Journal of Transport Geography 61 (2017) 104–117

Contents lists available at ScienceDirect

Journal of Transport Geography

journal homepage: www.elsevier.com/locate/jtrangeo

Critical Review

Association between the built environment and children's independent mobility: A meta-analytic review

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ARTICLE INFO

Keywords:
Built environment (BE)
Children's independent mobility (CIM)
Land use pattern
Street design
Meta-analysis

ABSTRACT

Children's independent mobility (CIM) is considered as a determining criterion of child-friendly built environment (BE). Researchers have made a substantial effort to identify the characteristics of the BE that affect CIM and thereby to inform city policy to promote CIM. Although the findings from these studies are useful to inform context specific CIM policy, together they provide inconclusive results. This study made a first attempt to draw a generalised conclusion through a meta-analysis of existing knowledge base. The analysis was conducted using primary studies reporting 13 BE-CIM links and published between 1980 and 2016. Overall effect size (ES), directions, and consistency of each link were calculated, also stratified by contexts, using the reported results from the primary studies and based on a random effect model. The results show that four BE factors (dead-end street, % of residential land, % of commercial land, and residential location type) have a positive association with CIM; traffic volume has a neutral association; and the remaining eight factors (vehicular street width, road density, intersection density, major road proportion, land use mix, availability of recreational facilities, residential density, and distance to destination) have a negative association. Living in a dead end street was found to have the strongest positive ES (0.352), with moderate level of consistency across the primary studies. In contrast, land use mix has the strongest negative ES (− 0.212) but with the highest level of inconsistency. Both ESs and consistencies, however, vary between developing and developed country contexts. Diversity in contexts, research design, and measurement instruments across the primary studies contributed to the heterogeneous results. The findings of this research serve as a guide for practitioners and researcher alike to make an informed decision about the BE factors that consistently foster or hinder CIM in different contexts.

1. Introduction

Child-friendly built environment is an important prerequisite for children's physical, mental, spiritual and social development (UNICEF, United Nations International Children's Emergency Fund, 1989). However, what constitutes a child-friendly built environment is debated in the literature (Kyttä, 2004; Nordström, 2010). Within this context, Broberg et al. (2013a) have provided an operational definition of child-friendly built environment using two criteria: children's possibilities for independent mobility, and their opportunities to actualize environmental affordances. This study focuses on the former criterion and aims to review the characteristics of the built environment that promote/hinder children's independent mobility. The findings from this research, therefore, contribute to the spatial dynamics – mobility nexus in the literature – i.e. how children independent mobility changes with respect to changes in the built environment (Priemus et al., 2001).

Children's independent mobility (CIM) is defined as the freedom and/or ability of children to travel around their neighbourhood without adult supervision (Carver et al., 2010b; Tranter and Whitelegg, 1994). It has been measured using various indicators in the literature such as home range (how far a child can travel from their home), independent time outside (how many minutes a child can stay outside of home independently), independent journey to destinations (child's independent movement to specific destinations), and parental license for children (whether a child is allowed to travel independently by parents) (Kyttä, 2004; Loebach and Gilliland, 2014; Villanueva et al., 2012a; Villanueva et al., 2012b). In this paper, these indicators are respectively referred to as CIM Range, CIM Time, CIM Destination, and CIM license. Built environment (BE) is referred to the human made features in a city and is often characterised by '5Ds' in the literature: density, diversity, design, distance and destination accessibility (Cervero and Kockelman, 1997; Ewing and Cervero, 2001). Each 'D' again is measured using a number of indicators. For example, density can be measured by: population density, residential density, floor area ratio etc. See

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http://dx.doi.org/10.1016/j.jtrangeo.2017.04.004
Received 19 August 2016; Received in revised form 8 April 2017; Accepted 16 April 2017
Available online 03 May 2017
0966-6923/

Cervero et al. (2009) for a detailed description of the '5Ds' and their indicators.

Research on the link between BE and CIM has been popularised recently for two reasons. First, an increasing evidence shows that the level of CIM dropped significantly over the last few decades. This decline led to childhood obesity (Whitzman et al., 2010); sense of loneliness and fear (Prezza and Pacilli, 2007); physical (Rushovich et al., 2006), social (Groves, 1997), and cognitive (Christensen and O'Brien, 2003) incompetencies; poor environmental knowledge (Rissotto and Tonucci, 2002); reduced social and recreational opportunities (Prezza et al., 2001); and car dependency (Lopes et al., 2014; Mackett, 2002). For example, in Australia, the overall proportion of unaccompanied children travelling to school had dropped from 61% to 32% from 1991 to 2012, arguably this figure may vary between different geographical contexts in Australia (Schoeppe et al., 2015). In contrast, the number of children with obesity increased from 21% to 26% between 1995 and 2012 (ANPHA, Australian National Preventive Health Agency, 2014). Second, the topic attracts research attention from multiple research disciplines (public health, urban planning, and psychology) due to its multiple policy benefits as outlined above.

Built environmental and socio-cultural transformations caused by growing pressure of urbanization are on the rise and are argued to have altered children's mobility pattern worldwide (Fyhri et al., 2011; Lopes et al., 2014; Malone and Rudner, 2011; Tranter and Sharpe, 2012). Consequently, research on the complex relationship between BE and CIM has increased since the first reported study in the early 1980s by Van Vliet (1983). These studies have investigated a range of built environment factors (e.g. availability and proximity of destinations, land use diversity and density, street connectivity) and assessed their impacts on CIM to inform policies (De Meester et al., 2014; Kyttä, 2004; Loebach and Gilliland, 2014; Monsur and Islam, 2011; Prezza et al., 2001; Villanueva et al., 2012a; Villanueva et al., 2012b; Villanueva et al., 2013).

Among the various studies, only a few of them have reported a consistent relationship between several BE factors and CIM. Despite their consistency (in terms of direction), the strength of association, however, varies substantially among the studies. For example, Broberg and Sarjala (2015) have reported that a strong negative correlation exists between CIM and land use mix in Finland, whereas the relationship was found to be moderately negative in Bangladesh (Islam et al., 2014). A number of studies have, however, identified that such a correlation does not exist at all - i.e. land use mix has no impact on boy's IM (Carver et al., 2014b). Further adding to this complexity, an opposite relationship has also been reported in the literature for several BE factors. For example, most studies have reported that a positive association exists between well-connected street networks and CIM (Braza et al., 2004; Kerr et al., 2006). Monsur and Islam (2011), in contrast, found that less-connected road networks (e.g. dead end streets) are more likely to increase CIM. These contradictions and ambiguity in research findings raise the question about the true effect of the BE on CIM; and despite decades-long exploration on this topic, there is clearly a dearth of studies that systematically and statistically investigated these inconsistencies.

Previously, four studies have conducted a systematic review of the CIM literature (Bates and Stone, 2015; Malone and Rudner, 2017; Moghtaderi et al., 2012; Schoeppe et al., 2013). These studies have mainly focused on the link between CIM and health benefits. This means that CIM has been used as an explanatory factor of health outcomes. However, Malone and Rudner (2017) have provided a descriptive summary of CIM in relation to different socio-cultural and ecological contexts. This current study draws on the relationship between BE factors and CIM measured by systematically reviewing effects of the former on the latter, considering cultural and geographic determinants, which may affect the expression of both variables. In particular, this research aims to answer the following four research questions: a) What are the different BE factors that significantly affect CIM?; b) What are the magnitudes and directions of the associations?; c) Which BE factors have more consistent relationships with CIM?; and d) What are the plausible causes of variations of the reported results in prior studies?

The paper employs a meta-analysis technique to answer the above research questions. A meta-analysis is a form of a structured review of the literature on a particular topic of interest. Previously, researchers have used a range of review techniques which can broadly be categorised as traditional or narrative literature review and systematic literature review. A detailed description of these methods is outlined in Jesson et al. (2011). Briefly, a narrative review examines a body of the literature and draws a conclusion about a topic in question. It aims to provide the readers with a comprehensive background for understanding existing knowledge and thereby to identify gaps for new research. In contrast, a systemic review uses more rigorous and well-defined criteria to select and review the literature to answer a well-developed research question in order to allow the readers to assess the reliability and validity of the review (Torgerson, 2003). In addition to meta-analysis, another form of systematic review includes meta-synthesis. A meta-analysis is different from a meta-synthesis in that the former is based on statistical analysis of findings reported in previous studies whereas the latter is a non-statistical technique used to integrate, evaluate and interpret the findings of multiple qualitative research studies (Borenstein and Wiley, 2009). Therefore, a meta-analysis permits to extract the strength and direction of associations between dependent and independent variables, and thereby allows a more objective assessment of the evidence and may clarify heterogeneity or similarities (Egger and Smith, 1997).

The objective of this meta-analytic review is to statistically summarize the current body of knowledge on the association between BE and CIM in an attempt to estimate the average impact of different BE characteristics on CIM. It first combines the effect size (ES) of the studies reporting an association between BE and CIM for generalizability, and then compares the average effect sizes across different variables to rank their relative strengths and validity. These findings would serve as a policy guide to design urban areas that promote travelling autonomy for children; ensuring them with greater freedom to explore their surroundings, which is one of the fundamental premises for a child-friendly city.

2. Research methods

2.1. Search strategy

An extensive search procedure was employed comprised of six stages in order to identify relevant studies for meta-analysis. First, a comprehensive search was performed within all major electronic databases including Scopus, Tailor & Francis online, BioMed Central and Science Direct. The search range was specified from January 1980 to May 2016. The 1980 was selected as the starting period because an initial search result indicated that the first study on this topic was published in 1983 by Van Vliet (1983). Search terms included, but not limited to, "*urban environment", "built environment", physical environment of neighbourhood, neighbourhood character, neighbourhood, land use, proximity, distance to destination, walkability, street connection, street network, accessibility* in combination with *"children's independent mobility"*, or *"children's autonomous mobility"*, or *children's*: *free movement"*, or *children's independent journey"*, or *"free play"*. Second, a selective search was performed, for the same time period, within the following journal titles: *Health and Place, Transportation Planning and Technology, Environment and Behaviour, Children's Geographies, Journal of Urban design, Journal of Transport Geography, Journal of Transport and Health, Transport Policy, and Journal of Science and Medicine in Sport.* The initial research showed that these journals published a majority of studies on this topic. Third, reference lists of the selected publications from the above steps were checked in order to identify additional studies not included previously. Fourth, Masters and PhD theses on this topic were identified from the thesis database 'ProQuest'. Fifth, a search of electronic databases including government websites, university websites, non-profitable and private sector websites were performed in order to identify unpublished research on this topic. Sixth, a search of the corresponding authors' available online personal profiles was conducted to locate further relevant documents.

2.2. Study inclusion criteria

Studies retrieved from the initial searches were screened using a seven stage process:

1. samples must be ≤ 18 years old;
2. the association between BE and CIM has been reported quantitatively (descriptive statistics, ordinary least square regression, bivariate regression, logit model);
3. reported any of the following statistical details to calculate ES for this study:
   a. odds ratios (OR) and 95% confidence intervals (CI);
   b. sample sizes and correlation coefficient;
   c. mean difference (MD) and standard deviation (SD);
   d. sample sizes and t value; *and*
   e. sample sizes and z-value;
4. published (or unpublished works) in English;
5. analysis can be cross-sectional and/or longitudinal in nature;
6. data collection can be based on objective and/or subjective measurement scales; and
7. inclusion of studies irrespective of data collection instruments (questionnaire, travel survey) or survey methods (directly from children, proxy reports).

2.3. Identification of relevant studies

The search strategies, as outlined in Section 2.1, resulted in 2808 primary studies including articles, reports, theses, books, book chapters and journal news. These studies were examined for inclusion using a systematic method as outlined in Fig. 1. Irrelevant and duplicate studies were excluded which resulted in a reduced list of 292 primary studies for further eligibility check. The title and abstract of the selected studies were reviewed afterwards for their eligibility based on study inclusion criteria 1 and 2 (see Section 2.2). This scoping exercise resulted in 105 primary studies for an in-depth review. A full-text review of these studies was then conducted and 35 eligible studies were coded. However, 23 of these studies were excluded in the final selection because of insufficient statistical details necessary for the meta-analysis as identified in the study inclusion criterion 3 (Section 2.2). Appendix 1 outlines specific reasons for exclusion of these studies. Table 1 lists the primary studies that were included for final review. Although the number of studies included in this review is limited (12), they were found to be representative of prior studies on meta-analysis in comparable research fields (Table 2). Moreover, research has highlighted that a combination of only two studies in meta-analysis provides a much stronger ground of evidence than a single study (Rosenthal and DiMatteo, 2001).

2.4. Selection of dependent and independent variables

The selected studies have investigated 66 different relationships between BE and CIM. This means that they have used 66 BE factors. However, a closer investigation of these 66 factors showed that although many of these are labelled differently, they represent the same BE feature. As a result, some of the BE variables were renamed for consistency and easy comparison. In addition, this research included only those BE factors that have been used at least in two primary studies in order to derive ES statistically. These operations resulted in a total of 17 BE factors for final evaluation. After congregating variables where possible, 13 BE factors were finally retained for further investigation: residential location type (urban/ suburban), distance to destination, residential density, land-use mix, availability of recreational facilities, proportion of residential land use, proportion of commercial land use, intersection density, road density, traffic volume, vehicular street width, presence of dead-end street, and proportion of main roads. The reported relationships between these variables and CIM are statistically synthesized in this research. Note that a separate investigation of these relationships was also conducted for developed and developing countries. The intent was to identify how contextual spatial dynamics influence the reported BE-CIM relationships. The primary

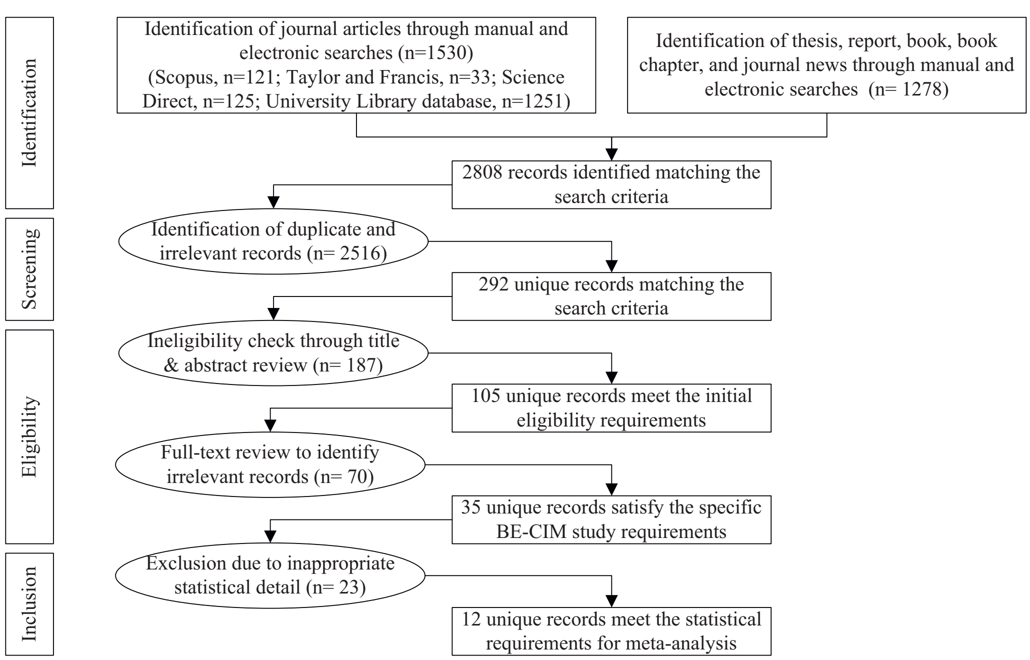


Fig. 1. Processes used to select the primary studies for this research.

Table 2
Sample sizes of several well-known meta-analysis studies.

Citation	Journal	Number of primary studies reviewed
Hajna et al. (2015)	BLC Public Health	4
Ewing and Cervero (2010)	Journal of the American Planning Association	61
Duncan et al. (2005)	International Journal of Behavioral Nutrition and Physical Activity	17
Leck (2006)	Berkeley Planning Journal	17
Vaughan et al. (2016)	Journal of Aging and Health	12
McGrath et al. (2015)	Sports Med	23
Gim (2013)	Transportation Planning and Technology	39

studies used all four types of CIM indicators: CIM range, CIM time, CIM license, and CIM Destination (Table 1).

2.5. Coding of studies

This study used a systematic coding scheme and a standard form to insert data for analysis following a detailed review of the selected primary studies. In addition to statistical data, various contextual variables were also coded in order to examine the sources of variations in the reported results among the primary studies such as sample sizes, age and gender of the respondents, geographic contexts of the study (urban, rural, suburban), economic context (e.g. developed or developing countries), research methodology used (theoretical basis, CIM dimensions, measurement scale of CIM and BE variables), publication year, and study design (cross-sectional and longitudinal). Efforts were made to obtain any missing data through a personal communication with the corresponding authors via email before eliminating a study from the analysis. In three primary studies, the reported results were in different format from what is required for meta-analysis. In these cases, further calculations were made to convert the reported format of data into a usable format based on either available information presented within the studies or the information received via email. In this research, the meta-analysis was not conducted separately for each of the CIM dimensions. Rather this study reported an aggregated result. The intent here is to extract the overall influence of the BE variables on CIM.

2.6. Data analysis strategy

2.6.1. Classification of the reported results of primary studies

The results of the primary studies were classified according to their reported format. This research found that five types of results have been reported in the selected 12 primary studies. These included: a) descriptive statistics outlining mean CIM for certain BE factors with standard deviation (SD); b) Pearson's or spearman's correlational coefficient value ‘r’ which describes the magnitude of correlation between CIM and BE variables c) t statistics with sample sizes when linear regression models are estimated to describe a link between BE and CIM; d) odds ratio (OR) with confidence interval (CI) to determine the odds of particular event between different types of outcome CIM and BE variables; and e) z value of statistical significance and sample sizes. Given that the aim of this study is to derive an overall effect size of the BE factors, these five types of studies were standardized into a common format as outlined below in Section 2.6.2.

2.6.2. Calculation of effect size (ES)

The results of the five types of studies were converted into a common ES ‘correlation (r) with 95% confidence interval (CI). Eq. 1 was used to calculate ES from studies that reported descriptive results:

$$r = d/\sqrt{(d^2 + a)} \quad (1)$$

where, d = standardized mean differences, a = correction factor for cases where $n1 \neq n2$, $[a = (n1 + n2)^2/n1n2]$, and n = sample sizes.

Eq. 2 was used to convert t statistics into a correlation:

$$r = \sqrt{(t^2/t^2 + df)} \quad (2)$$

where, t is the reported value for the t-test, and df is the degrees of freedom of the test.

Eq. 3 was used to compute correlation from z value of statistical significance:

$$r = \sqrt{(z^2/n)} \quad (3)$$

where n is the sample size.

Eqs. 4 and 1 were used to convert odds ratio (OR) into a correlation using a two-step procedure. First, odds ratios were converted into mean difference (d) by using Eq. 4. Second, the derived mean difference was again converted into a correlation value by using Eq. 1.

$$d = (\sqrt{3}/\pi)\ \ln(OR) \quad (4)$$

All calculations were conducted using the Comprehensive Meta-analysis software.

2.6.3. Identifying the overall ES of a BE factor

The individual effect sizes (ESs) from all primary studies focusing on a particular BE variable were aggregated in order to derive an overall ES for that BE variable. This study used a random effect model for aggregation over a fixed effect model because a fixed effect model assumes that the true effect size is same in all primary studies and the only reason that the ESs vary between studies is due to sampling error. Therefore, a fixed effect model ignores the possibility that the true effects might be different between studies due to variations in sample structure (e.g. age, gender, income of the sample). In contrast, a random-effect model allows that the true effect could vary from study to study. For example, the ES might be higher (or lower) in studies where the participants are relatively older (e.g. 16–18 years compared to 9–10 years). Consequently, in a fixed effect model, a larger weight is given to the studies that have larger sample sizes because it is assumed that better ESs are inherent in studies with larger sample sizes (less prone to sampling error). The random effect model takes into account the ESs of individual studies because each study provides information about a different ES (i.e. we cannot discount a small study by giving it a very small weight). Therefore, a random effect model delivers more balanced relative weights where extreme studies lose influence if they are large and gain influence if they are small (Card, 2015). The overall ESs were calculated for 13 different relationships between BE and CIM in this research. These results were further analysed through series of meta-analyses to understand the moderating effects of gender (girl vs. boy) and contextual variations (developed vs. developing country).

2.6.4. Determination of heterogeneity among the primary studies

A statistical test of heterogeneity was conducted to assess the consistencies of the reported results among the primary studies. Heterogeneity tests checked whether there were genuine differences underlying the results of the studies (heterogeneity), or the variations in findings are compatible with chance (homogeneity). This has been measured by I^2, which indicates the likelihood of total variation due to heterogeneity rather than homogeneity. I^2 was derived based on Eq. 5.

$$I^2 = 100\% x\ (Q - df)/Q \quad (5)$$

where, Q = Cochran's heterogeneity statistics, and df = degree of freedom.

Prior research has indicated that any values of $I^2 < 25\%$ are considered as low heterogeneity, values between 25% and 75% are considered as moderate heterogeneity, and values above 75% indicate a higher level of heterogeneity (Higgins et al., 2003).

2.6.5. Diagnosis of publication bias

This research also examined publication bias in the aggregated effect sizes through a visual evaluation of the symmetrical distribution of data points in the funnel plots followed by the Egger regression test (Egger et al., 1997). An asymmetric funnel plot or a significant result from the Egger test (1 tailed *p* value) indicates that the meta-analysis results may be exaggerated due to a lack of publications reporting non-significant results. Funnel plot is not applicable if the number of primary studies describing a particular relationship is < 10 (Borenstein et al., 2005). This was found to be the case for the majority of relationships in this study. As a result, an alternative test, the 'Fail Safe N' test was conducted to check the presence of publication bias (Rosenthal, 1979). The 'Fail Safe N' test identifies the number of non-significant missing studies required to nullify a significant result of an observed effect.

3. Results

3.1. Descriptive summary of the primary studies

Table 3 outlines the frequency distribution of primary studies according to their coded classification. It shows that most of the included studies were recent and published between 2000 and 2016 (92%). A majority of these studies (75%) were conducted in a developed country context, specifically in Europe (50%). Most of the studies are again cross-sectional in nature (83%), and only 16% of the studies investigated the BE-CIM links longitudinally. Sample sizes of these studies varied from 60 to 1314 individuals, but a majority of the studies (67%) collected data from < 500 participants. Again, most of the studies are focused on urban areas. 92% of the studies employed a subjective measurement scale to measure CIM whereas 16% used an objective measure of CIM based on, for example, GPS logger. Unlike CIM measurement scales, both subjective and objective scales were equally used to derive BE indicators. Data were collected directly from children in about 66% of the studies. The remaining studies relied on proxy reports from parents.

The frequency of investigation of the 13 BE factors, as reported in the selected 12 primary studies, is outlined in Table 4. Note that a single BE factor might have been investigated in various ways in a primary study. For example, the impact of distance to destination has been studied separately for males and females in a primary study. As a result, this study was entered twice for the calculation of ES. Again, a link between BE and CIM has been investigated using more than one indicator; or using different BE ranges from respondents' home locations (buffer distance). Consequently, these studies were entered multiple times in order to calculate ES assuming that each of the

Table 3
Characteristics of the primary studies.

Characteristics	n (%)	Study source
Study design		
Cross-sectional	10 (83)	(Broberg et al., 2013a, b; Broberg and Sarjala, 2015; Fyhri and Hjorthol, 2009; Islam et al., 2014; Kyttä, 1997, 2004; Lin and Chang, 2009; Loebach and Gilliland, 2014; Monsur, 2011; Villanueva et al., 2012b)
Longitudinal	1 (8)	(Christian et al., 2015)
Cross-sectional and longitudinal	1 (8)	(Carver et al., 2014a)
Sample size		
< 500	8 (67)	(Broberg and Sarjala, 2015; Christian et al., 2015; Islam et al., 2014; Kyttä, 1997, 2004; Lin and Chang, 2009; Loebach and Gilliland, 2014; Monsur, 2011)
> 500	4 (33)	(Broberg et al., 2013a, b; Carver et al., 2014a; Fyhri and Hjorthol, 2009; Villanueva et al., 2012b)
Country of sample		
Europe	6 (50)	(Broberg et al., 2013a, b; Broberg and Sarjala, 2015; Carver et al., 2014a; Fyhri and Hjorthol, 2009; Kyttä, 1997, 2004)
North America	1 (8)	(Loebach and Gilliland, 2014)
Asia	3 (25)	(Islam et al., 2014; Lin and Chang, 2009; Monsur, 2011)
Australia/New Zealand	2 (17)	(Christian et al., 2015; Villanueva et al., 2012b)
Geographic location		
Urban	8 (67)	(Broberg et al., 2013a, b; Broberg and Sarjala, 2015; Christian et al., 2015; Islam et al., 2014; Kyttä, 2004; Lin and Chang, 2009; Monsur, 2011; Villanueva et al., 2012b)
Urban-suburban	2 (17)	(Kyttä, 1997; Loebach and Gilliland, 2014)
Urban- rural	2 (17)	(Carver et al., 2014a; Fyhri and Hjorthol, 2009)
Destination type		
School	4 (33)	(Broberg and Sarjala, 2015; Carver et al., 2014a; Lin and Chang, 2009; Monsur, 2011)
Local destinations other than school	6 (50)	(Broberg et al., 2013a, b; Christian et al., 2015; Islam et al., 2014; Kyttä, 1997; Loebach and Gilliland, 2014; Villanueva et al., 2012b)
All destinations	2 (17)	(Fyhri and Hjorthol, 2009; Kyttä, 2004)
Publication year		
1983–2000	1 (8)	(Kyttä, 1997)
2000–2016	11 (92)	(Broberg et al., 2013a, b; Broberg and Sarjala, 2015; Carver et al., 2014b; Christian et al., 2015; Fyhri and Hjorthol, 2009; Islam et al., 2014; Kyttä, 2004; Lin and Chang, 2009; Loebach and Gilliland, 2014; Monsur, 2011; Villanueva et al., 2012b)
IM measurement		
Child reported	4 (33)	(Broberg et al., 2013a, b; Broberg and Sarjala, 2015; Islam et al., 2014; Lin and Chang, 2009)
Parent reported	1 (8)	(Christian et al., 2015)
Child and parent reported	4 (33)	(Carver et al., 2014b; Fyhri and Hjorthol, 2009; Kyttä, 1997, 2004; Villanueva et al., 2012b)
Objective[a]	1 (8)	(Loebach and Gilliland, 2014)
Objective and Subjective	1 (8)	(Monsur, 2011)
BE variables measurement		
Subjective	6 (50)	(Fyhri and Hjorthol, 2009; Islam et al., 2014; Kyttä, 1997, 2004; Lin and Chang, 2009; Monsur, 2011)
Objective[b]	6 (50)	(Broberg et al., 2013a, b; Broberg and Sarjala, 2015; Carver et al., 2014a; Christian et al., 2015; Loebach and Gilliland, 2014; Villanueva et al., 2012b)

[a] Objective IM measurements included GPS loggers, accelerometers, and pedometers.
[b] Objective BE measurements included GIS measures.

Table 4
Frequency of BE variables investigated in the primary studies.

BE variable	Number of studies	Number of entries in meta-analysis	Citation
Distance to destination	8	20	(Broberg et al., 2013a, b; Broberg and Sarjala, 2015; Christian et al., 2015; Fyhri and Hjorthol, 2009; Lin and Chang, 2009; Loebach and Gilliland, 2014; Monsur, 2011; Villanueva et al., 2012b)
Availability of recreational facilities	5	13	(Broberg and Sarjala, 2015; Kyttä, 2004; Monsur, 2011; Villanueva et al., 2012b)
Residential density	3	11	(Broberg et al., 2013a, b; Broberg and Sarjala, 2015; Loebach and Gilliland, 2014)
Land use mix	3	9	(Broberg and Sarjala, 2015; Carver et al., 2014a; Islam et al., 2014)
Residential location type	2	7	(Kyttä, 1997; Loebach and Gilliland, 2014)
Proportion of residential land use	2	3	(Islam et al., 2014; Lopes et al., 2014)
Proportion of commercial land use	2	7	(Islam et al., 2014; Lopes et al., 2014)
Intersection density	4	10	(Broberg and Sarjala, 2015; Islam et al., 2014; Lin and Chang, 2009; Lopes et al., 2014)
Vehicular street width	3	6	(Islam et al., 2014; Lin and Chang, 2009; Monsur, 2011)
Road density	2	10	(Broberg and Sarjala, 2015; Carver et al., 2014a)
Traffic volume	2	2	(Broberg et al., 2013a, b; Christian et al., 2015)
Dead end street	2	4	(Islam et al., 2014; Monsur, 2011)
Proportion of main roads	2	6	(Broberg and Sarjala, 2015; Carver et al., 2014a)

category/subgroup or outcome measure is an individual study. Among the 13 factors, the link between distance to destination and CIM has been studied most frequently (in 8 primary studies with 20 entries as shown in Table 4). Other frequently used BE variables are: the availability of recreational facilities, residential density, land use mix, intersection density and vehicular street width. According to the data presented in Table 4, seven of the 13 relationships were examined only in two primary studies. Although the number of primary studies seems to be quite small for these factors, the inclusion of multiple entries overcame the drawback of limited sample sizes in these cases. After the inclusion of multiple entries, only one factor remained with two entries (traffic volume) (Table 4).

3.2. Analytical results

Table 5 summarises the overall results of the 13 meta-analyses conducted in this research. It displays an overview of ES measured by correlation with 95% confidence interval, heterogeneity statistics, and publication bias test results. According to commonly applied guidelines, a value of ES equal to ± 0.10, ± 0.30, and ± 0.50 represents small, medium and large ES respectively (Card, 2015). The derived ESs were further classified based on economic contexts (developing vs. developed country) in order to understand whether the relationships hold between different contexts (Table 6). Table 6 contains many empty cells which means that these BE factors were not comparable between developed and developing country contexts for two reasons: a) all primary studies were originated from a single context; and b) ES calculation is not supported when there are fewer than two studies in any of the contexts. These restrictions allowed a comparison of only four BE variables in this study.

3.2.1. Strength of association

It is apparent from Table 5 that the BE variable with the strongest association with CIM falls within the moderate ES range. Of the 13 BE-CIM associations, six have a value ranging from small to moderate ES. These included (in order of strength): dead end streets, proportion of residential use, land use mix, vehicular street width, proportion of commercial use, and residential location type. The remaining 7 factors have a very small ES (less than ± 0.1). These are: distance to destination, residential density, availability of recreation facilities, traffic volume, proportion of major road, intersection density, and road density.

In terms of significance, a majority of the BE factors (7) stand against null hypothesis “no effect of the intervention” and found to

Table 5
Summary of meta-analysis results.

BE variable	Effect size and 95% interval						Heterogeneity statistics				Publication bias	
	Point estimate	Lower limit	Upper limit	CI value	*Z* value	*p* value	Q value	df (Q)	*P* value	I squared	Egger regression *(p value)*	Fail-safe N
Dead-end street	0.352	0.130	0.540	0.410	3.048	0.002	11.621	3	0.009	74.185	NA	37
Proportion of residential land use	0.267	0.128	0.395	0.267	3.706	0.000	4.170	2	0.124	52.038	NA	20
Residential location type (urban -suburban)	0.116	− 0.014	0.242	0.256	1.746	0.081	13.121	4	0.011	69.516	NA	9
Distance to destination	− 0.001	− 0.002	− 0.001	0.001	− 2.960	0.003	99.704	18	0.000	81.947	0.092	228
Intersection density	− 0.013	− 0.025	− 0.002	0.023	− 2.337	0.019	53.584	9	0.000	83.193	0.023	144
Road density	− 0.082	− 0.140	− 0.023	0.117	− 2.707	0.007	43.281	7	0.000	83.826	0.052	55
Vehicular street width	− 0.151	− 0.248	− 0.051	0.197	− 2.945	0.003	1.162	2	0.077	49.644	NA	23
Land use mix	− 0.182	− 0.293	− 0.066	0.227	− 3.062	0.002	75.513	8	0.000	89.118	NA	46
Proportion of commercial land use	0.118	− 0.028	0.258	0.286	1.589	0.112	31.369	6	0.000	80.873	NA	18
Residential density	− 0.005	− 0.020	0.010	0.030	− 0.651	0.515	62.180	10	0.000	83.913	0.284	11
Availability of recreational facilities	− 0.008	− 0.022	0.038	0.060	0.535	0.593	57.936	12	0.000	79.287	0.003	0
Traffic volume	0.000	− 0.021	0.020	0.041	− 0.025	0.980	2.558	1	0.110	60.903	NA	NA
Proportion of major road	− 0.006	− 0.017	0.005	0.022	− 1.045	0.296	10.535	5	0.061	52.540	NA	6

Table 6
Summary of meta-analysis results based on contextual differences.

BE variable	Developed country								Developing country							
	Effect size and 95% interval						Heterogeneity statistics		Effect size and 95% interval						Heterogeneity statistics	
	n (study)	n (entry)	Point estimate	Lower limit	Upper limit	*p* value	*P* value	I squared	n (study)	n (entry)	Point estimate	Lower limit	Upper limit	*p* value	*P* value	I squared
Dead-end street	–	–	–	–	–	–	–	–	2	4	0.352	0.130	0.540	0.002	0.009	74.185
Proportion of residential land use	1	2	–	–	–	–	–	–	1	1	–	–	–	–	–	–
Residential location type (urban -suburban)	2	7	0.116	− 0.014	0.242	0.081	0.011	69.520	–	–	–	–	–	–	–	–
Distance to destination	6	16	− 0.001	− 0.002	− 0.001	0.001	0.000	80.130	2	4	− 0.495	− 0.782	− 0.210	0.001	0.159	42.035
Intersection density	3	9	− 0.011	− 0.019	− 0.002	0.017	0.000	75.870	1	1	− 0.420	− 0.564	− 0.252	0.000	–	–
Road density	2	8	− 0.082	− 0.140	− 0.023	0.007	0.000	83.826	–	–	–	–	–	–	–	–
Vehicular street width	1	2	− 0.219	− 0.290	− 0.145	0.000	0.336	0.000	2	4	− 0.080	− 0.230	0.084	0.357	0.152	43.212
Land use mix	2	8	− 0.154	− 0.266	− 0.038	0.009	0.000	88.430	1	1	− 0.340	− 0.496	− 0.162	0.000	–	–
Proportion of commercial land use	1	6	–	–	–	–	–	–	1	1	–	–	–	–	–	–
Residential density	3	11	− 0.005	− 0.020	0.010	0.515	0.000	83.910	–	–	–	–	–	–	–	–
Availability of recreational facilities	4	10	− 0.008	− 0.022	0.038	0.593	0.000	81.551	–	–	–	–	–	–	–	–
Traffic volume	2	2	0.000	− 0.021	0.020	0.980	0.110	60.900	–	–	–	–	–	–	–	–
Major road proportion	2	6	− 0.006	− 0.017	0.005	0.296	0.061	52.540	–	–	–	–	–	–	–	–

have statistically significant association at the 0.05 level. These factors included: proportion of residential use, distance to destination, land use mix, dead end streets, intersection density, road density, and vehicular street width. The ES of residential location type variable was found to be signification at the 0.1 level. Among these 8 BE factors, only four of them (distance to destination, intersection density, road density, and vehicular street width) were found to have high precision in terms of their narrow CI (Table 5). The wider CI of the remaining four BE variables describes a lack of certainty inherent in these estimates (proportion of residential land use, residential location type, land use mix and dead-end street) due to either a lack of precision of individual primary study estimate or the small number of studies combined for each meta-analysis.

A comparison of ESs between developed and developing countries in Table 6 shows that the ESs are stronger in developing country context for three of the four BE variables. These are: distance to destination, land use mix, and intersection density. On the other hand, vehicular street width was found to have a stronger effect in developed country context than in developing countries.

3.2.2. Direction of association

A majority of the BE variables ($n = 8$) were found to have a negative correlation with CIM (distance to destination, residential density, availability of recreational facilities, land use mix, major road proportion, intersection density, road density, vehicular street width) (Table 5). Only, four BE variables have a positive influence on CIM (dead-end street, proportion of residential land use, proportion of commercial land use, and residential location type). One variable was found not to have any association with CIM (traffic volume, ES = 0).

The findings reveal that among all 4 variables that have a positive association with CIM, dead-end street has the strongest positive association than the other 3 BE variables (Table 5). The positive nature of this association means that the presence of dead-end street strongly encourages children to move more independently. However, this finding is valid only in the context developing countries because the effect was not investigated in developed country context (Table 6). On the other hand, among the factors with a negative association with CIM, land use mix has the strongest effect overall. This is, however, different when contextual information is considered. Table 6 shows that distance to destination and vehicular street width have the strongest negative effect on CIM in developing and developed country contexts respectively.

3.2.3. Consistency of association

Results from the heterogeneity tests are presented in this section to investigate the reliability of the findings. The heterogeneity statistics for random effects model as presented in Table 5 confirm that, of the 13 associations, 7 are highly heterogeneous (proportion of commercial use, distance to destination, availability of recreational facilities, land use mix, intersection density and road density). The remaining factors have a moderate level of heterogeneity (proportion of residential land use, residential location type, dead-end street, traffic volume and vehicular street width).

Although 8 factors were identified to have a significant association, only four of them present moderate heterogeneity (proportion of residential use, residential location type, dead-end streets, and vehicular street width). This means that most of the primary studies have reported a similar level of influence for these factors. Dead-end streets have the strongest positive association as well as moderate level of heterogeneity ($I^2 < 75\%$). In contrast, vehicular street width variable has a stronger negative influence with a moderate level of heterogeneity ($I^2 < 50\%$). The results of these 2 significant associations confirm that their results are certain and relatively homogenous across the studies.

Despite having the strongest negative association between land use mix and CIM, the association was found to be highly heterogeneous

Distance to destination

Study name	Subgroup within study	Outcome	Correlation	Lower limit	Upper limit	Z-Value	p-Value
Loebach, 2014	400m of home	CIM Time	-0.283	-0.423	-0.129	-3.549	0.000
Loebach, 2014	beyond 1600m of home	CIM Time	0.107	-0.056	0.265	1.291	0.197
Loebach, 2014	beyond 800 m of home	CIM Time	-0.009	-0.171	0.154	-0.107	0.915
Loebach, 2014	home-school distance	CIM Range	0.255	0.099	0.398	3.166	0.002
Villanueva, 2012	w/in 800m of home_Boys	CIM License	-0.003	-0.006	0.000	-1.950	0.051
Villanueva, 2012	w/in 800m of home_Girls	CIM License	-0.003	-0.006	0.000	-1.950	0.051
Monsur, 2014	Blank	CIM Destination	-0.382	-0.579	-0.141	-3.034	0.002
Monsur, 2014	Blank	CIM Range	-0.201	-0.433	0.056	-1.539	0.124
Monsur, 2014	Blank	CIM Time	-0.363	-0.565	-0.120	-2.868	0.004
Broberg, 2015	Cycle to school_home env	CIM Destination	-0.001	-0.001	-0.001	-5.871	0.000
Broberg, 2015	Cycle to school_sch journey env	CIM Destination	-0.001	-0.001	-0.000	-3.916	0.000
Broberg, 2015	Walk to school_home env	CIM Destination	-0.002	-0.003	-0.001	-4.557	0.000
Broberg, 2015	Walk to school_sch journey env	CIM Destination	-0.002	-0.002	-0.001	-6.836	0.000
Broberg, 2013	Blank	CIM Destination	0.044	0.023	0.065	4.153	0.000
Fyhri, 2009	school distance	CIM Destination	-0.031	-0.078	0.015	-1.327	0.185
Christian, 2015	closest medium size park	CIM License	0.000	-0.023	0.023	0.000	1.000
Christian, 2015	closest pocket park	CIM License	0.008	-0.015	0.031	0.704	0.482
Christian, 2015	closest small size park	CIM License	0.000	-0.032	0.032	0.000	1.000
Christian, 2015	large/district size park	CIM License	-0.020	-0.048	0.008	-1.395	0.163
Lin, 2010	to home	CIM Destination	-0.138	-0.242	-0.030	-2.503	0.012
			-0.001	-0.002	-0.000	-2.960	0.003

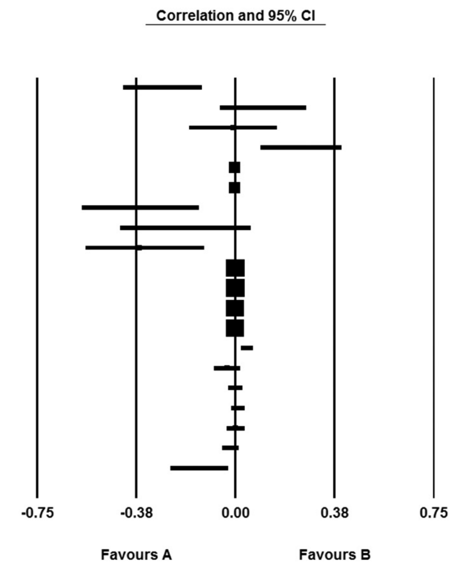


Fig. 2. The effect of distance to destination on CIM between different subgroups.

among the studies ($I^2 > 75\%$). The significant negative influence of distance to destination, intersection density and road density variables also appeared to have a higher level of heterogeneity with $I^2 > 75\%$. These high magnitudes of heterogeneity indicate the presence of genuine differences underlying the results of these studies.

BE factors that were identified with an insignificant effect, most of them possess a higher level of heterogeneity ($I^2 = 80\%$) (proportion of commercial land use, residential density). The overall findings, however, suggest that there is no linear connection between ES and heterogeneity because a higher level of heterogeneity exists within both significant and insignificant factors.

3.2.4. Sources of variation

Table 5 shows that a high level of heterogeneity exists ($I^2 \geq 75\%$) for seven BE-CIM relationships. Note that this research used random effect model to take into account the heterogeneity among the primary studies (Higgins and Green, 2011). Despite this consideration, the presence of a high level of heterogeneity in these seven associations implies the evidence of genuine differences among the primary studies. As a result, this research further investigates the plausible causes of this high level of heterogeneity. Figs. 2-5 show the contextual and methodological differences in these factors.

The main issue that can be extracted from these figures and is potentially contributing to the variations is the presence of a high number of subgroups within a study. This is also evident by the differences between the number of studies and the number of entries used. For example, seven entries were taken from two studies for the proportion of commercial land use factor. Similarly, 17 entries were taken from seven studies for the distance to destination factor. Moreover, a substantial difference exists among the entry types. For example, entries were classified based on: destination choice (Fig. 2: small, medium, and large parks), transport mode used for independent mobility (e.g. in Fig. 3: walk vs. cycle), the operational differences in terms of method used to derive BE factors (e.g. in Fig. 4: 1200 m buffer vs. 1600 m BE buffer), and gender differences (e.g. in Fig. 5: boys vs. girls) among others. A major variation also exists in terms of the indicators used to represent CIM. It appears that most of the BE-CIM relationships are represented with multiple measures of CIM. The use of all four CIM indicators (CIM time, CIM range, CIM destination, and CIM license) to measure an association with a particular BE factor is not uncommon in the literature (Fig. 2). In addition, the sample sizes used to assess the impact of BE on CIM in primary studies also vary considerably. For example, the sample sizes range from 109 to 1121 among the primary studies that used land use mix as a BE indicator (Fig. 5).

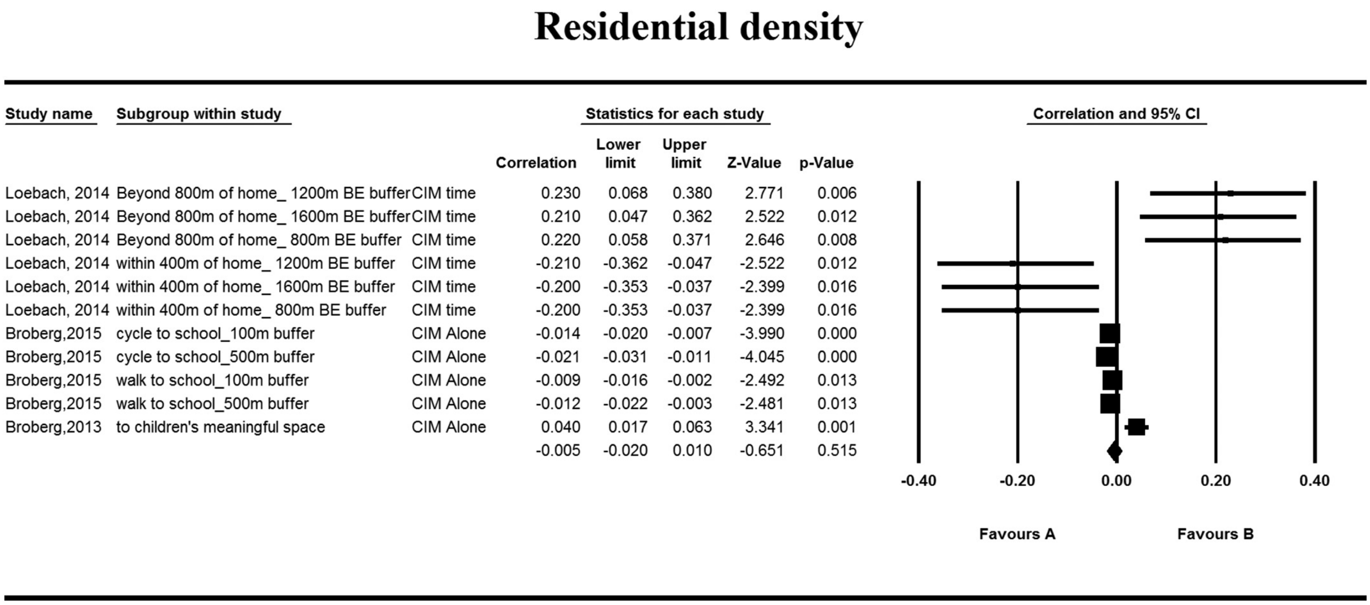
The level of heterogeneity also increased when results from different contexts were combined. Table 6 demonstrates that the heterogeneity levels of the 4 comparable factors are lower in each context compared to their aggregated levels as shown in Table 5.

3.2.5. Publication bias

The current review included both published and unpublished studies. Only 5 associations (distance to destination, availability of recreational facilities, residential density, intersection density and road density) in this study met the eligibility criterion to apply the 'Funnel Plot' followed by Egger test as per discussion in Section 2.6.5. The visual interpretation of the 'Funnel Plots' and results from the Egger regression test together confirm that one association suffers from a high level of publication bias (availability of recreational facilities-CIM). The 'Fail-Safe N' test also confirmed this (Table 5). This test was not applicable to the traffic volume variable because the test requires a minimum of 3 studies to identify publication bias. However, the ES of this variable was found to be non-significant, and as a result, the Fail-Safe N test has little relevance for this factor. In essence, a Fail-Safe N test indicates the number of additional publications required to bring the ES down to not statistically significant. The findings from the 'Fail-Safe N' results indicate that most of the significant ESs are not affected by publication bias in this research because a large number (> 20 in most cases) of additional studies are needed to nullify the results (Table 5).

4. Discussion and conclusion

This is the first meta-analysis conducted on the association between the built environmental (BE) factors and children's independent mobility (CIM) level. The goal of conducting this meta-analytic review is to



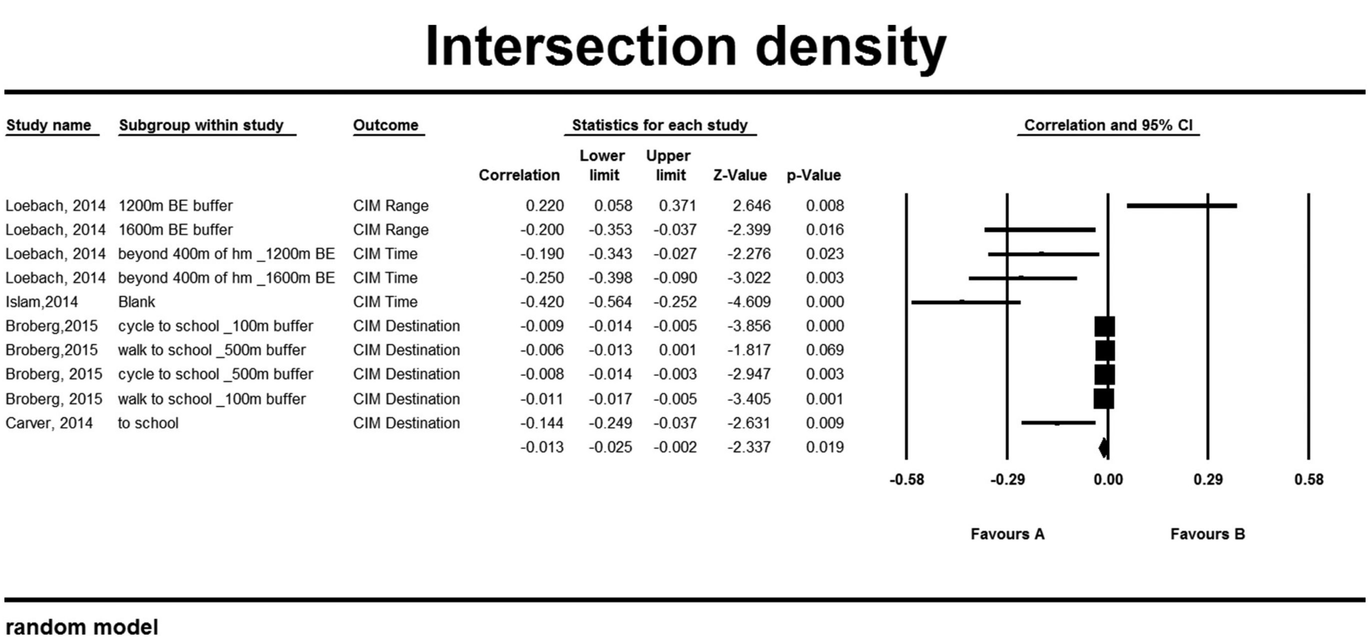
Study name	Subgroup within study		Correlation	Lower limit	Upper limit	Z-Value	p-Value
Loebach, 2014	Beyond 800m of home_ 1200m BE buffer	CIM time	0.230	0.068	0.380	2.771	0.006
Loebach, 2014	Beyond 800m of home_ 1600m BE buffer	CIM time	0.210	0.047	0.362	2.522	0.012
Loebach, 2014	Beyond 800m of home_ 800m BE buffer	CIM time	0.220	0.058	0.371	2.646	0.008
Loebach, 2014	within 400m of home_ 1200m BE buffer	CIM time	-0.210	-0.362	-0.047	-2.522	0.012
Loebach, 2014	within 400m of home_ 1600m BE buffer	CIM time	-0.200	-0.353	-0.037	-2.399	0.016
Loebach, 2014	within 400m of home_ 800m BE buffer	CIM time	-0.200	-0.353	-0.037	-2.399	0.016
Broberg,2015	cycle to school_100m buffer	CIM Alone	-0.014	-0.020	-0.007	-3.990	0.000
Broberg,2015	cycle to school_500m buffer	CIM Alone	-0.021	-0.031	-0.011	-4.045	0.000
Broberg,2015	walk to school_100m buffer	CIM Alone	-0.009	-0.016	-0.002	-2.492	0.013
Broberg,2015	walk to school_500m buffer	CIM Alone	-0.012	-0.022	-0.003	-2.481	0.013
Broberg,2013	to children's meaningful space	CIM Alone	0.040	0.017	0.063	3.341	0.001
			-0.005	-0.020	0.010	-0.651	0.515

Fig. 2. The variable effect of residential density on CIM between different subgroups.

generalize the frequently reported findings in previous studies. Along with generalization, another aspect of this investigation includes the identification of plausible causes of conflicting results in existing knowledge base. An intended by-product of this review is to identify research gaps for future conceptual, methodological and empirical work.

This study examined 13 BE factors which can broadly be categorised as: a) the distribution of land use patterns (proportion of residential land use, proportion of commercial land use, residential location type (urban -suburban), distance to destination, residential density, availability of recreational facilities and land-use mix); and b) street design patterns (dead end street, traffic volume, proportion of major road, intersection density, road density and street width). A major finding of this study is that both of these two aspects of the BE have a significant association with CIM. For example, dead-end street and proportion of residential land use have the most positive effects on CIM. In contrast, land use mix variable has the most negative effect on CIM. The findings suggest that both aspects of the environment are significantly important to facilitate CIM and thereby to design a child-friendly BE. Consistent with the width of vehicular street factor, most other street design factors were also found to have a negative association with CIM conforming with the concerns of researchers that street might be a reason for children to spend less time outdoors (Hillman and Adams, 1992; Karsten and van Vliet, 2006; Moore, 1987). A highly consistent result for the width of vehicular street variable reaffirms the significance of traffic safety factor to enhance CIM, because parents are less likely to give mobility license to their children when they face heavy traffic or perceive traffic danger (Björklid and Gummesson, 2013; Carver et al., 2010a; Hillman et al., 1990; Timperio et al., 2004; Villanueva et al., 2012b).

Most previous studies focusing on adult walking behaviour reported that intersection density has a positive influence and dead-ends have a negative influence on walking (Frank et al., 2005; Kamruzzaman et al., 2016; Saelens et al., 2003; Van Cauwenberg et al., 2011). These effects



Study name	Subgroup within study	Outcome	Correlation	Lower limit	Upper limit	Z-Value	p-Value
Loebach, 2014	1200m BE buffer	CIM Range	0.220	0.058	0.371	2.646	0.008
Loebach, 2014	1600m BE buffer	CIM Range	-0.200	-0.353	-0.037	-2.399	0.016
Loebach, 2014	beyond 400m of hm _1200m BE	CIM Time	-0.190	-0.343	-0.027	-2.276	0.023
Loebach, 2014	beyond 400m of hm _1600m BE	CIM Time	-0.250	-0.398	-0.090	-3.022	0.003
Islam,2014	Blank	CIM Time	-0.420	-0.564	-0.252	-4.609	0.000
Broberg,2015	cycle to school _100m buffer	CIM Destination	-0.009	-0.014	-0.005	-3.856	0.000
Broberg,2015	walk to school _500m buffer	CIM Destination	-0.006	-0.013	0.001	-1.817	0.069
Broberg, 2015	cycle to school _500m buffer	CIM Destination	-0.008	-0.014	-0.003	-2.947	0.003
Broberg, 2015	walk to school _100m buffer	CIM Destination	-0.011	-0.017	-0.005	-3.405	0.001
Carver, 2014	to school	CIM Destination	-0.144	-0.249	-0.037	-2.631	0.009
			-0.013	-0.025	-0.002	-2.337	0.019

Fig. 2. The effect of intersection density on CIM between different subgroups.

Land use mix

Study name	Subgroup within study		Correlation	Lower limit	Upper limit	Z-Value	p-Value
Islam, 2014	Blank	CIM Time	-0.340	-0.496	-0.162	-3.646	0.000
Broberg, 2015	cycle to school_100m buffer	CIM Alone	-0.562	-0.720	-0.348	-4.572	0.000
Broberg, 2015	cycle to school_500m buffer	CIM Alone	-0.361	-0.524	-0.171	-3.613	0.000
Broberg, 2015	walk to school_100m buffer	CIM Alone	-0.615	-0.802	-0.318	-3.623	0.000
Broberg, 2015	walk to school_500m buffer	CIM Alone	-0.339	-0.556	-0.078	-2.518	0.012
Carver,2014	walk_w/i 800m buffer_2007_Boys	CIM Alone	0.041	-0.019	0.101	1.331	0.183
Carver,2014	walk_w/i 800m buffer_2007_Girls	CIM Alone	-0.003	-0.070	0.064	-0.081	0.936
Carver,2014	walk_w/i 800m buffer_2008_Boys	CIM Alone	-0.003	-0.102	0.096	-0.055	0.956
Carver,2014	walk_w/i 800m buffer_2008_Girls	CIM Alone	0.076	0.011	0.141	2.302	0.021
			-0.182	-0.293	-0.066	-3.062	0.002

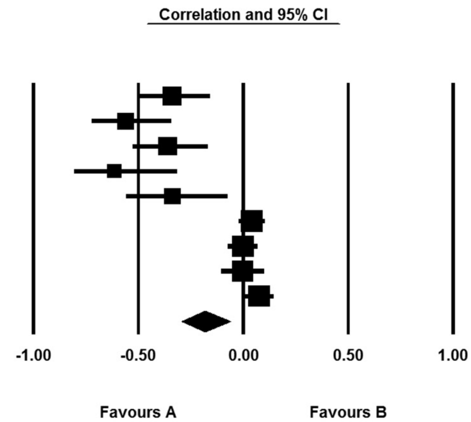


Fig. 5. The variable effects of land use mix on CIM between different subgroups.

were found to be reversed in case of CIM. This is conceptually plausible for children because dead-end streets generally serve less traffic with protected opportunities for children's outdoor activities (Brown and Werner, 1985; Carver et al., 2008; Hochschild, 2013). Furthermore, low-density traffic in front of child's home reduce safety concerns and ease parental restrictions (Islam et al., 2014; Moore, 1986). However, the conflicting findings between these two aged groups raise an important policy concern: how to design streets that facilitate walking for all aged groups, or in other words, how should city planner and urban designer negotiate between dead-ends and connected streets for the provisioning of road networks within a neighbourhood? It is also noticeable from the current review of the literature on BE-CIM link that the topological dimension of street network has rarely been studied. In contrast, the impact of street topology (measured using space syntax based indicators) on adult walking behaviour is increasingly being reported (Koohsari et al., 2016; Lee and Seo, 2013).

Unlike street design factors, the impacts of the distribution of land uses were found to be mostly positive (proportion of residential land use, proportion of commercial land use and residential location type). In contrast, the ES of land use mix variable was found to have the largest negative value among all the land use variables. Few relationships thus require a careful interpretation from a policy perspective. First, a significant positive ES of the proportion of residential land and an insignificant negative ES of residential density factor suggest that having a large residential area is important to enhance CIM irrespective of the design density. Second, this large residential zone must accommodate patches of commercial facilities (but not other land use types). Again, the commercial patches must be located close by. Third, priority should be given to the distribution of land uses of children's interest. Destinations where children might be interested in going from daily to occasional basis (e.g. school, friends' house, leisure destinations) should be located in close proximity. This is due to the fact that longer travel distance not only increases the restrictions on independent travel (Cervero, 1996; Zwerts et al., 2010), but also encourages the use of motorised vehicles and child's chauffeuring to destinations (Bradshaw, 1995; Fyhri et al., 2011; Mackett, 2002). Therefore, the findings are mostly consistent with prior studies on children mobility behaviour except for the land use mix factor. Finding from this research confirms that land use mix shrinks the territorial range of children (O'Brien et al., 2000; Villanueva et al., 2012b). Though for active travel, a greater land use mix has been reported to be an important predictor among adolescents (Larsen et al., 2009) and adults (Frank et al., 2003; Owen et al., 2004; Powell et al., 2003), but when it comes to children's independent travel, an increasing number of people on street due to diverse land uses might reduce mobility license and increase safety concern among children and parents. This finding confirms the negative impact of ‘stranger fear’ on CIM of previous studies (Hillman et al., 1990; Joshi and MacLean, 1995; Prezza et al., 2005; Valentine, 1997).

The generic findings and observations, as reported previously, might not be fully applicable in all contexts. As found in this research, the effects of the BE factors vary substantially between developed and developing country contexts. For example, distance to destinations, mixed land use, and intersection density factors were found to be a stronger barrier of CIM in developing countries whereas they have little to no effect in the context of developed country. In contrast, the width of vehicular street has the largest negative effect in the context of developed country but little effect in developing countries. This is largely due to the differences in safety perception between these contexts. It is likely that an increase of vehicular street width is likely to increase traffic volume, traffic speed and accident, and therefore, this factor is a greater concern for parents and children from developed countries. The variation in the level of CIM was also observed between settlement patterns (urban vs. suburb) within a context. These findings add to the understanding of the spatial dynamics of BE-CIM relationship (Priemus et al., 2001). It clearly shows how CIM changes with respect to the changes in the built environment, be it: contextual differences, or differences in urban structure (urban-suburban), or differences in urban form (density, dead-end streets).

One general observation that can be drawn from the findings of this research is that there exists a large heterogeneity among the primary studies. These statistical inconsistencies are the results of substantial differences in study locations (e.g. context, culture, and settlement pattern), study designs and sample characteristics (gender, age, size) among the primary studies. For example, further analysis (not reported in this paper) shows that the strongest effect of dead-end streets is more applicable to boys than girls in developing countries. This clearly reflect the need for peer accompaniment for girls to make them more comfortable to undertake independent mobility (Mackett et al., 2007). Moreover, no standard measurement strategies, either to represent BE factors or to represent CIM, have been followed in the primary studies. The inconsistencies in methods and measurement strategies hampered the homogeneity of the findings reported in this study. Often the survey instruments used in CIM studies are borrowed from the literature explaining adult travel behaviour which might not be a valid instrument for data collection from children.

One of the limitations of this study is the aggregation of different CIM dimensions to derive an overall ES. However, this is largely due to the limited number of studies reporting a BE-CIM relationships quantitatively. Again these studies were also found to be biased contextually. For example, residential location type, residential density, road density factors were extracted only from the developed country context whereas dead-end streets were investigated in the context of developing country context. To build a robust understanding of the role of different BE variables on CIM, more studies using comparable exposure and outcome measurement are needed. Also, an inconsistent use of BE variables among the primary studies resulted in a loss of sample in this research. For example, it was not possible to include some primary studies because they used intersection number instead of intersection density though they essentially measured the same BE characteristics.

Despite the above limitations, the evidence from this meta-analysis adds to the current body of knowledge documenting the most influential and consistent BE factors on CIM, one of the criteria used to characterize child-friendly cities. The findings serve as a guide for policy makers to design urban areas that promote CIM by creating environments where children enjoy the freedom of movement, exploration and play. Nevertheless, along with CIM, other criteria of the child-friendly city need to be fulfilled as specified in the child-friendly cities fact sheet (UNICEF, United Nations International Children's Emergency Fund, 2009). This study also unveils the reasons for inconsistent findings on this topic, and thus, would help researchers to be aware of the contextual factors that may impact their results.

Acknowledgement

The authors thank the associate editor (Prof David Keeling) of this journal and the two anonymous reviewers for their insightful comments and suggestions.

Appendix 1. Reasons for exclusion of some studies during the final screening

Sl	Excluded studies	CIM variable	Reason for exclusion
1	O'Brien et al. (2000)	CIM license	Results published in a statistical format not usable for this research
2	Lopes et al. (2014)	CIM destination	Results published in a statistical format not usable for this research
3	Villanueva et al. (2012a)	CIM range	Relationship of activity spaces with IM and walkability has been explored
4	Villanueva et al. (2013)	CIM destination	Only study that assessed relationship between walkability and IM
5	Schoeppe et al. (2016)	CIM range	Results published in a statistical format not usable for this research
6	Alparone and Pacilli (2012)	CIM destination	Used subjective perception about BE as independent factor
7	Loebach and Gilliland (2016)	CIM range, CIM destination	Results published in narratives
8	Van Vliet (1983)	CIM range	Results published in a statistical format not usable for this research
9	Prezza et al. (2001)	CIM destination	Results published in a statistical format not usable for this research
10	Carver et al. (2012)	CIM license	Comparison between urban and rural
11	Carver et al. (2014b)	CIM range	IM is used as independent variable and active transport as dependent variable
45	Björklid (2004)	CIM license	Results described using % only
13	Fagerholm and Broberg (2011)	CIM destination, CIM license	Results published in a statistical format not usable for this research
14	Drianda et al. (2015)	CIM license	Results published in narratives
15	Jones et al. (2000)	CIM destination	Used subjective perception about BE as independent factor
82	Ducheyne et al. (2012)	CIM license	Investigation on total cycling (IM is not specified)
17	Larsen et al. (2009)	CIM destination	Focus is on active travel, not on CIM
18	Tranter and Whitelegg (1994)	CIM destination, CIM license	Results published in a statistical format not usable for this research
19	Stone et al. (2014)	CIM license	IM is used as a mediator of physical activity
20	Johansson (2006)	CIM destination	Results published in a statistical format not usable for this research
21	Zwerts et al. (2010)	CIM destination	Results published in a statistical format not usable for this research
22	Ghekiere et al. (2016)	CIM range	Used subjective perception about BE as independent factor
23	Ghekiere et al. (2014)	CIM license	Investigation on total cycling (IM is not specified)

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