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Built environment and childhood obesity: A systematic review of the European literature

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ABSTRACT

Background: Childhood obesity is a major public health issue, identifying pathways to it is crucial. The term "obesogenic environment" describes neighborhood traits linked to higher obesity risk, but it's unclear which environmental factors increase this risk and which neighborhood changes can improve outcomes.

Methods: Articles published between 2000 and June 2024 from PubMed, Cochrane Library, and Web of Science databases conducted in EuropeanUnion countries were included, focusing on children aged 0-18.

Results: We found 2,531 articles initially and 1,278 in a second search, with 43 meeting all the criteria. Studies examined green space, air and noise pollution, facility richness, sports facilities, food environment, land-use mix, housing, walkability, street connectivity, and traffic. Only food environment and green space showed associations with childhood obesity, which mostly disappeared after adjusting for individual socioeconomic factors. Other environment variables showed no consistent associations. Further research is needed to understand how neighborhood properties influence childhood obesity.

Keywords: children, adolescents, obesity, built environment, Europe

INTRODUCTION

Childhood obesity is a worldwide and continuously debated topic. In the last decade, it has reached concerning levels in European countries; in 2010, approximately 28.4% of children under 10 years were classified as overweight or obese according to the WHO standards [1]. Since then, the prevalence of overweight and obesity (OAO) appeared to have plateaued temporarily but showed an increasing trend again after the COVID-19-related lockdowns [2, 3]. Thus, in 2022, the prevalence of overweight among 5-9 years old children was about one in three children (29.5%) [4].

Being overweight or obese at a young age leads to a higher risk of obesity in adults and is strongly associated with metabolic and cardiovascular diseases [5]. In addition, childhood obesity is associated with social exclusion, depression, lower income in later life, and the need for long-term medical treatment [4]. Hereby, it is estimated that obesity costs European health care systems about 152.91 billion dollars every year with additional 350.71 billion dollars of indirect costs and economic losses [6-8].

Before this background, it is of high priority to identify pathways leading to obesity that could potentially be used for prevention. Despite the establishment of biological and behavioral factors in research on OAO since many years, interventions targeting the individual have thus far been of limited use in ending the "obesity pandemic" [9-11].

Social Determinants of Childhood Obesity

Health is influenced by the circumstances that a person experiences in early life [12]. These economic and social conditions established by the WHO as social determinants of health are, at least in theoretical discourse, undisputed in their relevance to the emergence of diseases [13]. The distribution of social determinants is shaped by spatial clusters [14], which are also reflected in clusters of disease prevalence, such as the regionally clustered prevalence of childhood overweight. Hereby, childhood overweight is not evenly distributed across a city or country but clustered in certain neighborhoods [15]. Thus, more recent approaches in obesity research assume that the neighborhood itself may contain influencing factors that promote overweight in children. Therefore, close examination of the neighborhood environment has become a common strategy for the identification of relevant factors and promotion of suitable neighborhood interventions to tackle obesity among children [16].

In this context, the term "obesogenic environment" has become an established term. Generally, an obesogenic environment is characterized by a lack of ability to encourage physical activity, specific land use patterns, and an unhealthy food environment. However, due to different definitions and

Table 1. Urban environment characteristics

		N	Source	+	←	0	→	-
Green space	Green space unspecified	13	[R2, R3, R8, R9, R13, R15, R16.1, R17, R19, R23, R25, R30, R37]	0	1	4	7	1
	Vegetation NDVI	9	[R3.1, R9, R13, R15, R16.1, R19, R25, R31, R34]	0	0	1	4	4
Pollution	Air pollution	9	[R2, R15, R16, R20, R25, R27, R37, R39, R41]	4	2	2	1	0
	Noise pollution	5	[R2, R22, R25, R29, R37]	0	4	0	1	0
Facilities*	Facility density	5	[R9, R10, R11, R15, R24]	0	2	1	2	0
	Sports facilities & number of playgrounds	9	[R2, R3, R6, R9, R10, R11, R14.1, R16.2 R17, R28]	0	3	1	5	1
	Food environment	6	[R1, R5, R6, R9, R15, R21]	4	2	0	0	0
	Land-use mix	3	[R9, R15, R16.1]	0	1	1	0	1
	Housing	6	[R2, R4, R9, R12, R14, R30]	Explained in text				
Streets	Walkability	9	[R3, R7, R10, R11, R15, R18, R35, R36, R38]	0	2	1	4	2
	Street connectivity	6	[R8, R9, R10, R11, R15, R16.1]	1	2	2	1	0
	Traffic	10	[R2, R6, R7, R10, R15, R24, R26, R27, R32, R40]	2	2	3	3	0

Note. N: Number of articles that examined the variable; All associations are shown after adjustment for individual-level covariates: +: Positive association, remains significant after adjustment for covariates, ←: Positive association, either not significant or not certain after adjustment (confidence interval's including 1), 0: No association or insignificant associations in mixed directions; →: inverse association, either not significant or not certain after adjustment (confidence interval's including 1), -: Inverse association, remains significant after adjustment for covariates; & *Facilities including businesses, educational facilities, churches, libraries, museums, post offices, banks, supermarkets, shopping centers, pharmacies, and health services

methods of data collection and analysis, uncertainty remains regarding what an obesogenic environment consists of [17]. For our research, we adopted a broad conceptualization of the environment and collected all variables concerning the urban environment that appeared in the included articles. By the term "built environment", in the following we refer to physical factors surrounding an individual at the neighborhood level, such as food supply, spaces for recreation, traffic and road related factors and pollution.

Research Gap

Despite the longstanding investigation of built environment factors, data for continental Europe concerning these factors are scarce, with most research being done in the USA and the UK [18]. This is problematic since studies in urban planning have shown that continental Europe differs from both the USA and the UK in its urban planning tradition [19]. Therefore, it has been convincingly argued that much of the existing literature cannot be easily generalized to the European situation [20]. Furthermore, the majority of research on this topic investigates adult populations and can therefore not necessarily be used to inform interventions targeting childhood obesity.

To our knowledge, this review is the first to systematically collect built environment variables studied in continental Europe and assesses their relationship with childhood OAO.

METHODS

The purpose of this review was to identify the environmental variables that have been examined for their association with overweight European children. We conducted this review in accordance with the standardized PRISMA guidelines for systematic reviews [21, 22]. It was registered in PROSPERO under number CRD42022342914.

Search Strategy & Study Selection Criteria

We searched PubMed, Cochrane Library, and Web of Science with a 4 grouped search string inspired by the population, intervention, comparison and outcome method [23]. The population focus was on children, so the string included synonyms just as *child*, *primary school*, *pupil*, *infant*, and *adolescents.* To identifying environmental variables, we used the terms *neighborhood*, *residence*, *residential*, *residence characteristics*, *home environment*, and *environment*, in order not to cause bias by assuming particular variables in advance. The outcome group consisted of terms for weight measurements and overweight classifications like *obese*, *adipose*, *overweight*, and *BMI*. The full search string for each database and additional information on dates is presented in **Appendix A**. The fourth group contained the MeSH term Europe and named every country that is part of Europe in a broad sense on 7 April 2024 [24].

The selection criteria included articles published after 2000, written in English or German, with a cross-sectional or longitudinal study design. The study participants had to be younger than 18 years of age. To be eligible, at least one built environment variable of home residence had to be examined in association with childhood overweight. The outcome had to be measured in an established and age-appropriate manner, such as BMI percentile, BMI z-score, waist circumference, or diagnosed obesity according to the classification of diseases 10 (ICD-10).

Every study had to be conducted in a country that was part of the European Union on 7 April 2024 [24]. Two reviewers independently screened the article titles and abstracts using Rayyan's research collaboration platform [25]. Discrepancies were resolved by discussion and supervision between reviewers and a third expert adjudicated on full-group consensus when needed.

Data Collection, Synthesis, and Analysis

For each original article, data were extracted concerning the following information: first author, year of publication, publishing journal, country, study design, population size, participants' age, built environment variables assessed and their methods of evaluation, weight measurement, statistical model for the measurement of association, adjustment variables, and effect size. Each environmental characteristic that was investigated in at least two or more publications is evaluated descriptively in the following and is presented in **Table 1**. Due to the stark heterogeneity in the studies' reporting of the investigated association, no meta-analysis was possible. Still, we illustrate meta-analytical findings for selected built environment variables in forest-plots.

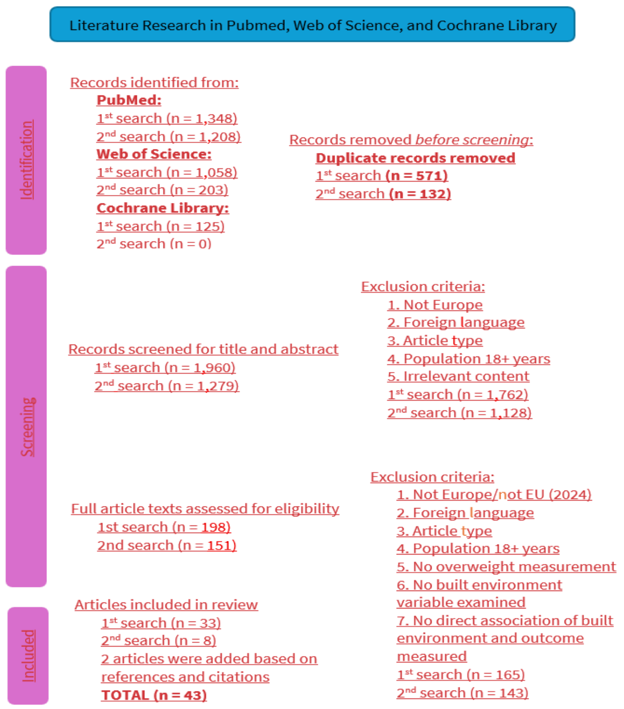

Figure 1. PRISMA 2020 flow diagram for new systematic reviews which included searches of databases and registers only [22]

Study Quality Assessment

The quality of the included studies was assessed using the JBI Critical Appraisal checklist [26].

RESULTS

The first search on 7th April 2022 identified 2,531 articles. After removing duplicates, title and abstract screening started with 1,960 individual articles. A total of 1,762 articles were excluded because they did not meet all the eligibility criteria. We then screened the remaining 198 full texts, of which 33 met all inclusion criteria and were included in our final analysis. We performed a second search on 4th June 2024 to identify articles published in between. Hereby, we screened another 1.278 individual articles, of which eight met all the inclusion criteria and entered our analysis. Based on references and a backward citation search, we identified two more articles relevant and suitable for inclusion, which led to a final number of 39 studies published in 43 articles (**Figure 1**).

Characteristics of the Included Studies

We included ten articles from Germany, ten from Spain, six from Portugal, four from Italy, three from the Netherlands, three from Sweden, and one from Belgium, Ireland, Denmark, the Czech Republic, and Lithuania each. Two studies recruited study subjects from up to eight different European countries. Thirty articles used a cross-sectional study design, 14 a longitudinal one and one article applied both. All articles were published after the year 2009.

The ages of the participants ranged from 0 to 18 years. The sample size varied between 62 and 944.487 children. For the most part, trained staff measured weight and height. Age and sex specific BMI percentile curves were applied to these measurements. The main characteristics of the included studies are presented in **Table 2**.

Table 2. Study characteristics

ID	Author	Year	Country	SS	Age	WM	SD	QA
R1	Buck et al.	2013	Germany	384.000	6-9	BMI z-score	CS	7/8
R2	Schüle et al.	2016		3.499	5-7	BMI IOTF	CS	8/8
R3	Zhou et al.	2020		22.678	4-8	BMI z-score	CS	8/8
R3.1	Zhou et al.	2021		22.678	4-8	BMI z-score	CS	8/8
R4	Bredenbeck	2010		1.195	9-7	BMI KHP	CS	7/8
R5	Lakes and Burkart	2016		28.159	5-6	BMI KHP	CS	4/8
R6	Lange et al.	2011		3.440	13-15	BMI KHP	CS	7/8
R7	Gose et al.	2013		485.000	6.1	BMI z-score	L	11/11
R8	Poulain et al.	2020		800.000	3-19	BMI z-score	CS	8/8
R33	Badpa et al.	2023		62.212	1.28	BMI z-score	CS	8/8
R9	Ribeiro et al.	2020	Portugal	5.203	7	BMI z-score	L	11/11
R10	Ferrao et al.	2013		2.690	3-10	BMI IOTF	CS	7/8
R11	Machado-Rodrigues et al.	2014		1.885	7-9	BMI IOTF	CS	4/8
R12	Pereira et al.	2019		929.000	7.28	BMI IOTF	CS	8/8
R13	Melo et al.	2021		62.000	12-18	BMI z-score	CS	7/8
R38	Lourenco et al.	2024		832.000	3-10	BMI IOTF	CS	8/8
R14	Villanueva et al.	2016	Spain	727	6-15	BMI IOTF	CS	6/8
R14.1	Albaladejo et al.	2014		727	6-15	BMI IOTF	CS	6/8
R15	de Bont et al.	2021		2.213	9-12	BMI z-score	CS	8/8
R16	de Bont et al.	2021		416.955	2-15	BMI z-score	L	11/11
R16.1	de Bont et al.	2020		79.992	1-5	BMI z-score	L	11/11
R16.2	Sánchez-Valdivia	2022		75.608	2-5	BMI z-score	L	11/11
R17	Molína Garcia et al.	2021		83	6-12	BMI CDC	CS	7/8
R18	Molína Garcia et al.	2017		465	14-18	BMI CDC	CS	6/8
R19	Dadvand et al.	2014		3.178	9-12	BMI z-score	CS	8/8
R37	López-Gil	2023		4.378	2-14	BMI IOTF	CS	8/8
R20	Frondelius et al.	2018	Sweden	5.815	4-5	BMI IOTF	L	11/11
R21	Hamano et al.	2017		944.487	0-14	ICD-10	L	11/11
R22	Wallas et al.	2019		4.089	1-16	BMI IOTF	L	11/11
R23	Hrudey et al.	2015	Netherlands	3.409	5-6	BMI z-score	CS	8/8
R24	Schmidt et al.	2015		1.887	4-9	BMI z-score	L	11/11

Table 2 (Continued). Study characteristics

ID	Author	Year	Country	SS	Age	WM	SD	QA
R25	Bloemsma et al.	2019	Netherlands	3.680	3-17	BMI IOTF	L	11/11
R26	Grassi et al.	2016	Italy	1.164	6-8	BMI WHO	CS	7/8
R27	Fioravanti et al.	2018		719.000	4-8	BMI z-score	CS, L	8/8, 11/11
R34	Bellisario	2022		2.065	11-13	BMI IOTF	CS	8/8
R36	Gallotta	2022		1.149	8-13	BMI IOTF	CS	8/8
R28	Nelson and Woods	2009	Ireland	4.720	15-17	BMI WHO	CS	8/8
R29	Christensen et al.	2016	Denmark	40.974	7	BMI z-score	L	11/11
R30	Spilkova and Spilkova	2016	Czech Republic	1.025	14-15	BMI WHO	CS	6/8
R31	Petraviciene et al.	2018	Lithuania	1.489	4-6	BMI IOTF	CS	8/8
R35	De Ryk	2024	Belgium	120.000	1-5	Belgian GRC	L	11/11
R32	Vrijheid et al.	2020	various	1.301	6-11	BMI z-score	L	11/11

Note. SS: Sample size; WM: Weight measurement; SD: Study design; QA: Quality assessment; & GRC: growth reference chart

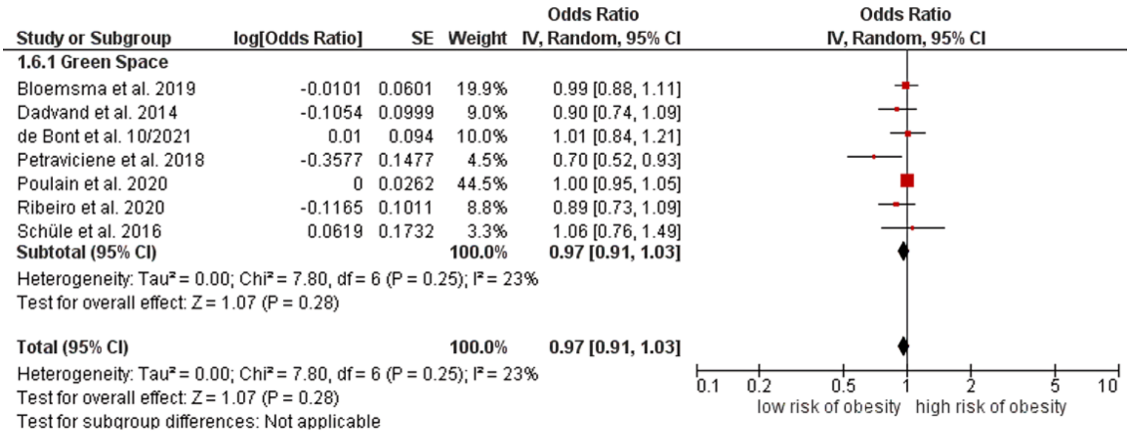

Figure 2. Forest plot green space (Source: Authors' own elaboration, generated with RevMan 5.4)

Environmental Determinants

We identified 15 built environment characteristics that describe an aspect of the area in which a child lives. The definitions of built environment variables contained both measured and subjectively perceived data. The variables that only appeared in a single study were species richness, light pollution, and accessibility of bus stops. Except for light pollution, these variables did not have an independent association with the outcome.

Not having access to the crude data, we created **Table 2** which displays the articles' information about the direction of the association and whether the association was deemed "statistically significant" by the authors of the respective study. For all outcomes that remained statistically significant after adjustment, effect sizes are provided in the main text for each corresponding variable, when available.

Green space

Green space emerged as built environment characteristic that was covered in studies most often, namely in 13 articles. Hereby, the definitions of green space were quite heterogeneous: the majority of articles measured "green space" as the presence of green space or park land within a 300-500 m radius around the home. Another three articles relied on parental perception and satisfaction with accessible green space via questionnaires [R2, R23, R30].

In terms of green spaces' association with childhood obesity, eight articles reported a negative association [R3, R9, R16.1, R17, R19, R23, R25, R30]. indicating that more green space is associated with less obesity. In seven of these, the associations were attenuated after adjustment for individual-level characteristics. In [R17], the negative association remains, but only for park land within a 250 m radius, and not for the number of parks. Three articles reported inconsistent findings with changing associations for different buffer zones for green space [R13] and different green space measurements [R2, R15]. Finally, one article reported no association [R8] and one article a positive one [R35].

With respect to potential confounders of the association between green space and obesity, the most common covariables that were considered for adjustment were parental education and individual or neighborhood socioeconomic status (SES), the latter often measured in the form of neighborhood deprivation. Interestingly, [R2] reported different directions of association between the measured park space and parent-perceived park space. The results of the studies for which the data were available are presented in a forest plot (**Figure 2**). It becomes evident that, after adjustment, only a small, pooled effect is observed, with a confidence interval that includes 1.

Vegetation

Conceptionally related to green space, vegetation is most often quantified using the normalized difference vegetation index (NDVI), a method to homogenize the varying definitions of green space, and to produce standardized data. Therefore, we categorized vegetation as a variable in its own right. Overall, nine articles examined the NDVI within 100 m, 300 m and 500 m buffers around the place of residence. Among them, eight articles reported a negative association, meaning that the more vegetation, the less overweight outcomes [R3.1, R9, R15, R16.1, R19, R25, R31, R34].

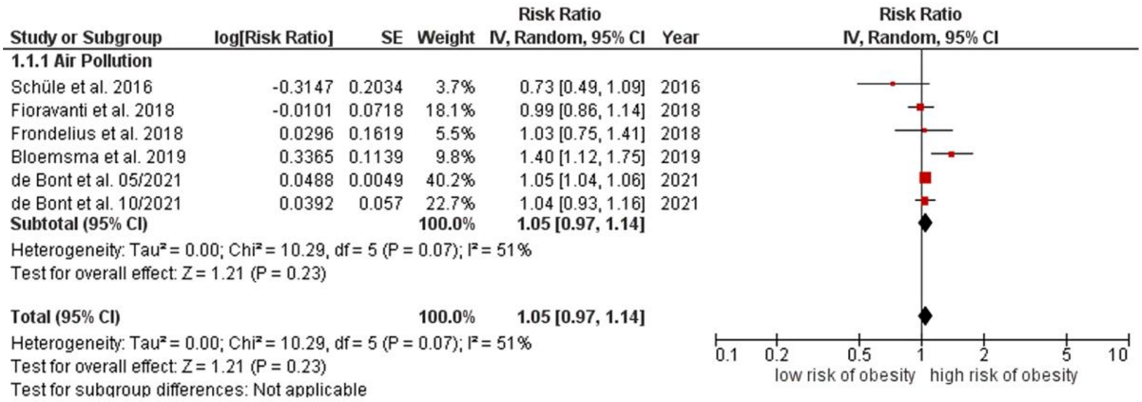

Figure 3. Forest plot air pollution (Source: Authors' own elaboration, generated with RevMan 5.4)

4 articles reported a remaining negative association after adjustment [R3.1, R19, R31, R34, R19] showed such an association for all distance buffer zones (100 m, 300 m, and 500 m), whereas [R31] displayed this only for the 100 m radius. For 100 m, the estimates in both studies were very similar: [R19]: OR = 0.83 (95% CI: 0.75; 0.93); [R31]: OR=0.70 (95% CI: 0.52; 0.91). Meanwhile, [R3.1] reported an extremely small effect (β = -0.01 [95% CI: -0.05; -0.01]) but showed that only green space measured in NDVI had a negative association with the outcome, while other green space measurements did not. R34 showed a significant association for NDVI within a 1,500 m buffer zone (OR = 0.11 [95% CI 0.02-0.56]). Each article adjusted its regression models for different covariables. Parental education at the individual level and the deprivation index at the neighborhood level were the most common.

Air pollution

Our search identified nine articles that investigated the association between air pollution and childhood overweight. Hereby, six articles measured NO_2 concentrations [R15, R16, R20, R25, R27, R39]; two quantified different sizes of particulate matter ($PM_{2.5}$ [R37] and PM_{10} [R35]); and one relied on parental perceptions of air pollution [R2].

Hereby, six articles showed positive associations [R15, R16, R20, R25, R35, R37], whereas one article showed a negative association [R2]. One article reported opposite associations for different age groups [R27] and another for different measurements of air pollution [R39]. In three articles, the associations vanished after adjusting for parental education, deprivation, parental BMI, and individual family income [R2, R15, R20]. As illustrated in **Table 2**, in four articles, the positive associations remained after adjustment ([R16] HR = 1.05 [95% CI: 1.04; 1.07]; [R25] OR = 1.40 [95% CI: 1.12; 1.74]; [R37] β = 5.82E-03 [95% CI: 2.65E-04; 1.14E-02]; [R39] OR = 1.35 [95% CI: 1.11; 1.64]).

It is noteworthy that the article that reported a negative association between air pollution and overweight [R2] measured parental perception and satisfaction with air quality, in contrast to the objective measures in other articles. This slightly positive but uncertain association is displayed in a forest plot in **Figure 3**.

Noise pollution

Five articles examined noise pollution in the neighborhood as a determinant of childhood obesity. Four of them measured road traffic noise in dB [R22, R25, R29, R35], whereas one relied on parental perceptions of noise burden [R2].

Four of these articles found positive associations: the higher the noise pollution, the higher the risk of being overweight or obese as a child. In contrast to that, one article reported an inverse relation.

Each article adjusted their regression models for slightly different individual-level variables, but all of them adjusted for maternal BMI and maternal education or occupation. In all articles, these adjusted models did not find a remaining association of noise pollution and overweight after adjustment.

Facility density

We analyzed five articles that examined the relationship between facility density and OAO in children. Facility density measures the presence of various destinations in a neighborhood, such as businesses, educational facilities, churches, libraries, museums, post offices, banks, supermarkets, shopping centers, pharmacies, or health services. Two articles applied measurements of facility density within a 300-400 m radius of children's homes [R9, R15]. Three articles used parental perceptions of facility richness [R10, R11, R24]. Articles employing objective measurements reported slightly positive associations between facility richness and childhood obesity, whereas articles based on parental perceptions reported slightly negative associations.

However, after adjusting for individual-level covariates, the observed associations became negligible or vanished. The most common adjustment variable was maternal or parental education level.

Sports facilities and number of playgrounds

Ten of the articles analyzed reported on sports facilities, the presence of playgrounds, and other leisure facilities. Three of these articles investigated the number of sports facilities per inhabitant and participants' distance to sports facilities [R6, R9, R14.1], whereas four other articles analyzed the number of and distance to playgrounds [R2, R3, R17, R16.2]. Additionally, three articles assessed parental perceptions of the availability of leisure facilities in neighborhoods [R10, R11, R28].

None of the objectively measured variables demonstrated an association with the outcome after adjusting for potential confounders and the directions of the associations varied across studies. In contrast, all subjectively perceived variables showed a negative association, indicating that neighborhoods perceived as having more leisure facilities were associated with a lower likelihood of childhood OAO.

Only one of the articles found a negative association that persisted after adjustment, but this association was negligible ([R28] OR = 0.98 [95% CI: 0.97; 0.99]).

Food environment

All six articles examining the food environment focused on the number of fast-food outlets or other sources of unhealthy meals within a given area or per capita.

All six articles reported a positive association between the availability of fast-food outlets and childhood OAO.

In four of these articles, the association remained after adjusting for confounders [R5, R6, R9, R21]. However, in the other two articles, the association disappeared after adjustment [R1, R15].

Each article included different sets of co-variables in their models, but it was consistently observed that adjustments for factors such as family income, parental education, or neighborhood deprivation often weakened the relevance of the food environment.

Land-use mix

Land-use mix, a built environment variable that relates facility density to the proportion of buildings designated for residential purposes, was examined in three studies [R9, R15, R16.1].

The findings across these articles were inconsistent: [R9] found no association between land-use mix and childhood OAO; [R15] reported a slightly positive association, which disappeared after adjustment for individual-level variables. Conversely, [R16.1] identified a negative association between land-use mix and overweight that remained after adjustment (β = -0.027 [95% CI: -0.042; -0.012]).

However, it is important to note that parental education, a commonly adjusted confounder in similar models, was not included as a covariable in [R16.1], so these findings might still be biased.

Housing

The relationship between housing and childhood obesity is complex and difficult to generalize because of the often crude categorization of housing types and the lack of precise scales for the measurement of housing quality.

Six articles explored the association between various housing forms and being overweight. Housing types were categorized into multiple dwellings [R2, R9]; suburban housing estates [R4, R30]; older buildings with mixed land use [R12], newer buildings with green spaces [R12], urban row houses [R12], and suburban semi-detached houses [R2].

[R4] found a positive association between peripheral large suburban housing estates and OAO in children, compared to a heterogeneous inner-city reference category. Similar results were found in [R2, R30], where children living in multiple dwellings or housing estates showed a higher risk of being overweight than those in other housing types. These positive associations remained after adjustment for [R2, R4] but disappeared in [R30] ([R2] OR = 1.65 (95% CI: 1.17; 2.31); [R4] β = 0.105 [95% CI: not given]). Adjustments in these studies accounted for SES and nationality. [R4] also found a negative association between OAO and living in older workers' suburbs, inner-city individual housing estates, and peripheral individual housing estates compared to a medium-exposed reference value.

[R12] reported a negative association between living in newer buildings with urban green space and OAO compared to older buildings and mixed land use (OR = 0.48 [95% CI: 0.24; 0.97]). In contrast, R9 did not find any association between dwellings per hectare and OAO, and the article did not further elaborate on the definition of the variable.

Walkability

The walkability of a neighborhood is another built environment characteristic explored in nine articles for its association with childhood weight outcomes. Six articles used an objectively measured walkability index score, with definitions varying but consistently incorporating population density, street connectivity, and land-use mix [R3, R7, R15, R18, R35, R36]. Three articles assessed parental perceptions of neighborhood walkability [R10, R11, R38].

Among the articles using objective measurements, [R3, R15, R38] reported a positive association between walkability and OAO, whereas [R7, R18] found negative associations. R38 presented mixed results, noting different directions of association across different age groups.

Articles based on parental perceptions [R10, R11] indicated that better perceived walkability in the neighborhood is associated with a slightly lower risk of being overweight in children. However, after adjusting for individual-level characteristics, most associations weakened or disappeared, as displayed in **Table 2**.

Notably, [R7, R36] reported positive associations for car-dependent neighborhoods, which is inverse to walkability. Both articles concluded that lower walkability is linked to increased OAO ([R7] β = 0.45 [95% CI: 0.18; 0.72]; [R36] OR = 6.89 [95% CI: 1.94; 24.43]).

Street connectivity

Six articles investigated the relationship between street connectivity and childhood OAO. Hereby, four articles used objective measures, counting street intersections and calculating the percentage of streets that are not dead ends per square kilometer or within defined buffer zones around the home [R8, R9, R15, R16.1]. Two articles relied on parental perceptions of four-way intersections in the neighborhood as a proxy for street connectivity [R10, R11].

The results were heterogeneous: [R9, R15] found no association between street connectivity and OAO. Meanwhile, [R8] reported slightly positive ORs for higher street connectivity, indicating a modest increase in the likelihood of OAO (OR = 1.09 [95% CI: 1.00; 1.18] for children aged 3-10 years; OR = 1.08 [95% CI: 1.01; 1.16] for those aged 10-19 years) after adjusting for gender, SES, and the proportion of social benefit recipients.

Unlike other articles, R8 did not adjust for parental education, which may explain some of the observed variations in the findings.

Traffic

Ten articles investigated the association between traffic and childhood OAO. Four articles used objective measurements, such as counting vehicles passing per day and calculating traffic density [R6, R15, R27, R32]. The other six articles collected parental perceptions of traffic, including the frequency of passing vehicles and general traffic levels around homes [R2, R7, R10, R24, R26, R40].

Four of the ten articles reported positive associations, indicating that higher traffic levels were associated with an increased risk of OAO in children. After adjusting for covariables such as parental education, ethnicity, birth weight, and SES, the positive associations remained in two studies ([R10] OR = 1.37 [95% CI: 1.11; 1.72]; [R32] OR = 1.39 [95% CI: 1.02; 1.89]).

Conversely, three articles found negative associations between parental perceptions of traffic and OAO; however, these associations disappeared after adjustment. Overall, the associations observed between the objectively measured traffic data and parental perceptions of traffic were not substantially different.

DISCUSSION

This systematic review examined the relationships between different dimensions of the built environment and OAO in children across the European Union. A total of 43 articles met the eligibility criteria, and 15 built environment characteristics were evaluated for their association with OAO. Hereby, our findings indicate that the current literature does not consistently identify built environmental characteristics that are independently (i.e., after adjustment for individual social status variables) associated with OAO in children. In the discussion, we will now focus on the two built environmental characteristics that most strongly indicate an association with the outcome, namely food environment and green space.

Food Environment

The association between OAO in children and built environmental characteristics appeared to be strongest for fast-food supply, which was investigated in six articles. All associations followed the same positive direction and four of them stated to have found an association that was not confounded by individual-level characteristics. These findings align with findings from another systematic review concerning overweight adults, stating that in some populations, accessibility of fast-food outlets can be identified as a risk factor for obesity, while there is no association in other populations [27]. Especially in the UK, neighborhood health research intensively engages with the relationship between food supply and health outcomes. Hereby, the study in [28] found mixed results in a large birth cohort in Southampton, where 10-11-year-olds were at a higher obesity risk with increasing density of unhealthy food outlets, but only if they did not move within the study period. In the longitudinal analyses of [29], the density of fast-food outlets in a 1 km radius around the home even showed an inverse association with the standardized BMI of adolescents. The study in [30] systematically reviewed obesity risk in children associated with the density of unhealthy food supply around schools in the UK and found that the association between fast-food retail location, fast-food consumption, and obesity is still disputable. Thus, even though neighborhood health research in the UK has a much longer tradition and relies on a more comprehensive body of research than continental European public health, the association between the availability of unhealthy food and children's nutritional status also remains unclear for this context.

Similarly, USA literature also presents inconsistent data [31]. Certain subgroups, such as populations with lower SES, are exposed to a higher density of unhealthy food retailers and are at greater risk of being overweight and obese [32]. Hereby age, gender, car ownership, and satisfaction with supermarket density are important examples of contextual factors that influence weight outcomes in children in the USA [33].

Green Space

A similar picture is shown in the research concerning green space: In our review, the majority of the 13 analyzed articles tended to have a negative association with the outcome, leading to the possible assumption that accessible green space may provide protection against overweight. Meanwhile, in seven of the eight articles, these negative associations were reduced to approximately zero after adjusting for individual-level characteristics. As already shown in **Figure 2**, there is a tendency toward an inverse association, but the overall effect includes zero and remains negligible after adjustment.

This aligns with findings from the USA, where the relationship between green space availability and childhood obesity strongly depends on other area-level and individual factors that seem to moderate the effect of green space on obesity [34]. Subgroup analyses demonstrate that the protective effect of green space is often contextual, showing associations only for boys, children with a migration background [35], children from families of low SES [36], or in areas with low crime rates [37]. This indicates that certain subgroups are more sensitive to exposure than others are and that some groups seem not to benefit from green space availability. Thus, a combination of different contextual exposures or a combination of contextual factors with certain individual characteristics could represent independent risk factors [38].

The observed associations also depend on the approach that is used for the measurement of green space. For example, the study in [35] found negative associations only when green space was quantified using the NDVI with a 30 m × 30 m resolution but not with other measures for green space. These findings underscore the importance of the measurement methods. Parental perceptions of green space often diverge from objectively measured green spaces [39], adding another layer of complexity to the interpretation of the results. In a Norwegian study, green space even was positively associated with overweight in children [40], most likely due to the socio-spatial differences between urban and rural areas.

In addition to context, the interplay of multiple environmental factors should also be considered as an influencing risk factor for OAO. The study in [41] conducted a cluster analysis and identified one cluster characterized by consistently higher levels of air pollution, road traffic, and road traffic noise, with limited mitigating exposures. Within this cluster, an association with increased z-BMI was observed. However, the analysis did not determine the specific environmental characteristics that were most likely to influence childhood obesity. This suggests that the influence of individual built environment variables, such as air pollution, might be too small for detection in many studies or that the studies lack sufficient power to identify such small effects. Alternatively, a combination of neighborhood characteristics may exert a stronger influence [42].

This inconsistency also extends to other built environment variables, suggesting the possibility of contextual factors or neighborhood compositions that remain undetected in the current analyses. This highlights the need for more nuanced, multivariable approaches to understand the complex interactions between built environment characteristics and childhood obesity.

Concerning Context and Composition

Collecting data on built environment variables, as traditionally practiced in public health research, does not appear to fully elucidate the urban clusters of OAO among European children. Despite extensive investigations, the range of associations involved is not yet fully understood while the interactions between individual-level factors, the built environment, and childhood overweight are not yet coherently conceptualized. Thus, the current status of knowledge is still insufficient for designing effective interventions [43].

The main conceptional problem hereby lies in the distinction between effects of the neighborhood and effects of individual social status:

People do not live randomly distributed in an area but are usually geographically clustered according to their individual social status (with prices for accommodation being a main clustering mechanism) [33]. Thus, individuals with similar individual risk profiles often cluster within spatial areas due to economic resources or educational level, which is described as compositional effect [44]. Compositional effects could explain why many studies are unable to find stable independent associations for the built environment characteristics, and why these associations vanish after adjustment for individual SES. At the same time, neighborhood composition also shapes the built environment, which then can have independent effects (called contextual effects in the literature) [45]. Recent research from Belgium for instance shows that food environments in less affluent areas tend to be unhealthier because of the allegedly lower demand for healthy food in neighborhoods where many poor individuals live [46].

The relation between contextual and compositional factors is further complicated by the fact that individuals are always exposed to a multitude of different factors, which might simultaneously have harming and protecting factors that neutralize each other. In addition, an unfavorable built environment may be only a small part of deprived spatial areas and patterns of health with non-built environmental factors (such as criminality or social coherence) having additional effects [47, 48].

Therefore, to advance this field, models that account for the complexities of neighborhood composition and the ways in which various elements of the built environment interact to influence health outcomes are needed. A more holistic approach that integrates individual behaviors, social determinants, and environmental factors could provide the nuanced insights needed to design targeted and effective interventions.

Strengths and Limitations

A strength of our review lies in the substantial number of European studies included and the wide variety of built environment characteristics that were identified and analyzed. These findings provide a comprehensive description of the environment in which children live. Furthermore, the included articles were generally of high quality, with most studies achieving full scores on the JBI Critical Appraisal Checklist. While all included studies account for covariates in their regression models, the specific selection of covariates varies across articles, which may introduce bias into our analysis.

A notable limitation of this review is the heterogeneity across datasets, which prevented us from conducting meta-analyses for all variables. **Figure 2** presents the forest plot for green space, incorporating 7 of the 13 included articles. The remaining articles did not provide data suitable for meta-analysis. Due to limited resources, it was not feasible to request crude data from all authors.

This variability highlights the need for more standardized methodologies in future research to enable more robust comparisons and synthesis of findings. There is no indication of a language bias, since the articles retrieved by our search were predominantly written in English.

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APPENDIX A

Table A1. Search strings for each database

Database	Search string	Results
PubMed	(child* OR “primary school” OR “secondary school” OR pupil OR infan* OR adolescents OR preschoolers) AND (neighbourhood OR residence OR residential OR “residence characteristics” OR “home environment”) AND (obes* OR adipos* OR BMI) AND (Europe[MesH] OR Albania OR Armenia OR Austria OR Azerbaijan OR Belarus OR Belgium OR “Bosnia and Herzegovina” OR Bulgaria OR Croatia OR Cyprus OR Czechia OR “Czech Republic” OR Denmark OR Estonia OR Finland OR France OR Georgia OR Germany OR Greece OR Hungary OR Iceland OR Ireland OR Israel OR Italy OR Kazakhstan OR Kyrgyzstan OR Latvia OR Lithuania OR Luxembourg OR Malta OR Moldova OR Monaco OR Montenegro OR Netherlands OR “North Macedonia” OR Macedonia OR Norway OR Poland OR Portugal OR “Republic of Moldova” OR Romania OR Russia OR “Russian Federation” OR “San Marino” OR Serbia OR Slovakia OR Slovenia OR Spain OR Sweden OR Switzerland OR Turkey OR Turkmenistan OR Ukraine OR “United Kingdom” OR UK OR England OR Wales OR Scotland OR “Northern Ireland” OR Uzbekistan)	1st search (7th April 2022): 1,348 2nd search (4th June 2024): 1,208
Web of Science	ALL=((child* OR “primary school” OR “secondary school” OR pupil OR infan* OR adolescents OR preschoolers) AND (neighbourhood OR residence OR residential OR “residence characteristics” OR “home environment”) AND (obes* OR adipos* OR BMI) AND CU=((Europe OR Albania OR Armenia OR Austria OR Azerbaijan OR Belarus OR Belgium OR “Bosnia and Herzegovina” OR Bulgaria OR Croatia OR Cyprus OR Czechia OR “Czech Republic” OR Denmark OR Estonia OR Finland OR France OR Georgia OR Germany OR Greece OR Hungary OR Iceland OR Ireland OR Israel OR Italy OR Kazakhstan OR Kyrgyzstan OR Latvia OR Lithuania OR Luxembourg OR Malta OR Moldova OR Monaco OR Montenegro OR Netherlands OR “North Macedonia” OR Macedonia OR Norway OR Poland OR Portugal OR “Republic of Moldova” OR Romania OR Russia OR “Russian Federation” OR “San Marino” OR Serbia OR Slovakia OR Slovenia OR Spain OR Sweden OR Switzerland OR Turkey OR Turkmenistan OR Ukraine OR “United Kingdom” OR UK OR England OR Wales OR Scotland OR “Northern Ireland” OR Uzbekistan))	1st search (7th April 2022): 1,058 2nd search (4th June 2024): 203
Cochrane Library	(child* OR “primary school” OR “secondary school” OR pupil OR infan* OR adolescents OR preschoolers) AND (neighbourhood OR residence OR residential OR “residence characteristics” OR “home environment”) AND (obes* OR adipos* OR BMI) AND (Europe OR Albania OR Armenia OR Austria OR Azerbaijan OR Belarus OR Belgium OR “Bosnia and Herzegovina” OR Bulgaria OR Croatia OR Cyprus OR Czechia OR “Czech Republic” OR Denmark OR Estonia OR Finland OR France OR Georgia OR Germany OR Greece OR Hungary OR Iceland OR Ireland OR Israel OR Italy OR Kazakhstan OR Kyrgyzstan OR Latvia OR Lithuania OR Luxembourg OR Malta OR Moldova OR Monaco OR Montenegro OR Netherlands OR “North Macedonia” OR Macedonia OR Norway OR Poland OR Portugal OR “Republic of Moldova” OR Romania OR Russia OR “Russian Federation” OR “San Marino” OR Serbia OR Slovakia OR Slovenia OR Spain OR Sweden OR Switzerland OR Turkey OR Turkmenistan OR Ukraine OR “United Kingdom” OR UK OR England OR Wales OR Scotland OR “Northern Ireland” OR Uzbekistan)	1st search (7th April 2022): 125 2nd search (4th June 2024): 0

Table A2. Results of quality scoring based on the Joanna Briggs Institute appraisal checklist for the included studies

First author	Study design	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Total score
Buck	Cross-sectional	Y	Y	Y	Y	Y	Y	N	Y				7/8
Schüle	Cross-sectional	Y	Y	Y	Y	Y	Y	Y	Y				8/8
Zhou	Cross-sectional	Y	Y	Y	Y	Y	Y	Y	Y				8/8
Zhou	Cross-sectional	Y	Y	Y	Y	Y	Y	Y	Y				8/8
Bredenbeck	Cross-sectional	Y	Y	N	Y	Y	Y	Y	Y				7/8
Lakes	Cross-sectional	Y	Y	Y	Y	N	N	N	N				4/8
Lange	Cross-sectional	Y	Y	Y	Y	Y	Y	Y	NA				7/8
Gose	Longitudinal	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	11/11
Poulain	Cross-sectional	Y	Y	Y	Y	Y	Y	Y	Y				8/8
Badpa	Cross-sectional	Y	Y	Y	Y	Y	Y	Y	Y				8/8
Ribeiro	Longitudinal	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	11/11
Ferrao	Cross-sectional	Y	Y	NA	Y	Y	Y	Y	Y				7/8
Machado-Rodrigues	Cross-sectional	Y	N	N	N	Y	Y	Y	NA				4/8
Pereira	Cross-sectional	Y	Y	Y	Y	Y	Y	Y	Y				8/8
Melo	Cross-sectional	Y	Y	NA	Y	Y	Y	Y	Y				7/8
Lourenco	Cross-sectional	Y	Y	Y	Y	Y	Y	Y	Y				8/8
Villanueva	Cross-sectional	N	N	Y	Y	Y	Y	Y	Y				6/8
Albaladejo	Cross-sectional	N	N	Y	Y	Y	Y	Y	Y				6/8
De Bont	Cross-sectional	Y	Y	Y	Y	Y	Y	Y	Y				8/8
De Bont	Longitudinal	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	11/11
De Bont	Longitudinal	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	11/11
Sánchez-Valdivia	Longitudinal	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	11/11
Molina García	Cross-sectional	Y	Y	Y	Y	Y	Y	Y	NA				7/8
Molina García	Cross-sectional	Y	Y	Y	Y	Y	Y	N	NA				6/8
Dadvand	Cross-sectional	Y	Y	Y	Y	Y	Y	Y	Y				8/8
López-Gil	Cross-sectional	Y	Y	Y	Y	Y	Y	Y	Y				8/8
Frondelius	Longitudinal	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	11/11
Hamano	Longitudinal	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	11/11
Wallas	Longitudinal	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	11/11
Hrudey	Cross-sectional	Y	Y	Y	Y	Y	Y	Y	Y				8/8
Schmidt	Longitudinal	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	11/11
Bloemsma	Longitudinal	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	11/11
Grassi	Cross-sectional	Y	Y	Y	Y	Y	NA	Y	Y				7/8
Fioravanti	Longitudinal	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	11/11
Bellisario	Cross-sectional	Y	Y	Y	Y	Y	Y	Y	Y				8/8
Gallotta	Cross-sectional	Y	Y	Y	Y	Y	Y	Y	Y				8/8
Nelson	Cross-sectional	Y	Y	Y	Y	Y	Y	Y	Y				8/8
Christensen	Longitudinal	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	11/11
Spilkova	Cross-sectional	Y	Y	Y	Y	Y	Y	NA	N				6/8
Petraviciene	Cross-sectional	Y	Y	Y	Y	Y	Y	Y	Y				8/8
De Ryk	Longitudinal	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	11/11
Vrijheid	Longitudinal	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	11/11
Nagrani	Cross-sectional	Y	Y	Y	Y	Y	Y	Y	Y				8/8

Note. Q: Question; Y: Yes; N: No; & NA: Not applicable