	Measures of land use mix (LUM)	Measures of weight-related behaviour	Measures of weight-related outcomes	Results about weight-related behaviour	Results about weight-related outcomes
	governmental and institutional)				
Tung (2016)[41]	Perceived LUM around children's homes by NEWS	PA questionnaire for older children and neighbourhood environmental walkability scale	NA	LUM was positively associated with PA.	NA
Van dyck (2013)[42]	Perceived LUM around children's homes by NEWS	PA questionnaire and the neighbourhood environmental walkability scale	NA	LUM density was positively associated with PA.	NA
Vanwolleghem (2016)[43]	Perceived LUM around children's homes by NEWS-Y	Accelerometer-determined MVPA	NA	LUM accessibility was negatively associated with MVPA.	NA
Verhoeven (2016)[15]	Perceived LUM around children's homes by NEWS	Walking to school	NA	LUM was positively associated with PA.	NA
Voorhees (2011)[44]	Perceived LUM around children's homes by NEWS	Accelerometer-determined MVPA	NA	LUM accessibility was positively associated with MVPA.	NA

Abbreviations: MVPA, moderate-to-vigorous physical activity; NA, not available; NEWS, Neighborhood Environment Walkability Scale; NEWS-Y, Neighborhood Environment Walkability Scale for Youth; PA, physical activity.

3.3 | Association between LUM and weight-related behaviours/outcomes

Twenty-four studies examined the association between LUM and weight-related behaviours expressed as odds ratio (OR) (Table S2) or coefficient values (β) (Table S3), with five studies not reporting OR or β. GIS-based and perceived LUM were measured in eight and 11 studies, respectively. The most number of studies examined children's PA in response to the GIS-based LUM (n = 8) and perceived LUM (n = 11). For GIS-based LUM, 27 associations from eight studies were assessed between LUM and PA among children and adolescents. Among them, 20 associations from five studies reported that an increased LUM was associated with increased PA among children and adolescents, whereas seven associations from three studies reported that no significant associations between them.

A total of 31 associations reported from 11 studies were between PA and perceived LUM, with 14 associations from eight studies about perceived LUM accessibility and 17 associations from eight studies about perceived LUM diversity. When assessing perceived LUM accessibility, 10 associations were positive, that is, the increased LUM accessibility had potential to increase PA among children and adolescents, whereas one study found that higher LUM accessibility was associated with a lower level of walking activity among children. However, three studies reported no significant associations between LUM accessibility and PA levels. Regarding perceived LUM diversity and PA, 13 associations from six studies were positive, but one study identified that higher LUM diversity was associated with a lower probability of walking home from school among adolescents. In addition, three associations from two studies reported no significant associations between LUM diversity and PA levels.

Three studies examined the association between LUM and weight-related outcomes, including overweight/obesity (n = 2) and BMI z-score (n = 1). Two studies reported a negative association between a higher GIS-based LUM and a lower BMI z-score among children (β = −0.11, p < 0.01)[34] and with a lower obesity rate among middle/high school students (β = −0.05, p < 0.01).[17] Another study reported no significant associations between GIS-based LUM and overweight/obesity rate.[16]

4 | DISCUSSION

This study for the first time reviewed the association between LUM and children's weight-related behaviours and/or outcomes. A total of 25 cross-sectional and two cohort studies were identified, and most of them were conducted in the United States. LUM was objectively measured in GIS as a dissimilarity index within a given area/buffer in 14 studies and subjectively perceived via survey instruments in 13 studies. The majority of the included studies measured weight-related behaviours, and only three studies assessed obesity outcome. We found that a higher LUM was associated with more healthy lifestyles and weight status among children and adolescents in two studies, with only one studies revealing a null association. Although some previous reviews for broader themes include some associations between LUM and PA among children and adolescents in subgroup analyses, without a dedicated effort to specifically review this association, the evidence has been weak by including only a limited number of studies conducted mainly in North America.[10,18] This study overcomes these limitations by including more studies from all regions that assessed LUM using both subjectively and objectively measurement for a more systematic and detailed discussion.

We found that a higher LUM, regardless of measures, was more likely to increase children's PA in most of the studies, whereas fewer studies reported negative or nonsignificant associations. The design and livability of neighbourhood environments are important factors in promoting healthier lifestyles and thus reducing the risk for childhood obesity. Studies have suggested that LUM may play an important role on children's active travel,[13] as LUM could increase connectivity.[45] A higher LUM may contribute to a more appealing walking environment or be a proxy for better social environmental factors. In addition, PA is also determined by a combination of multiple environmental factors, such as residential density, bike lanes and public transport infrastructure. Therefore, the independent effect of LUM on childhood obesity needs further theorizing.[14,46,47] Moreover, individual factors also influence this association, including gender and attitudes towards PA among both parents and children. One study included in this review reported gender differences for the association between LUM and walking/cycling independently to school, in which significant associations were only observed among girls.[23] Such gender differences may partly be explained by parental factors, as evidence suggested that fewer parental restrictions are placed on boys than on girls concerning walking/cycling independently to school.[48] As for weight-related outcomes, we found that the risk for overweight/obesity among children and adolescents became lower with the LUM degree increased in two studies. However, due to the small number of studies, this result requires careful interpretation. Given the aforementioned mediating roles of PA in the influences of environmental factors on childhood obesity,[49] future high-quality longitudinal studies are highly needed to examine whether and how LUM could influence childhood obesity.

Some studies suggested that objectively measured LUM did not always match residents' perception on the LUM of their neighbourhoods.[13] Although one may think that findings from studies using objectively measured LUM tend to be more credible than those from studies using subjectively measured LUM, perception may also matter. Using perceived LUM accessibility or diversity, we found that a higher LUM was more likely to increase PA among children and adolescents in most studies, whereas fewer studies reported negative or nonsignificant associations. Generally, a high LUM accessibility is characterized by more playgrounds and parks, and a high LUM diversity is characterized by a wide variety of recreational and leisure facilities; all of them are beneficial to increase children's and adolescents' PA. Therefore, we suggest that governments should provide healthy neighbourhoods with proper houses and a suitable living environment to improve access to mixed land use,[40] as well as increasing LUM diversity (e.g., proximity to green, entertainment and recreational space) to affect the amount of time spent outdoors or pedestrian behaviours.[50]

Some limitations of both this review and most of the current studies should also be noted. First, the current evidence remains limited by the number of available studies, especially longitudinal studies, which may have precluded us to make a causal inference.[51,52] Moreover, we cannot exclude inverse causation when interpreting results, as those involved in more outdoor activities or using more active transport may be more likely to perceive a higher LUM in the neighbourhood. Second, only three studies evaluated weight-related outcomes, which have limited our summarization of the associations between LUM and childhood obesity. Third, various measures of LUM in the included studies have affected the comparability among studies; some studies did not even report specific calculation methods for the entropy index. We were not able to conduct a meta-analysis with decent quality, as we could neither obtain sufficient homogeneous studies for the association between a given measure of LUM and any given outcome nor unify the measures and outcomes used in different studies.[53,54] Fourth, influences of various confounding factors in different studies on our findings could not be fully considered, also due to the lack of a consistent reporting style. Some environmental factors may affect PA and the risk for obesity differently (to different extents or in opposite directions) across regions and over time, such as greenness.[55] To better synthesize findings of different studies for supporting evidence-based policy-making, confounding factors should be better considered and reported in further studies.[56] Lastly, the current capacity of capturing changes in LUM is limited. To measure LUM more frequently to reveal the actual interaction between people and environment, more types of data should be used by multidisciplinary teams to construct time-varying LUM variables, such as satellite data, retail purchasing data and social media data.[57,58] This would also enable more novel methods of constructing LUM variable and the adaptation of LUM to other contexts, such as food outlet mix.[59]

5 | CONCLUSIONS

This study revealed a generally positive association between LUM and higher PA among children, although the independent roles of LUM in children's PA and childhood obesity remain to be explored by more longitudinal studies. We suggest that governments should improve the level of LUM in urban planning to achieve fine-scale urban functional zones. On the basis of the current evidence, we believe that a built environment made for the people but not just for the economy will be beneficial for the whole society from a long run.

ACKNOWLEDGEMENTS

We thank the International Institute of Spatial Lifecourse Epidemiology (ISLE) and the State Key Laboratory of Urban and Regional Ecology of China (SKLURE2018-2-5) for the research support.

CONFLICT OF INTEREST

We declare no conflicts of interest.

ORCID

Peng Jia https://orcid.org/0000-0003-0110-3637
Fangchao Liu https://orcid.org/0000-0001-6316-4481

REFERENCES

1. Han JC, Lawlor DA, Kimm SY. Childhood obesity. *Lancet (London, England)*. 2010;375:1737-1748.
2. Ogden CL, Fryar CD, Hales CM, Carroll MD, Aoki Y, Freedman DS. Differences in obesity prevalence by demographics and urbanization in US children and adolescents, 2013-2016. *JAMA*. 2018;319(23):2410-2418.
3. Jia P, Ma S, Qi X, Wang Y. Spatial and temporal changes in prevalence of obesity among Chinese children and adolescents, 1985-2005. *Prev Chronic Dis*. 2019;16:E160.
4. Ogden CL, Carroll MD, Kit BK, Flegal KM. Prevalence of childhood and adult obesity in the United States, 2011-2012. *JAMA*. 2014;311(8):806-814.
5. Nogrady B. Childhood obesity: a growing concern. *Nature*. 2017;551(7681):S96.
6. Rahman T, Cushing RA, Jackson RJ. Contributions of built environment to childhood obesity. *Mt Sinai J Med, New York*. 2011;78(1):49-57.
7. Zhang X, Zhang M, Zhao Z, et al. Obesogenic environmental factors of adult obesity in China: a nationally representative cross-sectional study. *Environ Res Lett*. 2020;15(4):044009.
8. Jia P, Xue H, Cheng X, Wang Y. Effects of school neighborhood food environments on childhood obesity at multiple scales: a longitudinal kindergarten cohort study in the USA. *BMC Med*. 2019;17(1):99.
9. Jia P, Xue H, Cheng X, Wang Y, Wang Y. Association of neighborhood built environments with childhood obesity: evidence from a 9-year longitudinal, nationally representative survey in the US. *Environ Int*. 2019;128:158-164.
10. Jia P, Cheng X, Xue H, Wang Y. Applications of geographic information systems (GIS) data and methods in obesity-related research. *Obes Rev*. 2017;18(4):400-411.
11. Jia P, Xue H, Yin L, Stein A, Wang M, Wang Y. Spatial technologies in obesity research: current applications and future promise. *Trends Endocrinol Metabol: TEM*. 2019;30(3):211-223.
12. Ding D, Sallis JF, Kerr J, Lee S, Rosenberg DE. Neighborhood environment and physical activity among youth a review. *Am J Prev Med*. 2011;41(4):442-455.
13. Christian HE, Bull FC, Middleton NJ, et al. How important is the land use mix measure in understanding walking behaviour? Results from the RESIDE study. *Int J Behav Nutr Phys Act*. 2011;8(1):55.
14. Frank L, Kerr J, Chapman J, Sallis J. Urban form relationships with walk trip frequency and distance among youth. *Am J Health Promot*. 2007;21(4_suppl):305-311.
15. Verhoeven H, Simons D, Van Dyck D, et al. Psychosocial and environmental correlates of walking, cycling, public transport and passive transport to various destinations in Flemish older adolescents. *PLoS ONE*. 2016;11:e0147128.
16. Spence JC, Cutumisu N, Edwards J, Evans J. Influence of neighbourhood design and access to facilities on overweight among preschool children. *Int J Pediatr Obes: IJPO*. 2008;3(2):109-116.
17. Dwicaksono A, Brissette I, Birkhead GS, Bozlak CT, Martin EG. Evaluating the contribution of the built environment on obesity among New York state students. *Health Educ Behav*. 2018;45(4):480-491.
18. Mackenbach JD, Rutter H, Compernolle S, et al. Obesogenic environments: a systematic review of the association between the physical environment and adult weight status, the SPOTLIGHT project. *BMC Public Health*. 2014;14(1):233.
19. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *BMJ (Clin Res Ed)*. 2009;339:b2535.
20. Pan X, Kaminga AC, Wen SW, Liu A. Catecholamines in post-traumatic stress disorder: a systematic review and meta-analysis. *Front Mol Neurosci*. 2018;11:450.
21. Amidi A, Wu LM. Structural brain alterations following adult non-CNS cancers: a systematic review of the neuroimaging literature. *Acta Oncol (Stockholm, Sweden)*. 2019;58(5):522-536.
22. Buck C, Tkaczick T, Pitsiladis Y, et al. Objective measures of the built environment and physical activity in children: from walkability to moveability. *J Urban Health: Bull N Y Acad Med* 2015;92:24-38.
23. Carver A, Panter JR, Jones AP, van Sluijs EMF. Independent mobility on the journey to school: a joint cross-sectional and prospective exploration of social and physical environmental influences. *J Transp Health*. 2014;1(1):25-32.
24. Deforche B, Van Dyck D, Verloigne M, De Bourdeaudhuij I. Perceived social and physical environmental correlates of physical activity in older adolescents and the moderating effect of self-efficacy. *Prev Med*. 2010;50 Suppl 1:S24-S29.
25. De Meester F, Van Dyck D, De Bourdeaudhuij I, Deforche B, Cardon G. Does the perception of neighborhood built environmental attributes influence active transport in adolescents? *The international journal of behavioral nutrition and physical activity*. 2013;10:38.
26. De Meester F, Van Dyck D, De Bourdeaudhuij I, Cardon G. Parental perceived neighborhood attributes: associations with active transport and physical activity among 10-12 year old children and the mediating role of independent mobility. *BMC Public Health*. 2014;14:631.
27. D'Haese S, Van Dyck D, De Bourdeaudhuij I, Deforche B, Cardon G. The association between the parental perception of the physical neighborhood environment and children's location-specific physical activity. *BMC Public Health*. 2015;15:565.
28. Hinckson E, Cerin E, Mavoa S, Smith M, Badland H, Stewart T, et al. Associations of the perceived and objective neighborhood environment with physical activity and sedentary time in New Zealand adolescents. *Int J Behav Nutr Phys Act*. 2017;14:145.
29. Hobin E, Leatherdale S, Manske S, Dubin J, Elliott S, Veugelers P. A multilevel examination of factors of the school environment and time spent in moderate to vigorous physical activity among a sample of secondary school students in grades 9-12 in Ontario, Canada. *Int J Public Health*. 2012;57:699–709.
30. Ito K, Reardon TG, Arcaya MC, Shamsuddin S, Gute DM, Srinivasan S. Built Environment and Walking to School Findings from a Student Travel Behavior Survey in Massachusetts. *Trans Res Rec*. 2017;78–84.
31. Kerr J, Frank L, Sallis JF, Chapman J. Urban form correlates of pedestrian travel in youth: Differences by gender, race-ethnicity and household attributes. *Trans Res D-Trans Environ*. 2007;12:177–182.
32. Kligerman M, Sallis JF, Ryan S, Frank LD, Nader PR. Association of neighborhood design and recreation environment variables with physical activity and body mass index in adolescents. *Am J Health Promot*. 2007;21:274–2777.
33. Larsen K, Gilliland J, Hess P, Tucker P, Irwin J, He M. The influence of the physical environment and sociodemographic characteristics on children's mode of travel to and from school. *Am J Public Health*. 2009;99:520–526.
34. Lovasi GS, Jacobson JS, Quinn JW, Neckerman KM, Ashby-Thompson MN, Rundle A. Is the environment near home and school associated with physical activity and adiposity of urban preschool children? *J Urban Health*. 2011;88(6):1143-1157.
35. Nelson NM, Woods CB. Neighborhood perceptions and active commuting to school among adolescent boys and girls. *J Phys Act Health*. 2010;7:257–266.

36. Noonan RJ, Boddy LM, Knowles ZR, Fairclough SJ. Fitness, Fatness and Active School Commuting among Liverpool Schoolchildren. *Int J Environ Res Public Health*. 2017;14.
37. Oreskovic NM, Blossom J, Robinson AI, Chen ML, Uscanga DK, Mendoza JA. The influence of the built environment on outcomes from a "walking school bus study": a cross-sectional analysis using geographical information systems. *Geospatial Health*. 2014;9:37–44.
38. Rosenberg D, Ding D, Sallis JF, et al. Neighborhood environment walkability scale for youth (NEWS-Y): reliability and relationship with physical activity. *Prev Med*. 2009;49(2-3):213-218.
39. Su JG, Jerrett M, McConnell R, Berhane K, Dunton G, Shankardass K, et al. Factors influencing whether children walk to school. *Health Place*. 2013;22:153–161.
40. Timperio A, Crawford D, Ball K, Salmon J. Typologies of neighbourhood environments and children's physical activity, sedentary time and television viewing. *Health Place*. 2017;43:121-127.
41. Tung SE, Ng XH, Chin YS, Mohd Taib MN. Associations between parents' perception of neighbourhood environments and safety with physical activity of primary school children in Klang, Selangor, Malaysia. *Child care Health Dev*. 2016;42:478–485.
42. Van Dyck D, De Meester F, Cardon G, Deforche B, De Bourdeaudhuij I. Physical environmental attributes and active transportation in Belgium: what about adults and adolescents living in the same neighborhoods? *Am J Health Promot*. 2013;27:330–338.
43. Vanwolleghem G, Schipperijn J, Gheysen F, Cardon G, De Bourdeaudhuij I, Van Dyck D. Children's GPS-determined versus self-reported transport in leisure time and associations with parental perceptions of the neighborhood environment. *Int J Health Geogr*. 2016;15.
44. Voorhees CC, Yan AF, Clifton KJ, Wang MQ. Neighborhood environment, self-efficacy, and physical activity in urban adolescents. *Am J Health Behav*. 2011;35:674–688.
45. Van Cauwenberg J, Nathan A, Barnett A, et al. Relationships between neighbourhood physical environmental attributes and older Adults' leisure-time physical activity: a systematic review and meta-analysis. *Sports Med*. 2018;48(7):1635-1660.
46. Pan X, Zhao L, Luo J, et al. Access to bike lanes and childhood obesity: a systematic review and meta-analysis. *Obes Rev*. 2020.
47. Kim J-H, Lee C, Olvera NE, Ellis CD. The role of landscape spatial patterns on obesity in Hispanic children residing in Inner-City neighborhoods. *J Phys Act Health*. 2014;11(8):1449-1457.
48. Carver A, Timperio A, Crawford D. Playing it safe: the influence of neighbourhood safety on children's physical activity—a review. *Health Place*. 2008;14(2):217-227.
49. Rundle A, Neckerman KM, Freeman L, et al. Neighborhood food environment and walkability predict obesity in new York City. *Environ Health Perspect*. 2009;117(3):442-447.
50. Botticello AL, Rohrbach T, Cobbold N. Differences in the community built environment influence poor perceived health among persons with spinal cord injury. *Arch Phys Med Rehabil*. 2015;96(9):1583-1590.
51. Jia P, Lakerveld J, Wu J, et al. Top 10 research priorities in spatial Lifecourse epidemiology. *Environ Health Perspect*. 2019;127(7):74501.
52. Jia P. Spatial Lifecourse epidemiology. *Lancet Planet Health*. 2019;3(2):e57-e59.
53. Pan X, Wang Z, Wu X, Wen SW, Liu A. Salivary cortisol in post-traumatic stress disorder: a systematic review and meta-analysis. *BMC Psychiatry*. 2018;18(1):324.
54. Higgins JP, Thompson SG. Quantifying heterogeneity in a meta-analysis. *Stat Med*. 2002;21(11):1539-1558.
55. Jia P, Wang T, van Vliet AJH, Skidmore AK, van Aalst M. Worsening of tree-related public health issues under climate change. *Nat Plants*. 2020;6(2):48.
56. Jia P, Yu C, Remais JV, et al. Spatial Lifecourse epidemiology reporting standards (ISLE-ReSt) statement. *Health Place*. 2020;61:102243.
57. Jia P, Stein A, James P, et al. Earth observation: investigating non-communicable diseases from space. *Annu Rev Public Health*. 2019;40(1):85-104.
58. Jia P, Stein A. Using remote sensing technology to measure environmental determinants of non-communicable diseases. *Int J Epidemiol*. 2017;46(4):1343-1344.
59. Wang Y, Jia P, Cheng X, Xue H. Improvement in food environments may help prevent childhood obesity: evidence from a 9-year cohort study. *Pediatr Obes*. 2019;14:e12536.

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

How to cite this article: Jia P, Pan X, Liu F, et al. Land use mix in the neighbourhood and childhood obesity. *Obesity Reviews*. 2020;1–11. https://doi.org/10.1111/obr.13098