Norwegian University of Life Sciences
Faculty of Landscape and Society
Departement of Public Health Science

Philosophiae Doctor (PhD)
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Health-promoting environments for children and adolescents: Built environment characteristics as resources for activity participation and well-being

Helsefremmende nærmiljø for barn og unge: Fysiske miljøkvaliteter som ressurser for aktivitetsdeltakelse og trivsel

Emma Charlott Andersson Nordbø

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"Health is created and lived by people within the settings of their everyday life: Where they learn, work, play and love."

The Ottawa Charter for Health Promotion (WHO, 1986)

Preface and acknowledgements

The work presented in this thesis was undertaken at the Department of Public Health Science, Faculty of Landscape and Society, at the Norwegian University of Life Sciences during the years 2015-2019. The research was supported by a doctoral fellowship funded by the faculty.

My first encounter with the academic environment at the Department of Public Health Science was back in 2012, when I was an undergraduate student in nutrition. An inspiring lecture about health promotion and the determinants of health, delivered by Camilla Ihlebæk, caught my interest and became the point of departure for my journey into the field of public health. The past few years have been exciting, and I am deeply grateful for the opportunity to conduct research within this inspiring and inclusive academic environment. Now, I have finally reached the point in my journey where I am able to thank all those people whose wisdom, guidance, encouragement, support and honest criticism made this doctoral thesis possible.

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Ås, July 2019

Emma Charlott Andersson Nordbø

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Summary

Childhood and adolescence are important stages of life with long-lasting implications for both the health and well-being of individuals and society as a whole. Accordingly, health-promoting efforts aimed at supporting the everyday lives of children and adolescents represent a key priority for public health. In Norway, there has been increased attention paid to neighborhoods and local communities as crucial settings for such efforts, and health-promoting changes to the built environment are deemed a promising strategy. This doctoral thesis has examined neighborhood and local community built environment determinants and their potential to support participation in activities and strengthening the well-being of children and adolescents. Such knowledge can contribute to provide inputs for policy making, development and planning to achieve good health and well-being in the younger population.

This thesis has brought together data from different sources using a pragmatic multi-methodology research strategy based on quantitatively driven approaches and geographic information systems (GIS) technology. Through a step-based research process, review designs were utilized together with a cross-sectional epidemiological design. The first review focused on methodological issues and involved identifying, systematizing and evaluating previously applied GIS-derived measures and operational definitions of the built environment characteristics and the spatial units of analysis. The second systematic review addressed the health-promoting potential of the built environment by synthesizing the existing empirical evidence of relations between the built environment and the participation in activities and well-being of children and adolescents. The cross-sectional studies were conducted within the Norwegian context. Data from 23 043 eight-year-olds in the Norwegian Mother and Child Cohort Study were linked to GIS-derived measures of population density, green spaces and facilities around the residential addresses of the study participants. Associations between these built characteristics and children's participation in leisure-time physical activity (PA), organized activities and social activity with friends were investigated. Further, mediation analysis techniques were applied to examine whether these built environment characteristics were related to children's subjective well-being and if participating in different leisure activities mediated any such associations.

The methodological findings show numerous GIS-derived measures of diverse built environment characteristics for which consistency in operational definitions is very much needed. The empirical results suggested that the multifarious characteristics of built environments act as resources for participation in different activities, and could thereby contribute to strengthening well-being in childhood and adolescence. In particular, the synthesis of existing evidence showed that living in neighborhoods characterized by low traffic, proximate facilities, high walkability, more safety features and well-established infrastructure for walking and cycling likely promotes active travel and, to some extent, physical activity. Findings from the cross-sectional studies revealed that neighborhood green space was associated with more leisure-time PA among Norwegian 8-year-olds in both the summer and winter. The results also showed that more densely populated areas and more facilities, such as playgrounds/sports fields and schools, were associated with greater participation in organized and social activities. Further, positive indirect relations between the built environment characteristics and children's moods and feelings, through greater participation in leisure activities, counteracted some of the negative direct associations observed between children's emotional state and the determinants higher population density, access to a park, more playgrounds/sports fields. These findings from the Norwegian context underscore the role that the built environment may have in terms of enabling participation in a variety of leisure activities for children's subjective well-being.

This thesis concludes that although many methodological issues and knowledge gaps remain, planning for public health cannot wait. The best available evidence at this very moment suggests that children and adolescents who live in neighborhoods with versatile built resources and activity venues likely engage more in leisure activities that in the long run might contribute to strengthening their health and well-being. Accordingly, holistic approaches to public health within these everyday settings are essential. Different stakeholders, including policy makers, public health professionals and planners should acknowledge the multifaceted nature of determinants and appreciate that a variety of resources for health and well-being can be found within built environments.

Sammendrag

Barndom og ungdomsårene er viktige stadier i livet som har langsiktige innvirkninger på både individets helse og livskvalitet og på samfunnet i sin helhet. Helsefremmende tiltak som tar sikte på å støtte barn og unge i deres hverdag er derfor en sentral prioritering innen folkehelsearbeidet. I Norge er det viet økt oppmerksomhet til nabolag og lokalsamfunn som avgjørende arenaer for slik innsats, og tilpasninger av våre fysiske omgivelser betraktes som en potensiell strategi. Det er derfor avgjørende å ha en god forståelse av hva som kjennetegner et helsefremmende nærmiljø. Denne doktorgradsavhandlingen har undersøkt de fysiske nærmiljøkvalitetene i nabolag og lokalsamfunn og deres potensiale for å fremme deltakelse i aktiviteter og styrke trivsel blant barn og unge. Slik kunnskap kan bidra med viktige innspill til politikkutforming samt samfunns- og arealplanlegging for å sikre god helse og trivsel blant de yngste i vår befolkning.

Med utgangspunkt i en pragmatisk multimetodisk forskningsstrategi, ble data fra flere ulike kilder innhentet gjennom kvantitative tilnærminger og bruk av geografiske informasjonssystemer (GIS). Avhandlingen bygger på en trinnvis forskningsprosess der ble det benyttet ulike review design og et epidemiologisk tverrsnittdesign. Den første kunnskapsoversikten belyste metodologiske problemstillinger og involverte å identifisere, systematisere og vurdere eksisterende GIS-avledete mål og operasjonelle definisjoner av fysiske nærmiljøkvaliteter samt de romlige analyseenhetene. Den andre systematiske kunnskapsoppsummeringen fokuserte på nærmiljøets helsefremmende potensiale ved å sammenstille eksisterende forskning om sammenhenger mellom fysiske nærmiljøkvaliteter, deltakelse i aktiviteter og trivsel blant barn og ungdom. De epidemiologiske tverrsnittstudiene tar utgangspunkt i den norske konteksten. Data fra 23 043 åtte-åringer i Den Norske Mor-Barn Undersøkelsen ble koblet til GIS-avledede mål på befolkningstetthet, tilgang til grøntarealer og fasiliteter rundt barnas bostedsadresser. Sammenhenger mellom disse fysiske nærmiljøkvalitetene og barnas deltakelse i fysisk aktivitet, organiserte aktiviteter og sosial aktivitet med venner ble studert. Videre ble medieringsanalyser benyttet for å undersøke om de ulike nærmiljøkvalitetene var forbundet med barnas trivsel, samt hvorvidt deltakelse i fritidsaktiviteter fungerte som en potensiell mediator i slike eventuelle sammenhenger.

Avhandlingens metodologiske funn avdekker at en rekke GIS mål og operasjonelle definisjoner av de fysiske nærmiljøkvalitetene finnes og benyttes i forskningen, og det er et stort behov for mer konsistent bruk av både mål og definisjoner. De empiriske resultatene tyder på at mangfoldige

fysiske nærmiljøkvaliteter kan være viktige ressurser for aktivitetsdeltakelse og derigjennom bidra til å fremme trivsel blant barn og unge. Den systematiske kunnskapsoppsummeringen viste spesielt at nabolag kjennetegnet ved lite trafikkeksponering, flere sikkerhetselementer, fotgjengervennlige områder, nærhet til fasiliteter og veletablert infrastruktur for gående og syklister med stor sannsynlighet kan fremme aktiv transport, og til en viss grad, fysisk aktivitet. Resultater fra tverssnittstudiene viste at tilgang til grøntarealer var forbundet med mer fysisk aktivitet blant norske 8-åringer. Videre ble det funnet positive sammenhenger mellom høyere befolkningstetthet og tilgang til flere fasiliteter, slik som lekeplasser/aktivitetsanlegg og skoler, og økt deltakelse i organisert aktiviteter og sosial aktivitet med venner. Positive indirekte sammenhenger mellom fysiske nærmiljøkvaliteter og barnas humør og følelser, via økt deltakelse i fritidsaktiviteter, bidro til å motvirke noen av de negative sammenhenger observert mellom barnas emosjonelle tilstand og determinantene høyere befolkningstetthet, tilgang til park, flere lekeplasser/aktivitetsanlegg. Funnene fra den norske konteksten understreker hvilken rolle våre fysiske omgivelser kan ha med tanke på å fremme deltakelse i aktiviteter for barns trivsel.

Avhandlingen konkluderer med at selv om mange metodologiske problemer og kunnskapshull fortsatt eksisterer så kan ikke planlegging for å sikre god helse og livskvalitet i befolkningen vente. Den beste tilgjengelige kunnskapen vi har på nåværende tidspunkt peker i retning av at barn og unge som bor i nabolag med ulike fysiske nærmiljøkvaliteter og arenaer for aktivitet trolig deltar mer i helsefremmende fritidsaktiviteter, noe som i det lange løp kan bidra til å styrke deres helse og trivsel. Derav er helhetlige tilnærminger til folkehelse på disse arenaene viktig. Både politikere, samfunns- og arealplanleggere bør anerkjenne de mangfoldige helsedeterminantene i nærmiljøet og sette pris på at en rekke ressurser for helse og livskvalitet finnes, og kan gjøres tilgjengelig, i våre fysiske omgivelser.

List of papers

This thesis includes the following four papers:

Paper I

Nordbø, E.C.A., Nordh, H., Raanaas, R.K., Aamodt, G. (2018). GIS-derived measures of the built environment determinants of mental health and activity participation in childhood and adolescence: A systematic review. Landscape and Urban Planning, 177: 19-37. DOI: 10.1016/j.landurbplan.2018.04.009.

Paper II

Nordbø, E.C.A., Nordh, H., Raanaas, R.K., Aamodt, G. (2019). Promoting activity participation and well-being among children and adolescents: A systematic review of neighborhood built environment determinants. *[Revised manuscript submitted]*.

Paper III

Nordbø, E.C.A., Raanaas, R.K., Nordh, H., Aamodt, G. (2019). Neighborhood Green Spaces, Facilities and Population Density as Determinants of Activity Participation among 8-year-olds: A Cross-Sectional GIS Study Based the Norwegian Mother and Child Cohort Study. *[Submitted]*.

Paper IV

Nordbø, E.C.A., Raanaas, R.K., Nordh, H., Aamodt, G. (2019). Disentangling how the built environment relates to children's well-being: Participating in leisure activities as a mediating pathway among 8-year-olds based on the Norwegian Mother and Child Cohort Study. *[Submitted]*.

Abbreviations

DAG	Directed acyclic graph
GIS	Geographic information systems
GRRs	General resistant resources
HiAP	Health in All Policies
JBI	Joanna Briggs Institute
MoBa	The Norwegian Mother and Child Cohort Study
PA	Physical activity
PROSPERO	International Prospective Register of Systematic Reviews
SOC	Sense of Coherence
SSB	Statistics Norway
UGCoP	The Uncertain Geographic Context Problem
VIF	Variance inflation factor
WHO	World Health Organization

1 Introduction

1.1 The topic of the thesis and its relevance

The research presented in this thesis covers the built environment characteristics of neighborhoods and local communities that may act as resources for activity participation and well-being in childhood and adolescence. I endeavored to provide increased insights into both how we can assess the built environment and how we can create living environments that promote health and well-being in the early years of life. Greater knowledge on these matters is relevant and important for several reasons, as will be detailed below.

A main goal of the current Norwegian public health policy is to ensure that everybody in the population reaches their fullest health potential and attains high level of well-being. The government emphasizes initiatives that target children and adolescents, and the promotion of health and well-being in the younger population is one of three key priority areas for public health efforts in the coming years (Ministry of Health and Care Services, 2019; The Norwegian Directorate of Health, 2017). At present, children and adolescents younger than 18 years constitute 21.1% of the population in Norway (Statistics Norway, 2019), and each one of them represents our emerging generation and symbolizes the country's future. A sound and healthy childhood and adolescence fosters resilience and lays the foundations for becoming a healthy adult. Thus, strengthening health and well-being in the younger population is of tremendous importance to future social sustainability (Daelmans et al., 2017; Layard et al., 2014).

Health and well-being are primarily built and maintained in a wide array of arenas outside the health sector (WHO, 1986) in which modifiable built and psychosocial features act together to influence health and well-being across the life span (Barton and Grant, 2006; Bronfenbrenner, 1979; Dahlgren and Whitehead, 1991). Thus, research focusing on these everyday settings is particularly important. According to the core policy document for health promotion, the Ottawa Charter, creating supportive environments is an important public responsibility and a key strategy that can contribute to strengthening the health and well-being of populations (WHO, 1986). In recent years, there has been an increased emphasis, both nationally and globally, on the crucial role that neighborhoods and local communities play in health promotion (The Norwegian Directorate of Health, 2014b; WHO, 2016; 2018). At the same time, sustainable development has become a mainstream concern in society (United Nations, 2018; WHO, 2014). The World Health

Organization (WHO) (2018) stresses the need to invest in people's health and well-being as a precondition for sustainable development, and designing neighborhoods and communities that promote healthy, thriving and resilient populations is considered vital in that respect (United Nations, 2018; WHO, 2016). For these reasons, the Norwegian government focuses on developing evidence-based initiatives that can contribute to strengthening a sense of mastery and promote belonging, participation and activity in neighborhoods and local communities (Ministry of Health and Care Services, 2019; The Norwegian Directorate of Health, 2017). As a prerequisite for evolving these initiatives and creating health-promoting surroundings, we need more research that targets the modifiable built characteristics within these settings (Kerr et al., 2013; Ministry of Health and Care Services, 2019; WHO, 2018). Such research can contribute to a much-needed base of evidence and in turn provide input for policy making, development and planning towards achieving good health and high levels of well-being in the population.

1.2 The built environment, health and well-being: discussions in the literature

The research in this thesis relates to and builds upon existing knowledge of the built environment and its influence on the health and well-being of children and adolescents. Thus, I will briefly outline some ongoing discussions in the literature that have contributed to shape the overarching aim and specific research objectives of this thesis. A detailed overview of the particular knowledge gaps that the thesis aims to fill is provided in Chapter 2.10.

Attention to the built environment as a health determinant to children and adolescents has increased over the last two decades and the evidence base has grown considerably (Bird et al., 2018; Ding et al., 2011). Within the field of public health and the associated discipline of epidemiology, this interest has been driven by several related trends in which the increased availability of geographic information systems (GIS) stands central (Chaix, 2009; Diez Roux and Mair, 2010; Elliott and Wartenberg, 2004). GIS are a unified set of software tools that display, store, edit, organize and analyze spatially referenced data (Moore and Carpenter, 1999). These GIS tools are considered a major advancement because they provide researchers with new and innovative methods suited to quantifying built environment characteristics (Diez Roux and Mair, 2010). However, using geographic data involve making theoretical and conceptual abstractions out of reality (Burrough and McDonnell, 1998), which raises important methodological questions. How can we suitably define and measure a neighborhood or area in a local community? How can we operationalize the built environment determinants? There seem to be no clear answers to these very important questions (Brownson et al., 2009b; Chaix, 2009; Kwan, 2012; Laatikainen et al., 2018; Spielman and Yoo, 2009; Zhao et al., 2018). Great methodological awareness is required when using GIS for different public health and research purposes, and these questions need further consideration.

Research suggesting that built environment characteristics, such as parks, walking paths, venues for activities and connected street networks can promote participation in activities and well-being in children and adolescents holds tremendous promise. However, there is still a long way to go before we fully understand the health-promoting potential of the built environment (Bird et al., 2018; Christian et al., 2015; McGrath et al., 2015; Twohig-Bennett and Jones, 2018). In environmental epidemiology, the focus has often been on studying risk factors for ill health, while there has been a dearth of ecological thinking through a health-promoting lens by means of examining resources for health and well-being in the population (March and Susser, 2006; Pekkanen and Pearce, 2001; Susser, 2004). This is also the case in Norway (Holmen et al., 2016). International agendas for future research on health-promoting environments have stressed a need for more detailed investigations, both conceptual and applied, into how well-being and different everyday activities are related to the built environment (Christian et al., 2015; Ding and Gebel, 2012). Furthermore, relationships between the environment, health and well-being may not be direct but are potentially mediated through several other factors (Chaix, 2009; Kyttä et al., 2015; Mouratidis, 2018b). More research that deepens our understanding on these matters can contribute to advancing the creation of health-promoting neighborhoods and local communities.

1.3 Overarching aim and structure of the thesis

Bearing in mind the aspects highlighted above, the *overarching aim* of this thesis is to investigate neighborhood and local community built environment determinants and their potential to support participation in activities and strengthening the well-being of children and adolescents. The topic touches upon several disciplines. Although contributions from a variety of fields are included and considered, this thesis is rooted in public health and epidemiology. A particular emphasis is placed on the health-promoting perspective by focusing on positive determinants that may act as resources for health and well-being.

This thesis contains seven chapters. This first introductory chapter has provided firm grounds for why it is important to examine the built environment determinants of health and well-being in the younger population. In addition, I have pointed to some ongoing discussions in the literature of relevance to this research endeavor. The second chapter focuses on the theoretical and empirical framework. The main aim and the specific research objectives are detailed in chapter three, while the fourth chapter is devoted to the research strategy, including the study design, data material and analysis methods. Short summaries of each of the four papers are presented in the fifth chapter. The sixth chapter offers a synthesized discussion of the findings. A conclusion that considers the thesis contribution to the scientific community, policy and practice, along with some closing remarks, is provided in the final chapter. This thesis will close with an epilogue, followed by the reference list, full-text papers and relevant appendices.

2 Theoretical and empirical framework

This chapter presents the theoretical and empirical foundations that underpin the research covered in this thesis. First, definitions of the main concepts are given to clarify how these are understood and applied herein. In addition, I provide empirical data that elucidates the state of health and well-being as well as the activity patterns of Norwegian children and adolescents. Then, this chapter briefly touches upon the broader political, societal and geographic context of this thesis, before the details of the theoretical framework are presented. Lastly, this chapter offers an overview of the identified knowledge gaps and the limitations of previous research this thesis attempts to address.

2.1 Children and adolescents

Children and *adolescents* represent the target populations in this thesis and refer to those in the younger population aged 0–18 years, as defined by Statistics Norway (SSB) and in the UN Convention on the Rights of the Child (Statistics Norway, 2019; United Nations, 1989). *Childhood* refers to the age span from birth through the age of 12 years, and individuals who are 12 years or younger are termed children. *Adolescence* herein encompasses the ages of 13 through 18, and those within this age range are termed adolescents. This distinction is based on the life-course approach to health (WHO, 2000), previous health and built environment research among these age groups (Ding et al., 2011) and the transition from elementary school (barneskolen) to junior high school (ungdomsskolen) in Norway, which occurs at approximately 13 years of age.

2.2 Understanding health and well-being

Health and *well-being* are core concepts in this thesis. How we understand, define and apply these concepts determines our focus when theorizing on and carrying out health-promoting research and efforts that aim to support the everyday lives of children and adolescents. Both concepts embody an array of meanings and understandings (Barstad, 2016; Carlquist, 2015; Naidoo and Wills, 2009) that will become visible through the elaboration provided below.

Health is commonly conceptualized in either a negative or positive way (Naidoo and Wills, 2009). In a narrow and negative sense, health is understood as the absence of a measurable disease or infirmity (Naidoo and Wills, 2009). A more positive way of understanding health has been suggested by WHO, which has defined health as "[a] state of complete physical, mental and social well-being and not merely the absence of disease or infirmity" (WHO, 1946). This definition has been extensively criticized for being unrealistic and counterproductive because it leaves nearly all of us unhealthy most of the time. Despite these criticisms, the definition has contributed to an important debate about what health means. The key point is that the absence of disease is not itself equal to health nor well-being, and this has created space for valuing more holistic perspectives of public health work and the goals of such efforts (Bickenbach, 2017). Within the context of health promotion, health has been defined as a resource that allows people to lead fulfilling lives, cope with normal stresses and contribute to society. Health is a resource for everyday life, not the object of living (WHO, 2008). This definition reflects some of the consensus about health that has emerged over the years, which has embraced the idea that health is a separate concept from well-being and is of intrinsic value to human beings. In itself, health is a resource for well-being, but at the same time, health arises as a result of well-being (Bickenbach, 2017; Salomon et al., 2003). With that in mind, we should take a closer look at the concept of well-being.

Well-being is regarded as a multidimensional concept that cannot be defined in general terms (Barstad, 2016). At present, we can distinguish between five different main perspectives or understandings of well-being that are applied in the literature (Figure 1): (1) hedonic well-being, (2) theories of life satisfaction, (3) desire- or preference-satisfaction accounts, (4) eudemonic well-being and (5) objective-list accounts (Barstad, 2016; Carlquist, 2015; Taylor, 2015). These main perspectives capture different aspects of well-being that are situated on a continuum extending from the subjective to the objective (Carlquist, 2015; WHO, 2013). Being familiar with these perspectives is important to understanding the concept of well-being. Thus, before embarking on an explanation of how the concept is applied in this thesis, I will provide an account of these perspectives.

Hedonic well-being is based on people's feelings and emotions (Carlquist, 2015). Hedonist perspectives consider well-being as the presence of pleasant, positive emotions, such as happiness and joy, and the absence of unpleasant, negative emotions, such as sadness and worry (Barstad, 2016). According to theories of life satisfaction, well-being reflects an individual's evaluation of or affective response to his or her life in general or his or her different life domains (Diener, 2000; Taylor, 2015). Subjective well-being usually refers to a combination of hedonic perspectives and life-satisfaction accounts (Barstad, 2016). As such, people's own cognitive and affective evaluations of life and their emotional states form the basis of the subjective dimension of well-being (Carlquist, 2015). However, subjective well-being has also been theorized as being made up of a combination of hedonic and eudemonic well-being and life-satisfaction accounts (OECD, 2013), although the eudemonic perspectives generally capture more objective aspects of well-being (see below) (Carlquist, 2015). Desire- or preference-satisfaction accounts view well-being as the fulfillment of personal desires or preferences. These accounts include both unrestricted theories (i.e., they consider all of a person's desires without any restrictions) and informed or rational desire theories (i.e., they focus on desires based on information or rationality) (Barstad, 2016; Taylor, 2015).

Closer to the objective end of the continuum, we find eudemonic well-being and something referred to as objective-list accounts (Carlquist, 2015). Eudemonic well-being goes beyond the cognitive and affective evaluations and considers psychological functioning, meaning and purpose in life. Moreover, it is concerned with activities in the sense that people perform activities to realize their abilities (OECD, 2013; Carlquist, 2015). Ryff and Singer (2008) conceptualize eudemonic well-being as comprised of autonomy, self-acceptance, purpose, positive relationships, personal growth and environmental mastery. Thus, eudemonic perspectives differ from hedonic well-being and theories of life satisfaction because they are orientated toward factors, conditions and capabilities as indicators of well-being (Carlquist, 2015; OECD, 2013). Accordingly, eudemonic perspectives are situated on the objective side of the continuum, although the different conditions and capabilities are usually measured by requesting people's own subjective assessments of their functioning (Carlquist, 2015). Lastly, we have the perspectives of the objective-list accounts. These perspectives share the view that the presence of a plurality of objective goods in a person's life constitutes well-being (Barstad, 2016; Taylor, 2015). The capabilities approach resembles an objective list-account perspective (Nussbaum, 2000) by considering a variety of opportunities, including those presented by societal and living conditions, that expands or limits our possibilities to achieving valuable human functioning (Carlquist, 2015; Nussbaum, 2000; Sen, 2005). At present, different objective lists exist. Barstad (2016) has put forward a list of beneficial characteristics of well-being, which includes, among other factors, good physical and mental health, financial security, social relationships and safe and supportive housing and neighborhoods. Likewise, The Children's Society (2012) has highlighted six essential factors for the well-being of children: having enough of what matters, positive relationships with friends and family, the right conditions in which to learn and develop, a safe and suitable living environment, opportunities to thrive through taking part in activities and a positive view of one's self and an identity that is respected by others. These two lists are similar to those provided by bodies such as the Organization of Economic Co-operation and Development (2013).

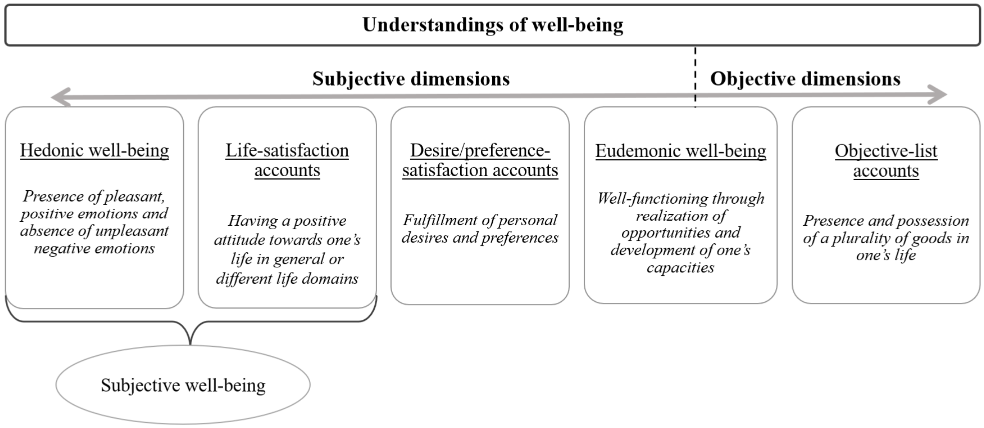


Figure 1. A simplified overview of the main perspectives of well-being based on Carlquist (2015).

So which perspectives underlie the understanding of health and well-being in this thesis? In summary, the research presented herein relies on a positive and holistic definition of health in which health is considered a profound resource vital for individuals and society. Further, this thesis takes the view that health and well-being are distinct but highly interrelated concepts, and there is a reciprocal relationship between the two of them (WHO, 2013). Both health and well-being include aspects of life that matter to human beings, and they are seen as resources for each other and as distinct goals for public health efforts (Barstad, 2016; WHO, 2013). The concept of well-being is understood as something more than just an individual matter. This thesis considers that supportive built environments and participation in activities are important aspects of children's well-being irrespective of their own subjective opinions. However, it also considers how these essentials relate to children's subjective feelings and emotions. As such, this research focuses on addressing both the objective and subjective dimensions of children's well-being through what could be considered an objective-list account perspective (Barstad, 2016; Carlquist, 2015).

2.3 The health and well-being of Norwegian children and adolescents

What is the current state of health and well-being in the younger population? Norway ranks high in international comparisons with respect to health and some aspects of well-being (Save the Children, 2019; UNICEF Office of Research, 2013), and recent national statistics indicate that children and adolescents in Norway are in good physical health (Norwegian Institute of Public Health, 2018). At present, we lack complete data on the well-being of children and adolescents, but a few health surveys have assessed life and school satisfaction as well as self-perceived health among young people (Norwegian Institute of Public Health, 2018). Before taking a glance at these numbers, it should be kept in mind that the health survey statistics presented mainly address children and adolescents over 10 years of age, except those statistics related to mental health problems. The reason is that few of the national surveys address young children, though efforts are underway to increase our knowledge of health and well-being within this age group (Evensen and Løvgren, 2018).

The majority of adolescents in Norway perceive their general health as good or very good, and they report high life satisfaction (Bakken, 2018; Norwegian Institute of Public Health, 2018; Samdal et al., 2016). Further, over 90% of Norwegian children and adolescents (fifth graders in elementary school and older) report that they are highly satisfied with their everyday life at school (Wendelborg, 2017). Although the younger population in Norway is healthy in general, mental health problems represent a growing proportion of the total burden of health issues nationally in those younger than 18. At present, such problems are deemed among the most important public health issues to address among Norwegian children and adolescents (Ministry of Health and Care Services, 2019; Norwegian Institute of Public Health, 2018). It has been estimated that 15-20% of those aged between three and 18 years have experienced mental health problems (Norwegian Institute of Public Health, 2009). These estimates concur with recent numbers from sixth, eighth and tenth graders in Norway. Among sixth graders, 24% reported that they felt depressed at least once every month whereas 9% felt depressed at least once a week for the past six months (Samdal et al., 2016). These numbers are higher for adolescents (Bakken, 2018). Further, about 7% perceive their general health as poor (Bakken, 2018; Samdal et al., 2016); girls, in particular, tend to be less satisfied with their own health (Bakken, 2018). It is also assumed that a large fraction of Norway's high-school dropout rate (currently nearing 21%), is attributable to mental health problems (Norwegian Institute of Public Health, 2018).

It is important to emphasize that these negative symptoms and emotional difficulties rarely fulfill any criteria for the presence of mental health disorders. All human beings experience ups and downs as part of their everyday lives, and in most children and adolescents, these negative symptoms are temporary. Yet for some, they are long-term, and the risk of long-term psychological distress increases with the child's age (Norwegian Institute of Public Health, 2009). Hence, health-promoting efforts in early childhood are still essential. Although the thesis does not address how we can prevent the mental health issues raised above, there is a reciprocal relationship between mental health and well-being (see Chapter 2.2). Thus, investigating the potential resources for well-being is valuable because it could provide improved understanding of how children and adolescents remain healthy despite facing everyday difficulties. Knowing more about such resources can contribute to counteracting mental health issues (Steptoe et al., 2015). This brings us to the benefits of participating in activities for the health and well-being of children and adolescents.

2.4 Participation in activities and its importance to children and adolescents

Participating in activities herein refers to involvement in leisure activities, including organized and informal meaningful activities (Law, 2002), and regular active transport-related activities, such as walking or cycling to and from school (Sallis et al., 2006). Organized activities encompass activities that involve regular commitment and are usually directed by adults and guided by rules. Further, organized activities are often goal-oriented, with an emphasis on developing skills and knowledge. Examples of organized activities include scouts, music and theatre and individual and team sports. Informal activities include non-compulsory, unplanned or spontaneous activities with few explicit goals. These activities are generally initiated by the child or adolescent him or herself and might include indoor and outdoor play, hanging out with friends, unstructured leisure-time PA and other recreational activities (Desha and Ziviani, 2007; Law, 2002).

Participating in activities is vital for the health and well-being of children and adolescents (Law, 2002; Mahoney et al., 2005; Passmore, 2003). Repeatedly, studies have emphasized the importance of being physically active on a daily basis to improve physical fitness and to reduce the risk of lifestyle-related diseases. Other health benefits of PA have received less attention, but being active on a regular basis has been linked to fewer depressive moods and psychological symptoms (Goldfield et al., 2011; Janssen and LeBlanc, 2010). Furthermore, participating in organized activities is related to better self-perceived health, higher academic achievements, more positive social relationships and higher satisfaction with life (Badura et al., 2015; Breistøl et al., 2017; Mahoney et al., 2005). Considerable evidence has also demonstrated the importance of spending time and taking part in social activities with friends and peers for physical, psychological and social well-being in childhood and adolescence (Goswami, 2012; Thoits, 2011; Umberson and Montez, 2010).

There is a strong relation between physical activity levels and age in the Norway's young population. The proportion of the population that engages in at least 60 minutes of daily physical activity is greatest among Norwegian 6-year-olds, of which 87% of girls and 94% of boys meet the recommendation determined by the health authority (The Norwegian Directorate of Health, 2014a; Steene-Johannessen et al., 2019). After the age of six, physical activity levels gradually decline and continue to do so throughout adolescence. Just about 64% of 9-year-old Norwegian girls and 81% of 9-year-old Norwegian boys comply with the recommendation, whereas the proportions are 40% and 51% among 15-year-old girls and boys, respectively (Steene-Johannessen et al., 2019). The activity levels of girls remained quite stable across all age groups between 2005 and 2018, while among 9- and 15-year-old boys, the proportion who satisfy the recommendation has decreased by 6% since 2012 (Kolle et al., 2012; Steene-Johannessen et al., 2019). Other investigations also demonstrate similar results when comparing sixth, eighth and tenth graders in Norway, showing that tenth graders are the least physically active (Samdal et al., 2016).

Recent numbers on active travel behavior among children and adolescents in Norway show that 62% of 6-year-old children use passive transport to get to and from school; of these, 50% are driven. This represents an almost 10% increase of passive transport for younger children compared to results from 2011 (Kolle et al., 2012; Steene-Johannessen et al., 2019). Among the 9-year-olds, over 70% walk or cycle to and from school. At the age of 15 years, close to 67% of adolescents travel actively to and from school on a regular basis. There seems to be a trend towards increased active travel among the 9-year-olds, while the proportion has dropped nearly 5% since 2011 among the 15-years-olds (Kolle et al., 2012; Steene-Johannessen et al., 2019). The underlying reasons for low levels of physical activity and the declines in active travel may include how the built environment is designed (Sallis et al., 2006). In terms of health promotion, strategies that contribute to the increase of physical activity levels and the promotion of active travel among children and adolescents in Norway could be of significance.

Besides this, results from national health surveys also show that Norwegian children and adolescents participate in many kinds of activities in diverse arenas. Of the organized leisure activities, team sports attract the largest proportion of those aged 12 years or older (Bakken, 2018; Samdal et al., 2016). Similarly, the majority of the 9-year-olds participate in organized team sports (Kolle et al., 2012), but scouts, individual sports, music and theater and activities of a more religious character are also common (Bakken, 2018; Samdal et al., 2016). Furthermore, nearly 60% spend time with their friends at least twice a week (Kolle et al., 2012). Thus, in addition to promoting physical activity and active travel among children and adolescents in Norway, sustained engagement and participation in these meaningful leisure activities could also be a relevant health-promoting strategy as well – but how can we do this?

2.5 Neighborhoods and local communities as settings for health promotion

Health promotion can be distinguished as one of the processes for securing public health (Naidoo and Wills, 2009). Health promotion is defined as "[t]he process of enabling people to take control over the determinants of health and thereby improve their health" (WHO, 1986). Unlike preventive actions, which aim to prevent diseases and detect risk, health-promoting efforts aim to facilitate and strengthen positive factors and activities that make us healthier. Health promotion represents a comprehensive process that embraces actions directed at strengthening the skills and capabilities of individuals, and it also describes efforts toward changing social, environmental and economic conditions (WHO, 2008). The Ottawa Charter for Health Promotion outlines five priority action areas, and building healthy public policy and creating supportive environments are the two key action areas related to the subject matter of this thesis (WHO, 1986). Building healthy public policy is defined as "[p]lacing health on the agendas of policy makers in all sectors and at all levels, directing them to be aware of the health consequences of their decisions and to accept their responsibilities for health" (Naidoo and Wills, 2009, p. 172; WHO, 1986). Such coordinated and joint action across sectors can contribute to the provision of supportive, safe, stimulating, satisfying and enjoyable environments (WHO, 2018).

The health-promoting actions and efforts detailed above can target different contexts or settings (Whitelaw et al., 2001), often referred to as the settings for health promotion (Naidoo and Wills, 2009). A setting for health promotion is defined as "[t]he place or context in which people engage in daily activities and in which environmental, organizational and personal factors interact to influence health and well-being" (WHO, 2008, p. 19). Schools, kindergartens, primary health-care facilities and hospitals all represent settings for health promotion (Naidoo and Wills, 2009). It is outside the scope of this thesis to provide details about health-promoting efforts within these specific settings. Yet, it should be mentioned that kindergartens and schools are considered relevant facilities within *neighborhoods* and *local communities*, which are the two key settings for health promotion that this thesis focuses on (Naidoo and Wills, 2009). This thesis investigates neighborhood and local community settings in two ways: (1) methodologically by appraising how we can define and delineate such setting using GIS methods, and (2) empirically, by examining whether and how built environment characteristics within these settings are related to participation in activities and well-being. The subsequent section explains the built environment characteristics in further detail.

2.6 The built environment through a socio-ecological public health lens

The Ottawa Charter for Health Promotion recognizes that our societies are complex and interrelated (WHO, 1986) and the determinants of health and well-being in childhood and adolescence are multifaceted (Helliwell et al., 2017; Viner et al., 2012). This establishes foundations for a socio-ecological approach to public health and epidemiological research upon which this thesis is based on. The main drive behind the use of a socio-ecological lens is to understand the multiple determinants and thereby use each available means that has potential to strengthen health and well-being across the life span (Bentley, 2013; Crosby et al., 2013). The socio-ecological perspective is rooted in certain core principles for understanding relations among the environment, health and well-being. First, the environment has both physical and psychosocial determinants that may influence a range of outcomes, as shown below. Second, there are dynamic relations between the environment and individuals. This implies that the same environmental determinants might influence people's health and well-being differently depending on factors such as age, gender and socio-economic position. Third, the environment can be characterized in terms of its objective qualities as well as its perceived qualities (Stokols, 1992; 1996).

The much-cited determinant model of Dahlgren and Whitehead (1991) comprises several layers of influencing factors on health and well-being. All these factors are modifiable and include individual lifestyle habits, social and community network, living and working conditions and a wider set of societal, cultural and global environmental conditions. Barton and Grant (2006) created a modified model that renders the specific determinants within our neighborhood and local community settings (Figure 2). The figure illustrates that the built environment characteristics investigated in this thesis represent *determinants of health* and *well-being.*

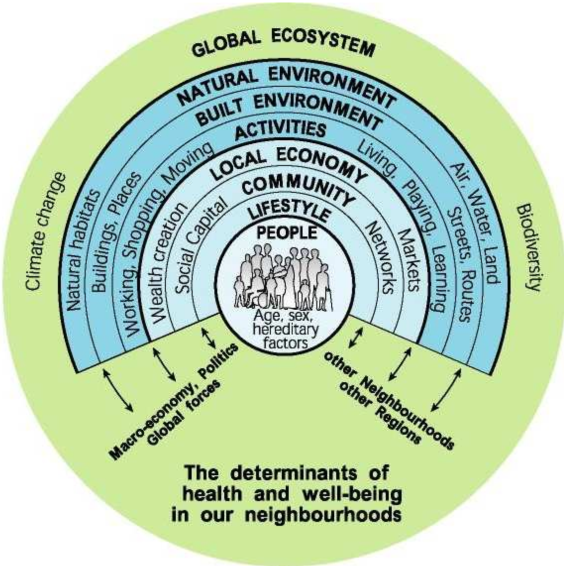


Figure 2. Determinants of health and well-being in the neighborhood (Barton and Grant, 2006).

Determinants or characteristics within neighborhoods and local communities are both of physical and psychosocial character. The physical environment includes attributes, such as parks, streets, roads, buildings, walking paths, residential areas and recreational venues, while psychosocial factors relate to the sense of identity and social cohesion (The Norwegian Directorate of Health, 2014b). The research presented in this thesis addresses the physical attributes, also described as the built environment determinants or the built environment characteristics. The built environment is defined as part of the physical environment (Saelens and Handy, 2008), and both terms are used interchangeably in the literature. Herein, the built environment refers to both physical and natural attributes of neighborhoods and local communities, including the people who live there.

Built environment determinants interact with an array of other essential determinants (e.g., genetic and biological factors such as gender, lifestyle and psychosocial aspects, such as parental influences) through complex mechanisms and a dynamic interplay, which may eventually threaten or promote an individual’s health and well-being (Naidoo and Wills, 2009). The research in this thesis is unable to account for all the potential determinants. Thus, when considering the findings of this thesis, it is crucial to keep in mind that the built environment determinants represent only a small part of the whole Gordian knot, in which the broader political and societal determinants also play a role.

2.7 The Norwegian political, societal and geographic context

Norway is the study area of the present thesis. The built environment determinants under investigation, and their potential relations to the leisure activities and well-being of children and adolescents, are embedded in this broader political, societal and geographic context. It is outside the scope of this thesis to consider all these factors in detail. However, I will briefly provide some background information about the context of this thesis to shed light on the Norwegian circumstances, especially since several of these factors also direct strategic public health work in Norway.

Over the last decade, a shift in focus from preventing diseases to promoting health and well-being as an overall public health goal has been noticeable in Norway (The Norwegian Directorate of Health, 2010). Today, a health-promoting mindset has permeated Norwegian public health policy (Ministry of Health and Care Services, 2019), and cross-sectoral collaboration is anchored both in the Public Health Act (2012) and the Planning and Building Act (2008). The Public Health Act (2012) emphasizes the following principles for public health efforts: sustainable development, public participation, the strategy of Health in All Policies (HiAP) and the reduction of social inequalities in health. The Public Health Act intends to facilitate long-term and systematic public health efforts, and all Norwegian municipalities are obliged to have an overview of their inhabitants’ health and the positive and negative factors of influence. Moreover, the Planning and Building Act (2008) states that a substantive consideration in planning should be to protect children and adolescents and to ensure they have good conditions in which to grow up. This strong focus anchored in national legislation provides solid grounds for health-promoting efforts connected to the built environment within neighborhoods and local communities.

Several WHO programs make efforts to translate health-promotion concepts and strategies into actions in different settings, including, among others, the Healthy Cities and Municipalities strategy (WHO, 2008). In Norway, such efforts are facilitated through the *“Sunne kommuner”*

(Healthy Municipalities) network, which is a partner in the global WHO Healthy Cities network. At present, *"Sunne kommuner"* has 35 members (30 municipalities and five counties) across Norway. The network operates both at local, regional and national levels to create communities that promote health and well-being in the population. All these long-term initiatives aim to place health high on the agendas of decision-makers and strengthen strategies for health promotion and sustainable development (WHO, 2014).

Public health work in Norway developed rapidly after the Public Health Act entered into force in 2012. Several efforts have been made to raise awareness and increase knowledge about public health in different public sectors. Between 2012 and the end of January 2015, the Office of the Auditor General (Riksrevisjonen), which is responsible for monitoring the public sector, assessed the extent to which public health work in Norwegian counties and municipalities was long-term and systematic. The office raised several remarks and issues and emphasized that public health efforts were not sufficiently evidence-based nor sufficiently embedded in sectors other than health (The Office of the Auditor General, 2015). Recent studies have shown that nearly 55% of Norwegian municipalities currently include public health and associated efforts as objectives in their planning strategies. This particularly pertains to social planning, whereas public health is less integrated in the spatial planning sections of municipal master plans (Hofstad, 2018; Thoren et al., 2018). Transferring knowledge about public health and related issues and making it relevant and more accessible for spatial planning is important but challenging. It has been stated that public health goals need to be more operationally relevant for spatial planning (Hofstad, 2018).

Present population development trends provide a basis for national, regional and municipal planning. The Norwegian population will increase over the next 50 years and is estimated to reach about 7 million people in 2060. Today, approximately 82% of the population lives in densely populated areas, and nearly 45% of those reside within the four metropolitan regions of Oslo, Bergen, Stavanger and Trondheim (Ministry of Health and Care Services, 2015). Additionally, we observe an increase of more centralized settlement patterns across the country, and this is expected to continue in forthcoming years. Since 2002, the proportion of the population residing in densely populated areas has increased from 77% to 82% (Statistics Norway, 2018). Although a rising proportion of the population resides in densely populated areas, Norway is still characterized by low population density and rich access to green space compared to other countries (World Bank, 2017). Centrality refers to how easy or demanding it is to reach most of the facilities needed in everyday life, such as school, shops, workplaces, health-care facilities, cultural venues and neighboring home (Høydahl, 2017). There are large regional differences across Norway, but generally municipalities are characterized by low centrality (Figure 3). At present, governmental planning guidelines for coordinated housing, land-use and transport planning emphasize that development patterns and transport systems should promote compact cities and settlements (Ministry of Local Government and Modernisation, 2014). According to the Ministry of Health and Care Services (2015), all areas of growth and development offer opportunities for integrating health-promoting built environment qualities in local community planning and development processes.

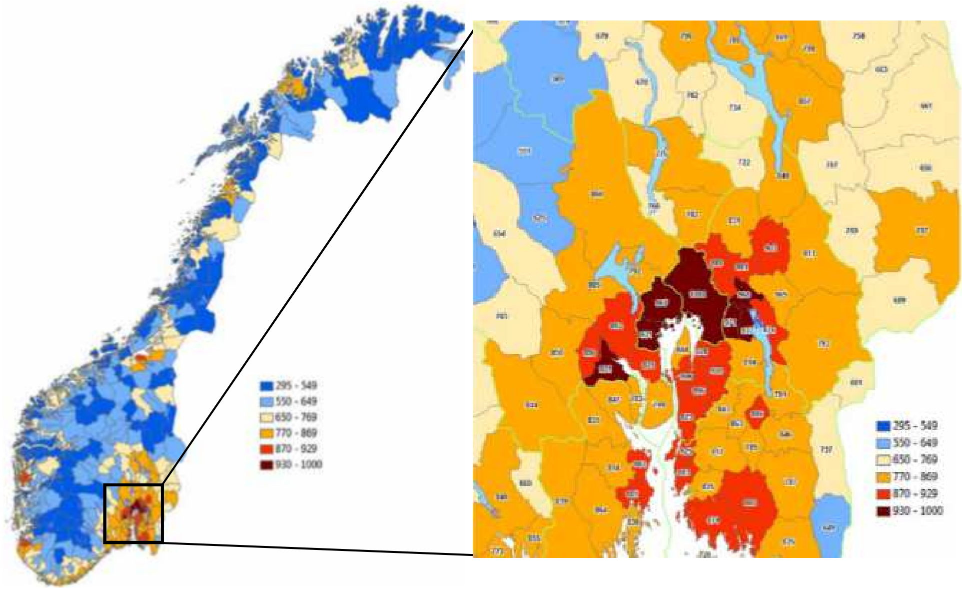


Figure 3. Norwegian municipalities, with a detailed view of Oslo and surrounding municipalities, grouped according to centrality ranging from low to high. Based on data from Høydahl (2017).

2.8 The built environment and activities as resources for health and well-being

As illuminated in the previous sections of this second chapter, this thesis deals with a complex phenomenon, and its topic is highly interdisciplinary. This implies that a plethora of theories and perspectives could have fruitfully contributed to informing this research endeavor (Carlquist, 2015; DiClemente et al., 2013), a fact I acknowledge. From a socio-ecological public health perspective, the use of multiple theories is seen as essential to understand the phenomenon under study: health-promoting environments for children and adolescents (DiClemente et al., 2013). Viewed through a socio-ecological lens, this thesis is made up of three main elements: (1) the health and well-being of children and adolescents, (2) their participation in activities, and (3) neighborhood and local community built environment determinants. Different theoretical perspectives could give a better and more cohesive understanding of health-promoting environments when one attempts to interpret the elements and their interrelations. Accordingly, the thesis embraces theoretical eclecticism (Cooksey, 2001), which means that I drew upon multiple theories and ideas to gain a more complementary insight into the research topic.

Figure 4 illustrates and links the key concepts addressed earlier in this chapter, the thesis's main elements and the different theoretical perspectives. As stated, this research has a socio-ecological public health lens. The health-promoting perspective based on *salutogenesis* represents the focal theoretical and interpretive framework for examining the potential positive determinants (resources) that may strengthen health and well-being. The concepts of *sense of coherence* (SOC) and *general resistant resources* (GRR), both situated under the salutogenic umbrella (Antonovsky, 1996), were applied to understand the health-promoting potential of the built environment. Herein, the possible GRRs for developing a strong sense of coherence, and thereby greater well-being, represent participation in activities, which were considered from an *occupational science perspective,* and the built environment characteristics, which I grasped through the concept of *affordances*. Thus, the occupational science perspective and affordance theory worked as supportive theoretical lenses in understanding how built environment characteristics might influence the well-being of children and adolescents through participation in activities.

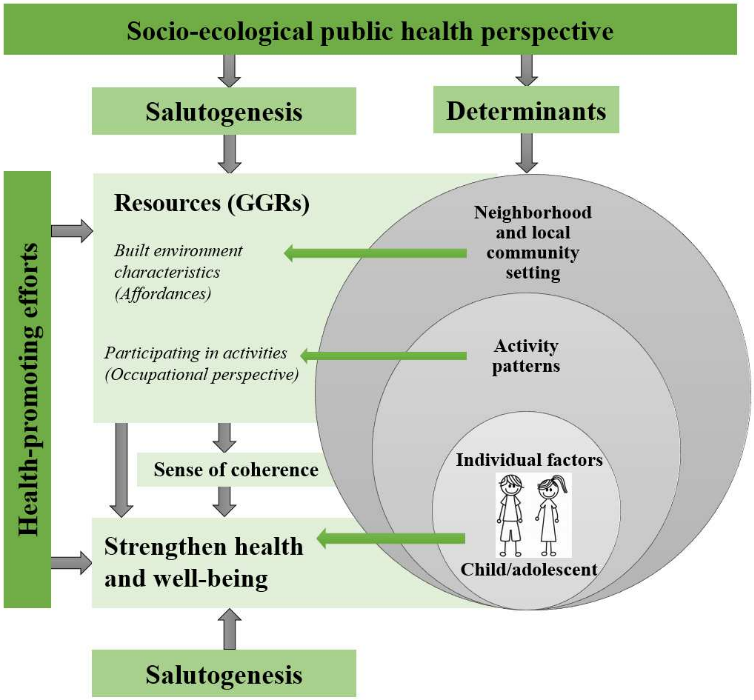


Figure 4. Linking it all together: key concepts, elements and theoretical lenses. Inspired by Bauer et al. (2006).

2.9 Salutogenesis as an overarching framework

As stated above, *salutogenesis* represents the overarching theoretical framework in this thesis. Instead of examining factors that disrupt health, salutogenesis focuses on addressing the potential resources for health (Antonovsky, 1996). Salutogenesis, known as the origins of health, is a broad framework for understanding the positive or salutary determinants of health and well-being. The framework comprises convergent concepts and theories that all contribute to explaining health, including sense of coherence (Eriksson and Mittelmark, 2017), which I will come back to later. Applying a salutogenic perspective when examining the determinants of health and well-being has been deemed crucial in confronting the health issues that we currently face in society (Morgan and Ziglio, 2007), and this theoretical lens is increasingly applied to understand different health-promoting settings, such as neighborhoods (Bauer, 2017). A salutogenic perspective corresponds with the essence and values of health promotion where the main goal is enabling people to take control of the determinants in addition to strengthening positive resources for health at the individual, group and societal levels. Morgan and Ziglio (2007) argued that we should search for resources that support health, including health-promoting qualities in our daily living environment. As such, the salutogenic perspective is useful for studying health-promoting environments.

2.9.1 Sense of coherence and general resistant resources

Antonovsky introduced the salutogenic theory by posing the question "What creates health and makes people stay healthy?" (Antonovsky, 1979; Mittelmark and Bauer, 2017). Antonovsky suggested that health and illness are not on or off states. Rather, he conceptualized health as a continuum on an axis between illness and total health, and all individuals occupy a place on this continuum. His notions evolved by observing that although people experienced significant life events, such as a disease, as part of their lives, they were still able to move towards the health end of the continuum (Lindström and Eriksson, 2005; Mittelmark and Bauer, 2017). Thus, Antonovsky found interest in the positive or salutary factors that nurture health, and he claimed that all these peoples' life orientations influenced their health. As an answer to his own question of what creates health, he formulated and established the two theoretical concepts of sense of coherence and general resistant resources (Antonovsky, 1996).

Antonovsky stated that individuals with a life orientation described as SOC, which means they experience the world as coherent, consistent, reasonable and comprehensible, experienced good health (Antonovsky, 1996). SOC reflects a person's view of life and capacity to respond to stressful situations by identifying and using resources to maintain and develop health. SOC composes three dimensions denoted as comprehensibility, manageability and meaningfulness (Eriksson and Lindström, 2007; Lindström and Eriksson, 2005). Comprehensibility refers to the degree to which an individual perceives various stimuli as comprehensive and that the stimuli are predictable, ordered and explicit. Manageability is the extent to which a person perceives that resources are at their disposal and that these resources are adequate to meet the demands of the stimuli. The last dimension, meaningfulness, refers to the extent to which a person feels that life makes sense emotionally (Lindström and Eriksson, 2005). When people understand the world they live in and perceive their own life as meaningful, comprehensible and manageable, they can utilize resources within themselves and their environment to maintain and develop positive health (Eriksson and Lindström, 2007; Lindström and Eriksson, 2005).

It has been proposed that a strong SOC develops through the internalization of resources. Internalization processes turn resources into GRRs, and this is driven by significant life events (Maass et al., 2017). GRRs refer to all the resources available to an individual that enable his or her movement to the health end of the continuum. Such resources can be found within individuals in the form of resources related to their personal characteristics as well as the material and non-material qualities in their immediate and distant environments. The GRRs provide a person with a set of meaningful and coherent life experiences (Lindström and Eriksson, 2005).

An interesting question with respect to this thesis's focus on health-promoting environment is whether and how built environment qualities within neighborhoods and local communities might contribute to perceptions of the world as comprehensive, manageable and meaningful. Can this in turn enable children and adolescents to utilize resources within themselves and their environment to maintain and develop health and well-being? It has been suggested that settings, such as the neighborhood, might influence the development of SOC by facilitating significant events and offering resources to handle them. Through this, environmental resources are internalized and become GRRs (Maass et al., 2014). It is assumed that neighborhood resources, such as built environment characteristics, influence health in two ways: by facilitating the development of a strong SOC and by working as a resource for individual health-promotion strategies (Maass et al., 2014), herein referred to as resources and opportunities to take part in leisure activities. Participating in activities is in turn a potential resource for developing a strong SOC and attaining high well-being.

2.9.2 An occupational science perspective

In this thesis, the importance of participating in activities for the health and well-being of children and adolescents is considered in light of *an occupational science perspective.* The word *occupation* comprises all meaningful activities that people do in their everyday lives (Wilcock and Hocking, 2015c). The occupational perspective on health states that people have innate needs to participate in different meaningful activities, which have evolved through human evolutionary history. This innate need is regarded as one of the primary health mechanisms of human beings. The need to participate in activities motivates the provision of other basic requirements and enables people to use their own abilities, meet sociocultural expectations and thereby thrive. Some activities are necessary or compulsory, such as attending school, whereas other activities are preferred for the particular purposes of meeting basic human needs and interests, such as being with friends or visiting recreational areas (Wilcock and Hocking, 2015c).

The meaning an individual experiences and derives through participating in activities is important. The notion of activities as meaningful in terms of doing, being, belonging and becoming provides a deeper understanding of the role that activities potentially play for the health and well-being of children and adolescents (Wilcock and Hocking, 2015a). *Doing* is about undertaking activities that maintain and promote health. However, meaningful doing is more than acquiring requirements for health and survival. People do what they do because it offers purpose, meaning, satisfaction, a sense of belonging and achievements for health and well-being (Wilcock and Hocking, 2015b). As a meaningful dimension of doing activities, *being* creates space for our identities and support the meaning-making of the activities that we engage in. *Belonging* relates to humans as social beings, and as such, belonging is a central dimension of meaningful doing. The connectedness that people might experience when engaging in activities together and the influence that such relationships have on health and well-being are essential for choosing and doing activities. Lastly, the dimension of becoming implies that individuals develop their interests and satisfy needs to become healthy and thrive trough meaningful doing (Gallagher et al., 2015).

There has been a tendency to view participation in activities mainly as an individual matter. However, this perspective has been criticized (Laliberte Rudman, 2013). Gallagher et al. (2015) proposed an understanding of participation in activities within a social world. People take part in everyday activities in different contexts embedded in time and place. As such, environmental and social conditions govern and contribute to shape of our activities. A fundamental aspect of viewing activities within a social world is that people must have possibilities and resources to participate in activities to be healthy and thrive (Gallagher et al., 2015). This notion of activities as embedded in diverse contexts undoubtedly mirrors the principles of interrelations between built environment determinants, health and well-being within the socio-ecological framework for health promotion (Stokols, 1996). Thus, the occupational perspective provides a fruitful and complementing view in this thesis, and it can explain the essentials of having opportunities to engage in different meaningful activities for the well-being of children and adolescents. These opportunities to engage in different activities may be found as affordances within the neighborhood and local communities.

2.9.3 Affordances as potential health-promoting environmental characteristics

The theoretical concept of affordances, first described by Gibson (1979) and built upon by Heft (1988; 1989) and Kyttä (2003), inspired this research endeavor. Heft (2010, p. 28) stated that "[b]ecause affordances are action-related properties of environments, they are particularly well suited for considering the implications of environmental design for health promotion and 'active living'." This makes the concept of affordances relevant for examining built environment characteristics as essential resources within neighborhoods and local communities.

When children and adolescents engage in different activities, they do so in settings such as the neighborhood and local community. According to Gibson, we can describe the environment with respect to what it affords individuals (Gibson, 1979). Affordances refer to environmental characteristics that are momentous because of the activities they facilitate or inhibit. They are seen as opportunities for action or functional experiences (Gibson, 1979), such as rocks that afford sitting or climbing and surfaces that afford running or walking, and they are also seen as opportunities for social activities and emotional experiences (Heft, 1988; Kyttä, 2003; 2012). According to Heft (1989; 2010), affordances are both objectively real environmental characteristics to be utilized (i.e., they exist whether an individual perceives them or not) and subjectively significant qualities that need to be perceived to be actualized (i.e., persons perceive, define and actualize the affordances). Thus, a distinction has been made between the *potential* and the *actualized affordances* (Heft, 1989; Kyttä, 2002). Likewise, Greeno (1994) stated that potential affordances are vital for activities to occur, but although the environment provides affordances for particular activities it does not imply that these activities transpire (i.e., the affordances are not necessarily actualized).

The majority of built environment characteristics investigated in this thesis can be seen as *positive potential affordances* (Kyttä, 2003). They exist whether a child or adolescent perceives them or not, and they are regarded as potential resources for activities and well-being. As explained above, we can measure and identify potential affordances, but whether the affordances are actually utilized can only be considered in relation to a specific individual (Heft, 2013). I recognize the importance of considering actualized affordances, but the empirical research presented herein lacks this dimension. As such, it is important to note that this thesis cannot say anything about the actualization of affordances among children and adolescents. The focus has been on assessing relations between having positive potential affordances (built environment characteristics) in the neighborhood and local community and the extent to which they facilitate participation in different activites.

2.10 Existing research and knowledge gaps

The great value of scientific inquiry into the relations between the built environment and the activities and well-being of children and adolescents is recognized by several disciplines. A considerable and still growing body of evidence has identified different characteristics of the built environment that promote participation in activities, health and well-being among children and adolescents (Christian et al., 2015; D'Haese et al., 2015b; Ding et al., 2011; MacMillan et al., 2018; McGrath et al., 2015; Smith et al., 2017; Tillmann et al., 2018; Twohig-Bennett and Jones, 2018). Neighborhoods with higher street connectivity, mixed land-use and compact residential design are linked to higher levels of physical activity in the younger population (Ding et al., 2011; McGrath et al., 2015). Furthermore, densely populated areas with greater access to facilities are shown to increase levels of physical activity as well as improve mental health (Bird et al., 2018). A great many studies have also revealed that neighborhoods with high walkability, low traffic exposure, more safety related features, short distance to facilities, such as schools, and pedestrian infrastructure for walking and cycling support active travel (D'Haese et al., 2015b; Panter et al., 2008; Pont et al., 2009; Smith et al., 2017). There is also some evidence that access to green spaces and higher safety promote children's outdoor play (Christian et al., 2015). A couple of studies have linked short distances to green space and recreational facilities, such as sports fields, swimming pools and parks, to increased participation in sports (Boone-Heinonen et al., 2010a; D'Haese et al., 2015a). Several studies have also revealed that densely populated areas are related to higher levels of physical activity (Buck et al., 2011; Kowaleski-Jones et al., 2016) and outdoor activity (Rodríguez et al., 2012) when compared to less populated areas. Thus, public health and planning professionals are increasingly encouraged to consider these determinants as resources for health and well-being in different planning and development processes (Bird et al., 2018). Notwithstanding the wealth of research in this field, limitations in the existing literature need attention, and several knowledge gaps need to be addressed to establish a more thorough understanding of built environment determinants and their health-promoting potential. The existing shortcomings and knowledge gaps revolve around both methodological issues and a lack of empirical evidence.

A wide array of methods for assessing the built environment for research purposes exist, from which GIS technology has emerged as an innovative method with important applications to examining health-promoting environments in public health through eco-epidemiological thinking (Chaix, 2009; Diez Roux and Mair, 2010). Particularly, the feasibility of GIS methods to provide objective environmental measures in studies involving individuals spread across large geographic areas has been emphasized (Brownson et al., 2009b). More studies that apply GIS measures of the built environment from a broader range of countries are requested (McGrath et al., 2015), and studies from Norway are almost non-existent. However, applying GIS technology and its associated methods is not straightforward. The issues of defining and documenting GIS-derived measures have been given little attention in the literature (Forsyth et al., 2006). Brownson et al. (2009b) found large variability and a lack of clarity in operational definitions applied for delineating geographic areas of exposure (e.g., a neighborhood) and for defining and measuring different built environment characteristics. At present, few studies that examine systematically synthesized knowledge about geographic areas and the determinants typically measured in previous studies that investigated relations between the built environment and health in childhood and adolescence exist. To raise methodological awareness that can contribute to facilitating the choices and computation of relevant GIS-derived measures for research, public health and planning purposes, greater informativeness, systematization and evaluations of different ways to operationalize the built environment determinants are needed.

A comprehensive understanding of neighborhood built environment determinants is essential to ensure evidence-based decision-making, policy changes and spatial planning (Kerr et al., 2013). Given the wealth of studies continuously published, it has become increasingly difficult for researchers and stakeholders to have an overview of the evidence concerning health-promoting environments (Gebel et al., 2015). Previous reviews of the built environment determinants of health in childhood and adolescence have often focused on and synthesized results for participation in unspecified physical activity (Davison and Lawson, 2006; Ding et al., 2011; MacMillan et al., 2018; McGrath et al., 2015). A common finding of several of these reviews is that associations between the built environment and physical activity are inconsistent across studies. Such inconsistent findings might have resulted from inappropriate conceptualization of relationships between the built environment characteristics and the activity outcomes under investigation (Ding and Gebel, 2012). It is presumed that the relationship between the built environment and physical activity vary according to different domains of activities, such as leisure-time PA, outdoor play and active travel to and from school or other destinations (Gebel et al., 2015; Giles-Corti et al., 2005; Sallis et al., 2006). For example, results that are more consistent have been revealed in reviews that have exclusively addressed the determinants of active travel (D'Haese et al., 2015b; Panter et al., 2008; Pont et al., 2009; Smith et al., 2017). This demonstrates the importance of being both outcome- and determinant-specific in the synthesis of results from separate studies, which is a shortcoming of several existing systematic reviews. Furthermore, several of the past syntheses do not report any methodological quality assessments (Christian et al., 2015; Davison and Lawson, 2006; Ding et al., 2011; Panter et al., 2008), which is regarded as a limitation (Bird et al., 2018).

The majority of the studies mentioned above have focused on total physical activity and the active travel behavior of children and adolescents. The built environment potentially influences other activities that are important for children's well-being, but these activities have not been fully examined. Few empirical studies have addressed built environment determinants as resources for participating in organized activities and informal social activities with friends. There has also been a lack of attention paid to the influence of the built environment on 5- to 8-year-olds' daily activities (McGrath et al., 2015). Moreover, there have been few large-scale studies that include children across diverse geographical areas.

Less attention has also been devoted to the possible benefits of the built environment for the well-being of children and adolescents both in previous syntheses of the literature as well as in empirical investigations. Clark et al. (2007) have shown that a lack of access to green space and poor neighborhood quality diminished children's mental health. The most recent syntheses focus on green and natural environmental determinants of well-being (Gascon et al., 2015; Tillmann et al., 2018; Twohig-Bennett and Jones, 2018), and reviews that have considered the broader built environment have mainly included individuals aged over16 years (Gong et al., 2016; Kim, 2008; Truong and Ma, 2006). Several studies have suggested that neighborhoods with more green space are advantageous for well-being. More precisely, higher proportions of green space have been connected to less behavioral problems (Amoly et al., 2014; Feng and Astell-Burt, 2017), and better self-perceived health (Kyttä et al., 2012). Additionally, longer distances to green spaces and poor aesthetic neighborhood conditions have been associated with more behavioral and mental health problems (Butler et al., 2012; Markevych et al., 2014; Singh and Ghandour, 2012), although inconsistencies exist in the results (Amoly et al., 2014; McCracken et al., 2016). A scant number of studies address environmental qualities other than green space as resources for children's well-being. Furthermore, researchers have argued that associations between built and natural features and well-being may not be direct but are mediated through other key variables (Hartig et al., 2014; Kyttä et al., 2015; Lachowycz and Jones, 2013; Mouratidis, 2018b). Up until now, previous studies have mainly assumed and examined the direct relationships between the built environment and the well-being of children, while the question of how the built environment might strengthen the well-being of children remains largely unaddressed (Twohig-Bennett and Jones, 2018).

3 Aim and objectives

This thesis endeavors to contribute to the scientific community, policy and practice by bridging some of the methodological and empirical research gaps and limitations brought up in the previous chapter. The *overarching aim* of this thesis is to investigate neighborhood and local community built environment determinants and their potential to support participation in activities and strengthen the well-being of children and adolescents. This overarching aim was achieved through four specific research objectives, each representing a separate paper in this thesis. The objectives capture both methodological aspects and limitations as well as empirical knowledge gaps related to several different research questions (Table 1). The four specific research objectives are set out below.

- To identify, systematize and evaluate (1) operational definitions of GIS-derived built environment measures and (2) the geographic areas of exposure applied in previous studies that have examined the impact of the built environment on the mental health of children and adolescents and their participation in activities (Paper I).
- To identify, evaluate and synthesize the findings of the built environment determinants and their relation to participation in different domains of activities, including physical activity and recreational and social activities, and well-being among children and adolescents from a broader public health perspective (Paper II).
- To examine whether the built environment determinants population density, green spaces and facilities are associated with participation in leisure-time PA, organized activities and social activity with friends in a large and geographically diverse sample of 8-year-old children in Norway (Paper III).
- To examine whether the built environment determinants population density, green spaces and facilities are associated with children's well-being and if the participation in different leisure activities operates as a potential mediator in such associations among Norwegian 8-year-olds (Paper IV).

Table 1. An overview of the research questions addressed in each of the four papers.

Paper	Research questions
Paper 1	• Which built environment determinants have been measured using GIS in existing studies conducted among children and adolescents? • How are the built environment determinants measured and operationalized? • How are neighborhoods/communities (geographic areas of exposure) measured and delineated?
Paper 2	• What are the current relationships between built environment determinants and different domains of activities and well-being among children and adolescents? • Which built environment determinants seem to promote participation in activities and well-being in childhood and adolescence? • What are the existing knowledge gaps?
Paper 3	• Are neighborhood and local community green spaces, facilities and population density associated with participation in physical activity in the summer and the winter among Norwegian 8-year-olds? • Are neighborhood and local community green spaces, facilities and population density associated with participation in organized activities among Norwegian 8-year-olds? • Are neighborhood and local community green spaces, facilities and population density associated with participation in social activities with friends/peers among Norwegian 8-year-olds?
Paper 4	• Are there any direct associations between neighborhood and local community green spaces, facilities and population density and the well-being of Norwegian 8-year-olds? • Are there any indirect associations between neighborhood and local community green spaces, facilities and population density and well-being via participation in leisure-activities (mediator) among Norwegian 8-year-olds?

4 Research strategy, materials and methods

4.1 Research approach and design

The substantial amount of research conducted into health-promoting environments for children and adolescents means that developing new knowledge in this area requires approaches that can meet the specific research gaps within the field. Therefore, an emphasis was placed on the gaps and problems identified in the literature in deriving the research questions, choosing the research approach and designing each study. In addition, the complexity of the research process, which imposed a need to respond to challenges and problems along the way while at the same time sustaining rigor, required a pragmatic multi-methodology research strategy (Creswell, 2014). As such, the research drew on data from diverse sources and employed different analytical approaches, but the methods were based on quantitatively driven approaches. Review designs were combined with a cross-sectional epidemiological design to address the overarching aim and the four research objectives. Review designs were applied in Papers I and II (see details in Chapter 4.2), whereas a cross-sectional epidemiological design was utilized in Papers III and IV (see details in Chapter 4.3). An overview of the methodological elements and methods applied in this thesis are presented in Table 2.

The research process involved three phases. Each phase contributed and added knowledge to the sequential process of this thesis toward the main aim, and the separate studies informed each other in the different research phases. Figure 5 displays the logical sequence of the research process. The obvious starting point of the project was the conducting of reviews. In the first phase, the built environment determinants were in focus. The research focused on methodological issues and involved identifying, systematizing and evaluating previously applied GIS-derived measures and operational definitions of the built environment determinants. The first objective of the thesis was addressed in this first phase, and the study provided an overview of importance for the later empirical research. The overview informed both the synthesis of results in the second phase and the choices of which GIS-derived measures and operational definitions to apply in the third phase. In the second phase, some methodological limitations of previous reviews were addressed and the existing empirical findings on the relations between built environment determinants, participation in activities and the well-being of children and adolescents were synthesized, and the second objective was thereby addressed. This study informed the objectives and research questions formulated in the third phase of the research process whereby a cross-sectional epidemiological design was utilized to conduct two empirical studies within the Norwegian context. The results from Paper III informed the mediation analysis approach applied in Paper IV. The third and fourth objective were addressed in this third and final phase of the research process.

Table 2. The main methodological elements and methods applied in the thesis.

Objective	Design	Data sources	Analytical approach
To identify, systematize and evaluate (1) operational definitions of GIS-derived built environment measures and (2) the geographic areas applied in previous studies that have examined the impact of the built environment on the mental health of children and adolescents and their participation in activities (Paper I).	Systematic review	Existing studies in the field identified through searches in the following databases: • PubMed • Web of Science • Medline • PsychINFO • SweMed+	Narrative synthesis approach including textual descriptions, descriptive statistics and content analysis.
To identify, evaluate and synthesize the findings of the built environment determinants and their relation to participation in different domains of activities, including physical activity and recreational and social activities, and well-being among children and adolescents from a broader public health perspective (Paper II).	Systematic review	Existing studies in the field identified through searches in the following databases: • PubMed • Web of Science • Embase • Medline • PsychINFO • CINAHL	Narrative synthesis approach including textual descriptions, groupings, vote counting and descriptive statistics.
To examine whether the built environment determinants population density, green spaces and facilities are associated with participation in leisure-time PA, organized activities and social activity with friends in a large and geographically diverse sample of 8-year-old children in Norway (Paper III).	Cross-sectional epidemiological study	Exposures: GIS-derived measures of the built environment using map data from the Norwegian Mapping Authority and Statistics Norway Outcomes and covariates: Questionnaire data obtained from MoBa	Statistical analysis including descriptive statistics and logistic regression techniques.
To examine whether the built environment determinants population density, green spaces and facilities are associated with children's well-being and if participation in different leisure activities operates as a potential mediator in such associations among Norwegian 8-year-olds (Paper IV).	Cross-sectional epidemiological study	Exposures: GIS-derived measures of the built environment using map data from the Norwegian Mapping Authority and Statistics Norway Outcomes, mediators and covariates: Questionnaire data obtained from MoBa	Statistical analysis including descriptive statistics and the counterfactual approach to mediation analysis using different regression techniques.

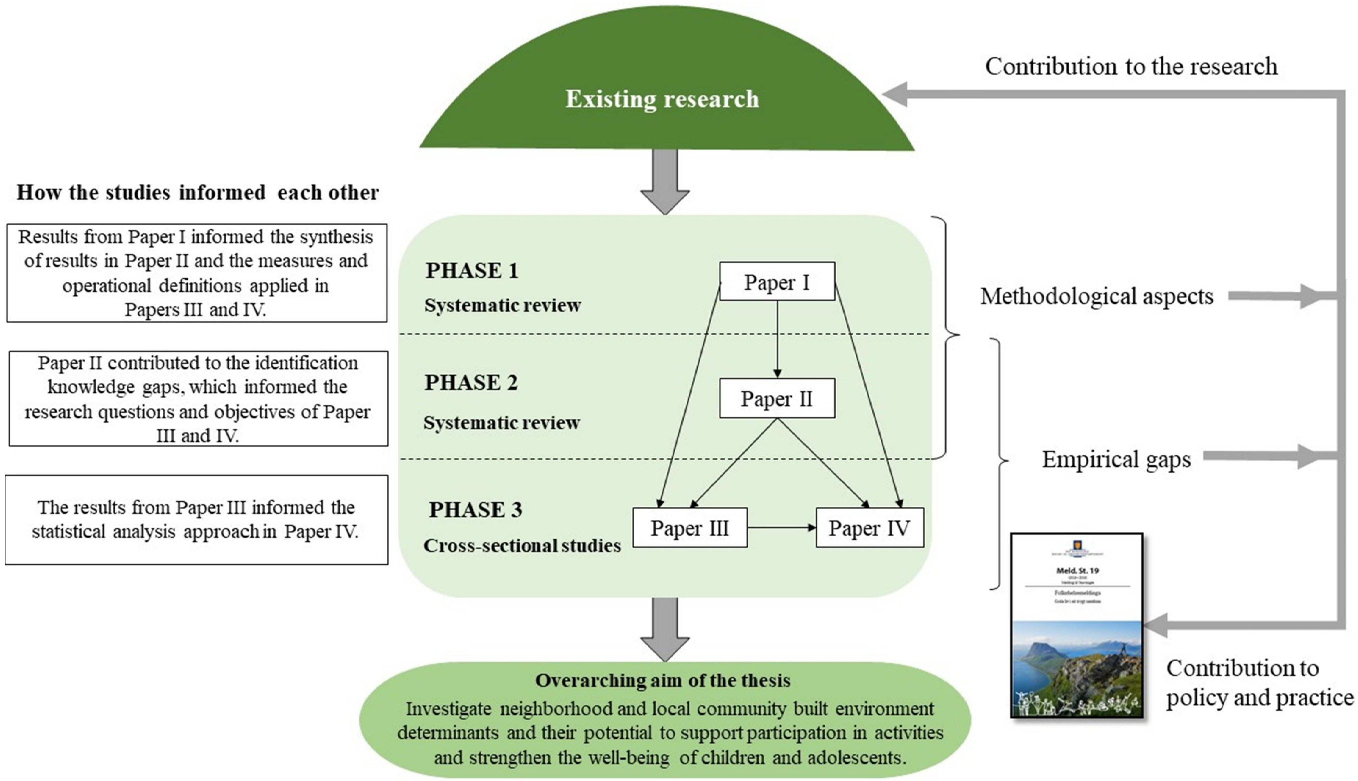


Figure 5. The logical sequence of the research process.

4.2 The systematic reviews (Papers I and II)

The review studies were designed and carried out according to the recommended methodologies and guidelines for conducting systematic reviews formulated by the Joanna Briggs Institute (JBI) and the PRISMA group (Aromataris and Munn, 2017; Moher et al., 2009; Tricco et al., 2018). Different review approaches were chosen to stay true to the purposes of each review. The systematic review of the GIS-derived measures followed an approach that paralleled what has been suggested for scoping reviews (Tricco et al., 2018), whereas the systematic review of associations between the built environment, participation in activities and well-being followed common guidelines for systematic reviews of effectiveness and etiology/risk (Aromataris and Munn, 2017; Moher et al., 2009). Both review approaches require rigorous and transparent methods to ensure that the results are trustworthy (Munn et al., 2018). Thus, the reviews were carried out in similar ways. However, since they served different review objectives and research questions, they followed separate guidelines with different methodological components and requirements. In general, the first review (Paper I) was broader in scope by investigating applied GIS methodology, and therefore, it was subject to less stringent requirements than the systematic review of the quantitative results (Paper II). Figure 6 shows the design steps and the related methodological elements involved in the conduct of the systematic reviews. All the elements are described in further detail in the sections below.

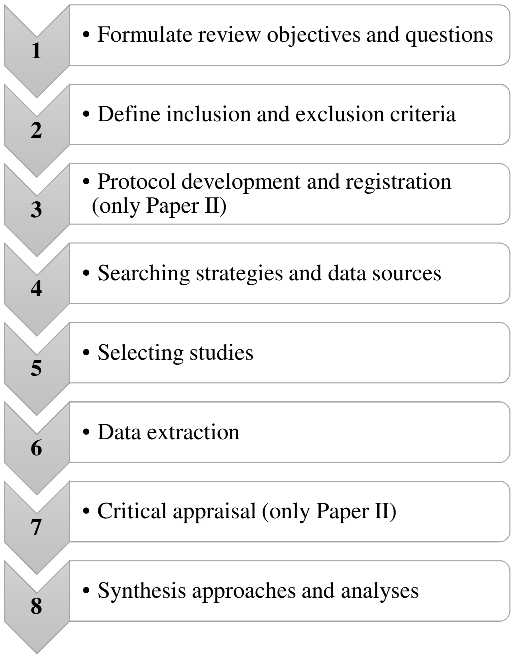


Figure 6. Design steps and methodological elements of the systematic reviews.

4.2.1 *Review objectives and questions*

The first step in designing the systematic reviews was to formulate the objectives and research questions. The mnemonics PCO (population, concept, outcome) and PEO (population, exposure, outcome) assisted in structuring these review objectives (Aromataris and Munn, 2017). In both reviews, the population comprised children and adolescents. The GIS-derived measures of the built environment were the concepts of interest (Paper I), and the built environment determinants were considered as the exposures (Paper II). The outcomes of relevance for both reviews were well-being and participation in activities. The formulated objectives and questions supported and informed the next steps of the review processes by establishing a basis for defining inclusion and exclusion criteria and later for developing a well-structured search strategy.

4.2.2 *Inclusion and exclusion criteria*

Inclusion and exclusion criteria were defined to explicitly frame and delimitate the focus of each systematic review based on the formulated objectives and questions. The inclusion and exclusion criteria revolved around the population, concept/exposure and outcomes, as well as the types of evidence to be considered. The broader scope of the first review led to inclusion criteria that were more expansive than the criteria applied in the second review.

Population: The reviews considered studies that included children and adolescents aged 0–18 years (Paper I) and 5–18 years (Paper II). Studies that also included participants aged below or above 5–18 years were considered for inclusion in the second review only if stratified results were provided for age groups within the predetermined age range.

Concepts/exposures: Studies were eligible for inclusion if they measured at least one built environment determinant as an independent variable. The determinants were defined as modifiable built characteristics within the neighborhood or local community, such as residential density, land-use, buildings, roads and streets, traffic, pedestrian infrastructure, green space, facilities, safety and aesthetic conditions. To be included in the first review, determinants had to be operationalized and measured using GIS. In the second review, there were no restrictions on the mode of measurement, but articles were not considered if they validated specific methodologies for assessing the built environment or if they focused on the school area or schoolyard only.

Outcomes: Articles with activity participation or well-being (or both) as the main outcome were considered for inclusion in the two reviews. Activities encompassed the leisure activities of the target population, including physical activity, outdoor play, active travel, and recreational and social activities. Considering the scope of the reviews, studies examining sedentary activities (e.g., hours of TV-viewing) were not eligible for inclusion. Well-being was broadly defined to encompass positive outcomes portraying an individual thriving, functioning well, experiencing positive emotions and feelings and realizing his or her own abilities. The definition further included the contrasting outcomes characterized by negative emotions and feelings, as well as mental health and behavioral problems. There were no restraints on the mode of measurement in any of the systematic reviews.

Types of evidence: Both reviews considered only peer-reviewed original articles written in English for inclusion. There were no particular restrictions on study designs in the first review, but the built environment determinants had to be measured in a neighborhood or community context and not under experimental laboratory conditions. This criterion also pertained to the second review. Additionally, studies eligible for inclusion in the second review had to report test statistics (e.g., odds ratio, regression coefficient or prevalence ratio) for associations between the built environment determinants and the outcomes. Descriptive cross-sectional studies were therefore not eligible for inclusion.

4.2.3 Protocol development and registration

To comply with the PRISMA guidelines for reviews of effectiveness and etiology/risk (Moher et al., 2009), a review protocol was developed for the study presented in Paper II. The protocol offered key information about the design and conduct of the systematic review, and was registered in the International Prospective Register of Systematic Reviews (PROSPERO) in November 2018. The registration was done after finalizing formal screening of search results against inclusion and exclusion criteria. The record is available in PROSPERO's open access electronic database under the registration number CRD42018114413.

4.2.4 Search strategies and data sources

Step-based, comprehensive search strategies were developed to identify the relevant published original articles. Here, I briefly describe the general characteristics of the search strategies and highlight some differences between the searches undertaken in the two reviews. More information regarding the search terms and strategies utilized in each of the systematic reviews is explicitly provided in the papers (see the search strategy sections and the modified PRISMA flow charts in Papers I and II as well as the individual search strategies for all databases detailed in Appendix I of Paper II).

First, different main groups of keywords were generated based on the mnemonics and the review objectives. Next, relevant search terms and synonyms were identified within each of the main groups. Then, the search queries were systematized and built by combining synonyms within each main group with the Boolean operator OR. Last, the groups of keywords were assembled with the Boolean operator AND. This full strategy was tailored for each database. For the review presented in Paper I, searches were undertaken in PubMed, Medline, Web of Science, PsychINFO and SweMed+, whereas the following six databases were searched in the review presented in Paper II: PubMed, Medline, Web of Science, Embase, CINAHL and PsychINFO. The reference lists of all the included full-text articles were screened for additional studies in Paper I, whereas in the systematic review of quantitative evidence, the reference lists of 50% of the included articles were screened for additional studies not identified through searches in the databases (Paper II).

The search strategy of the first review included keywords only, whereas the searches in the second review contained both keywords and MeSH index terms. SweMed+ was searched in the first review without providing any results (see flow chart in Paper I). Thus, when developing the search strategy for the second review, a limited test search was conducted in SweMed+. This test search did not identify any records, and consequently, the database was excluded. The databases CINAHL and Embase were only searched in the second review. Since the issues of defining and documenting GIS-derived measures and operational definitions have been given very little attention in the literature, there were no time limits for the search conducted in the first review. In contrast, reviews have previously examined relations between the built environment and physical activity among children and adolescents. To avoid duplicating these results, searches in the second review were limited to identify articles published after 2010.

4.2.5 Selecting the studies

All the identified records of the searches were managed in two separate EndNote libraries. The study selection processes involved (1) removing duplicates, (2) screening the title and abstract of each unique record and (3) assessing the selected full-text articles for eligibility based on their congruence with the inclusion criteria. I myself completed the study selection process in the first review, but all co-authors assessed four of the articles due to uncertainty about inclusion or exclusion. The study selection process in the second review was more rigorous to comply with the recommended guidelines for reviews of effectiveness and etiology/risk. The co-authors duplicated the eligibility assessment for 43 full-text articles as detailed in Paper II.

4.2.6 Data extraction

Self-developed data-extraction forms facilitated the process of extracting and recording relevant data and results from the primary studies included in the systematic reviews. The data-extraction forms ensured that the same information was extracted across all of the included studies. I extracted all the data for the first review, whereas in the second review, the co-authors duplicated the data extraction for 30 articles, as described in Paper II. Table 3 provides an overview of the information extracted from the included studies in each of the systematic reviews. Complete data-extraction forms with associated data are presented in Appendix A of Paper I and Appendix III of Paper II.

Table 3. An overview of the data extracted from the primary studies included in the reviews.

Information extracted in Paper I	Information extracted in Paper II
General study characteristics	**General study characteristics**
Citation	Citation
Age of the participants	Country
Health outcomes	Age of the participants
Built environment determinants	Sample size and gender
Concepts for synthesis	Study design
Operational definitions of determinants	Health outcomes
Geographic areas of exposure	Method of measurement (outcomes)
Buffer distance	Built environment exposures
Buffer technique	Method of measurement (built environment)
Geographic centroid	Results from multivariate adjusted analyses
	Effect measures with 90% or 95% CI
	Effect measures with SE and p-values
	Results for the synthesis
	Number of positive, negative and non-significant results

4.2.7 *Critical appraisal*

A critical appraisal was performed to assess the methodological quality of all the included studies in the second review (Paper II) as required for systematic reviews of effectiveness and etiology/risk. The aim with the assessment was to decide to what extent the studies addressed risk of bias in their design, conduct and analyses, which is important in establishing validity (Aromataris and Munn, 2017). It is essential that critical appraisal tools are appropriate for the study design. Since different study designs were utilized in the included studies, validated critical appraisal tools tailored for cross-sectional, longitudinal, case-control and quasi-experimental designs from JBI were used (Moola et al., 2017; Tufanaru et al., 2017). Each tool contains a certain number of items to be assessed, which have the following responses: "Yes," "Unclear," "No" and "Not applicable." All the tools are available online (http://joannabriggs.org/research/critical-appraisal-tools.html). JBI provides no guidelines for how to weight the items but states that decisions about scoring should be made in advance and be agreed upon by participating reviewers before the appraisal commences (Aromataris and Munn, 2017). The items were weighted equally ("Yes" = 1 vs. "Unclear/No/Not applicable" = 0). Furthermore, all studies were included, irrespective of quality. However, each article received a total score, and based on this score, the articles were rated to be of "good," "fair" or "poor" quality. In the overall synthesis, we weighted the evidence accordingly. As recommended, independent pairs of reviewers critically appraised 90 out of 127 studies, whereas I myself assessed the remaining 37 studies. More details regarding the assessment of methodological quality and the evidence-weighting are provided in Paper II.

Unless there are specific requirements due to the nature of the review objective, critical appraisal is generally not performed in syntheses following a scoping review approach (Munn et al., 2018). As the first review aimed to provide an overview of previously applied GIS-derived measures and operational definitions, an assessment of methodological limitations was not considered relevant for such review purposes. However, without conducting any formal assessment, the review addressed methodological limitations related to the operational definitions provided in the included papers, such as highlighting when definitions were absent.

4.2.8 *Synthesis approaches and analyses*

The synthesis of a systematic review is the process of bringing together findings from the included studies to draw conclusions from the existing body of evidence. Both reviews applied a narrative synthesis approach, which is a form of storytelling. This means that the syntheses relied primarily on the use of words and text to summarize review findings (Popay et al., 2006). As the first review dealt with concepts and operational definitions, this approach was most suited for such purposes. In the second review, the narrative synthesis approach was selected due to the methodological heterogeneity of the included study, making statistical pooling of results by means of meta-analysis challenging.

Different analytical techniques were utilized in the two systematic reviews. The first review (Paper I) utilized descriptive statistical analyses to measure the frequency of the different buffer distances and the operational definitions applied to delineate the geographic areas of exposure. Furthermore, a content analysis, based on a meta-synthesis approach (Murray and Stanley, 2015), was carried out to systematically compress the built environment determinants and their operational definitions into content categories (Popay et al., 2006). The content analysis evolved as an iterative process involving three stages. The extracted data as well as the objective of providing a useful overview for researchers and planners dealing with built environments for children and adolescents governed the analysis. Paper I presents more information about the content analysis.

The second systematic review (Paper II) included 127 studies. Thus, the first step of the analysis process involved uniting the included studies into groups to make the process of analysis more manageable. Organizing studies into groups has been considered a useful way of aiding the process of description, analysis and looking for patterns within and across groups (Popay et al., 2006). All the included studies were grouped based on their general study characteristics, such as year of publication, geographic origin, age of the participants, sample size, study design, methods for assessing the built environment, the specific built characteristics measured, mode of outcome measurement and outcomes. The grouping followed the logic of a previously published review in the field (Ding et al., 2011). The content categories that evolved through the analysis conducted in Paper I were utilized to group all the built environment determinants that were examined in the included studies of the second review. After grouping the studies, a vote-counting analysis was conducted (Popay et al., 2006). The frequency and the percentage of positive, negative and non-significant associations between each built environment determinant category and each group of outcomes were calculated. The quality-weighting of the studies was taken into account when results were presented in the tables (see Tables 3-8 in Paper II) and in the narrative descriptions.

4.3 The cross-sectional epidemiological studies (Papers III and IV)

The reason for choosing a cross-sectional epidemiological design was to assemble data that would permit the investigation of associations between the built environment, participation in activities and the well-being of Norwegian children. The opportunity to assemble such data was provided through the ongoing Norwegian Mother and Child Cohort Study (MoBa), which could be linked to GIS-derived built environment measures based on the participants' addresses. The following sections describe the material and methods used in the cross-sectional epidemiological studies.

4.3.1 Data sources

Health registry data from MoBa were obtained to derive outcome variables and covariates for the cross-sectional studies. MoBa is an ongoing, nationwide, prospective and population-based cohort study conducted by the Norwegian Institute of Public Health (Magnus et al., 2006). Pregnant women attending a routine ultrasound examination in week 17 of their pregnancy were invited from across Norway to participate in the cohort during the years 1999–2008. Invitations were sent to women in 277 702 pregnancies, of which 41.0% consented to participate. Currently, the cohort comprises about 114 500 children. Questionnaires were given to mothers in weeks 17 and 22 of their pregnancy and to fathers in week 17. Follow-up data were collected through age-specific questionnaires. The mothers responded to surveys at six and 18 months after birth and when the children were three-, five-, seven-, eight- and 13 years old (Magnus et al., 2016). The questionnaire submitted to the mothers when the child turned 8 years old addressed the child's leisure activities and social and psychological development. For the research objectives of this thesis, data from this questionnaire were desired. The response rate for the questionnaire was 47.0% (Schreuder and Alsaker, 2014). In November 2015, the Norwegian Institute of Public Health made a new version (IX) of the quality-assured MoBa data files available for research. Data from this particular data file provided the basis for the cross-sectional studies in Papers III and IV. Available questionnaire data were obtained from those children who turned 8 years old during the years 2011, 2012, 2013, 2014 and 2015 (recruited in 2003, 2004, 2005, 2006 and 2007, respectively).

Map data from the digital portal Geonorge, developed and organized by the Norwegian Mapping Authority, were obtained to derive exposure data for the cross-sectional studies. The data are available online (https://www.geonorge.no/) and were downloaded for all municipalities in Norway (n = 426) in January 2017. To address the objectives of Papers III and IV, five different map layers that contained geographic data relevant to deriving measures of the built environment qualities of interest were obtained. Table 4 provides an overview of the downloaded map data.

Table 4. The downloaded map data used to calculate exposure to the built environment.

Data set	Updated	Data owner	Type	Brief description
Matrikkelen Adresse	Jan. 2017	The Norwegian Mapping Authority	Point data	Contains all the official physical addresses registered in Norway.
N50 Kartdata	Jan. 2017	The Norwegian Mapping Authority	Point, lines and polygon data	Land cover data that describes the built and the natural environment.
FKB Arealbruk	Jan. 2017	The Norwegian Mapping Authority	Point, lines and polygon data	Land-use data that describes the actual use of geographic areas.
FKB Bygning	Jan. 2017	The Norwegian Mapping Authority	Point, lines and polygon data	Contains all types of buildings and provides information about what the buildings are being used for and the activities they host.
Befolkning på rutenett 250 m	2016	Statistics Norway	Statistical grid data (250-m × 250-m)	Provides an overview of the population across Norway. The data source for the grid data is the registered population on each official physical address in Norway.

4.3.2 GIS procedures for calculating the exposures

All GIS calculations were performed using ArcGIS 10.3.1 and QGIS 2.14. To comply with ethical principles of protecting privacy and ensuring anonymity of the participants (see Chapter 4.4 for further elaboration on ethical considerations and approvals), the GIS-derived variables had to be calculated for all residential addresses in Norway. Thus, I prepared 19 different map documents in ArcMap 10.3.1 to facilitate the comprehensive analysis process. This was done by assembling all the downloaded map layers for every single municipality within a county into a map document, and each of these 19 map documents represented a county in Norway. To ensure that variables could be computed for addresses located near the county boarders, map layers from adjacent municipalities in neighboring counties were added to the documents as well. After preparing map documents and defining projections, I carried out the analyses county by county. First, the geographic areas of exposure were defined and delineated. Then, the different built environment qualities were operationalized and computed. These two processes were guided by the findings of the systematic review of GIS-derived measures and operational definitions presented in Paper I. All operational definitions applied for computing exposure variables for the cross-sectional studies are detailed below. When all computations were completed, a data file with all addresses in Norway and the associated GIS-derived exposure measures was created. This data file was sent to Statistics Norway for data linkage. This linkage procedure is described in Chapter 4.3.3.

Official physical addresses, represented as points in the Matrikkelen-Adresse dataset, provided the basis for defining and delineating the *geographic areas of exposure.* I applied ego-centered definitions, which were most frequently used in previous research (see Paper I). By using the geocoded addresses, each child's home represented a centroid single point and was the center for the spatial unit and subsequent GIS analyses. The systematic review in Paper I identified considerable variation in buffering techniques and buffer distances applied around the centroids. In this project, it was only feasible to calculate circular buffers around the geocoded addresses. The computational burden of creating network buffers would have been too high based on the total number of addresses. I calculated the built environment exposures within two buffer zones. As identified in Paper I, the most frequent distance used in the existing research was 800-m. Accordingly, a buffer radius of 800-m was selected to represent the children's neighborhood surroundings. Larger buffer distances ($\geq$ 3 000-m) are less common but have been applied in studies investigating built environment determinants of physical activity and emotional well-being (see Paper I). It was thought that activity venues spread across larger geographical areas were important to investigate for the following reasons: (1) the Norwegian context is characterized by low centrality in many areas; (2) the young age of the children signifies that they likely also participate in activities with their parents or under parental supervision; and (3) organized activities (one of the outcomes; see Chapter 4.3.5) are not necessarily undertaken in the neighborhood area of 800-m. Therefore, a larger buffer distance of 5 000-m was chosen to represent the greater community in which the 8-year-olds resided. Figure 7 shows the geographic areas of exposure used in the cross-sectional studies delineated from an arbitrary address in central Oslo.

Exposure to different built environment determinants was computed within the delineated areas displayed in Figure 7. Given the activity outcomes of interest and the research gaps identified in the literature, I chose to focus on the following main content categories of measures (identified in Paper I) in the cross-sectional studies: population measures, green and open space measures and facility and amenity measures. In the following pages, I will provide details on each of the determinants measured within these main categories and the operational definitions applied.

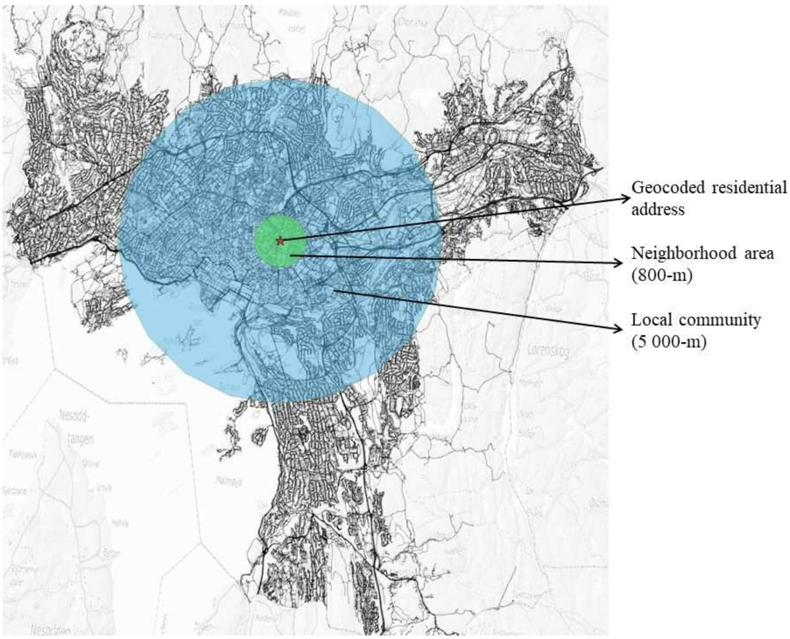


Figure 7. The geographic areas of exposure defined and delineated in the cross-sectional studies.

Population measures

The Statistical Grid dataset (250m × 250m) with population data from Statistics Norway was used to assess *population density*. The operational definition of population density was the total number of residents per square kilometer around the residential home address of each child. Due to high computational burden, I calculated this determinant within the 800-m radius only.

Green and open space measures

The N50 Kartdata (land-cover maps) and the FKB Arealbruk (land-use maps) datasets were utilized to calculate three green space measures. One of the measures captured the *proportion of total green space*. This determinant was operationalized as the total area in square kilometers of parks, forests, marshland and golf courses within the buffer divided by the total land area within the buffer. Additionally, separate measures of the *proportion of park area* and the *proportion of golf course area* were calculated. The operational definitions applied to these two determinants were identical. They were calculated by taking the total area in square kilometers of parks or golf courses within the buffer and dividing this area with the total land area within the buffer. Due to high computational burden, the proportion of total green space was calculated within the 800-m radius only, whereas the proportions of park and golf course area were computed within both the 800- and the 5000-m radii. Golf course areas were included in the total green space measure and as a separate determinant because they in some areas are open public spaces, which also can be used for skiing during wintertime.

The downloaded land-cover and land-use maps contained fixed definitions of categories, such as parks, forests, marshland, and golf courses, established by the Norwegian Mapping Authority. Thus, all the computed green space measures were based on these specific definitions. Forests included all types of forest land, such as coniferous, deciduous and mixed, as well as felled woodland, larger than 4 000 m^2 and wider than 30-m. Marshlands were defined as open areas with marsh vegetation larger than 4 000 m^2 and wider than 30-m. Parks were considered as green areas in cities or densely populated areas larger than 2 000 m^2 and wider than 30-m, with lawns, plants, seating, paths and water features. Golf courses were defined as facilitated areas for golfing with either six, nine or 18 holes (The Norwegian Mapping Authority, 2017).

Facility and amenity measures

I utilized the FKB Arealbruk and FKB Bygning datasets in computations of the total number of facilities and amenities within the buffer zones. Each facility/amenity represented a point in the map layers. I derived four different counting measures by counting these points within the delineated geographic areas. One of the measures counted the *total number of facilities/amenities* that could serve as arenas for the studied activity outcomes. The following facilities/amenities were included in this particular measure: shopping malls, convenience stores, cafés, kindergartens, schools, museums, libraries, zoos and botanical gardens, sports and ice-skating arenas, swimming pools, cinemas, local community centers, cultural venues, churches and other venues for religious activities and community health-care centers. Besides this total measure, separate counts of *playgrounds/sports fields*, *schools* and *schools/kindergartens* were derived.

The Norwegian Mapping Authority also provides fixed definitions of the facilities and amenities measured within the map data of FKB Arealbruk and FKB Bygning. Table 5 presents the predetermined definitions for those facilities/amenities for which details were provided in the map data specifications (The Norwegian Mapping Authority, 2016a; 2016b)

Table 5. Definitions of the facilities/amenities from the Norwegian Mapping Authority.

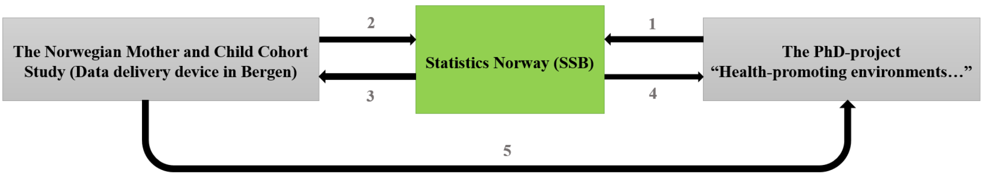
Facilities/amenities	Predetermined definitions
Community health-care center	Building containing different health services, such as maternal and childcare, school nurses, physiotherapy and medical doctors.
Cultural venue	Multifunctional venue for cultural and sports activities, including youth clubs.
Ice-skating arena	Indoor ice-skating arenas primarily used for ice-skating and ice hockey.
Local community center	Multifunctional venue and a central activity center within the community used for a range of purposes, such as sporting events, community gatherings and other social activities.
Playgrounds	Areas for play, either with or without permanent and portable play equipment. Some play areas in schoolyards and kindergartens are registered as playgrounds. Areas with play equipment in private yards are not included.
School	Includes separate schools for children aged 6-12 years and adolescents aged 13-15 years, or schools in which both age groups are present, and high schools.
Shopping mall	Shopping area that contains several different stores.
Sports arena	Indoor sports arenas primarily used for different sports.
Sports fields	Outdoor areas for participation in sports and other physical activities larger than 2 000 m^2 and 30-m wide.
Swimming pool	Indoor swimming arenas with facilities used for education, exercise or competitions.

4.3.3 Data linkage

A distributed linkage was selected as the preferred procedure for linking the built environment data calculated in GIS to each 8-year-old in MoBa. SSB was the entrusted coordinator of the data and performed the data linkage for the cross-sectional studies. The linkage of built environment exposures was based on the registered addresses of the mothers the year the children turned 8-years and whereupon the mothers responded to the 8-year follow-up questionnaire. Figure 8 displays the distributed linkage procedure. The steps involved are outlined below.

- The PhD project sent a data file to SSB with the GIS-derived built environment data calculated for all residential addresses in Norway.
- The MoBa data delivery device at the Norwegian Institute of Public Health sent a data file with the social security numbers (11 digits) of the mothers, the year in which the mothers answered the 8-year follow-up questionnaire and the participants' MoBa ID to SSB.

- SSB derived the addresses for the sample of participants in MoBa based on their social security numbers. As we aimed to use the addresses when the children were 8-years old, SSB used the residential addresses from 2011, 2012, 2013, 2014 and 2015.
- SSB linked the GIS data to the participants using the identified addresses as the linkage key.
- After the linkage was completed, SSB removed the residential addresses and the social security numbers. Then, SSB created a project-specific linkage key, which they exchanged with the data delivery device at the Norwegian Institute of Public Health.
- The data delivery device at the Norwegian Institute of Public Health used this linkage key to link project-specific ID numbers to the participants in MoBa before they sent the 8-year follow-up questionnaire data to the PhD project with project-specific ID numbers only.
- After the data delivery device at the Norwegian Institute of Public Health confirmed they had deleted the link key, SSB returned the data file with the GIS data to the PhD project, which now contained both the GIS variables and the project-specific ID numbers of the participants.
- The PhD project completed the final step of the linkage procedure by using the common project-specific ID numbers received in the files from SSB and the data delivery device at the Norwegian Institute for Public Health. The two data files were merged into a complete data set containing both GIS-derived exposures and MoBa data for each child.



1. A data file with a list of all residential addresses in Norway and the related GIS-derived measures was sent to SSB.
2. A data file with social security numbers, the year in which the mothers answered the questionnaire and their MoBa ID was sent to SSB.
3. Exchange of a project-specific linkage key with the data delivery device of MoBa.
4. A data file with the GIS-derived measures together with the project-specific ID number was sent to the PhD project.
5. A data file with the 8-year follow-up questionnaire data together with the project-specific ID number was sent to the PhD project.

Figure 8. Flow chart for the distributed data linkage and de-identification procedure.

4.3.4 Study participants

Figure 9 shows the participant flow diagram for the cross-sectional studies presented in Papers III and IV. A large number of the 114 500 children initially included in the cohort have been lost to follow-up over the years. Moreover, the 8-year follow-up had not yet been completed at the time of the release of the IX version of the research data file. Thus, this project retrieved available data for 32 076 eligible 8-year-olds in MoBa. To be included in the cross-sectional studies, the GIS-derived exposures had to be successfully linked to each participant's geocoded residential address. We excluded children with chronic and severe diagnoses. Further, children living in post-separation families were removed as the GIS variables were computed around the mothers' addresses only. Lastly, we excluded children whose years of participation in the 8-year follow-up were unknown. Consequently, the total sample for the cross-sectional studies was 23 043 children. Demographic- and individual-level characteristics for these children are presented in Table 6. As shown in Table 6, data were missing. After removing subjects with missing data for the key variables used in the analyses of each study, the final analytical sample constituted 21 146 and 20 644 children in Paper III and Paper IV, respectively. Demographic- and individual-level characteristics for the analytical sample of Paper III, as well as the excluded participants, are also provided in Table 6. The total sample of the cross-sectional studies constituted 48.5% girls and 51.3% boys. More than one third of the mothers (38.8%) had more than 4 years of university education, and 71.6% of the children attended after-school care. Among those excluded, there were slightly more girls than boys, and the mothers were younger and less educated (Table 6). Additionally, those excluded lived in neighborhoods with somewhat higher density and more facilities in the immediate surroundings of their home. This also pertained to those excluded from Paper IV.

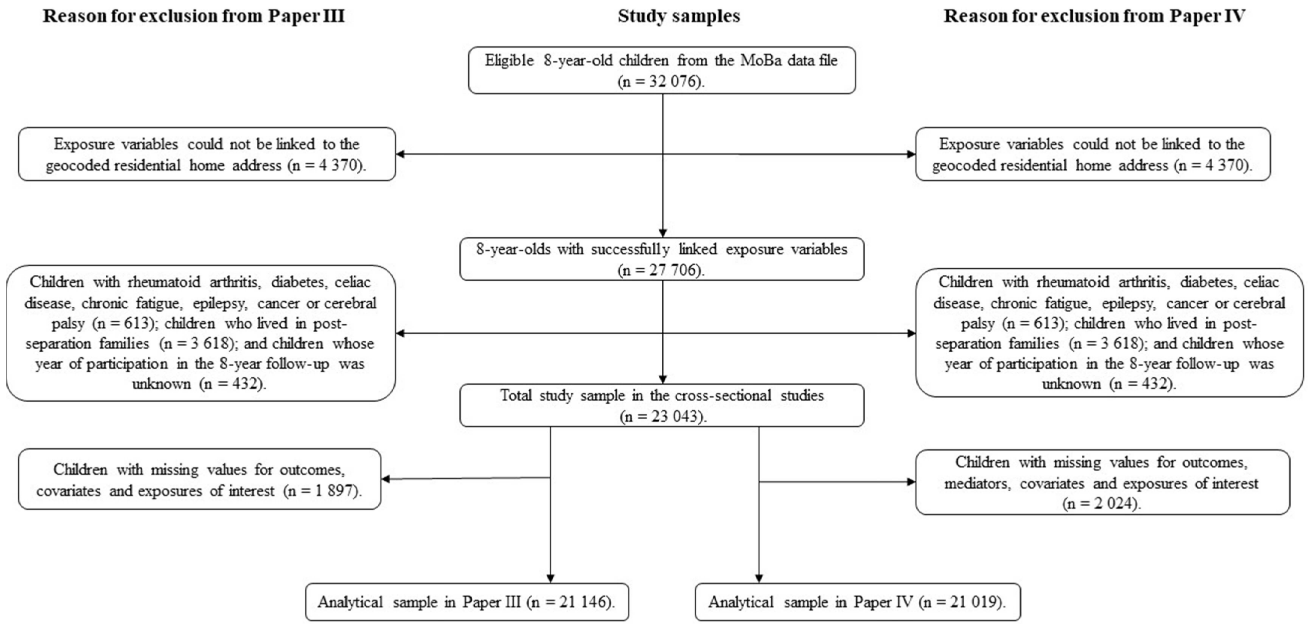


Figure 9. Flow chart showing how the samples of the cross-sectional studies were derived.

Table 6. Demographic- and individual-level characteristics of the total study sample, the analytical sample and the excluded participants of Paper III.

Characteristics	Total sample (n = 23 043), N (%)	Analytical sample Paper III (n = 21 146), N (%)	Excluded participants Paper III (n = 6 560), N (%)	P-value[a]
Gender				
Boys	11 826 (51.3)	10 932 (51.7)	3 228 (49.6)	0.003
Girls	11 176 (48.5)	10 214 (48.3)	3 282 (50.4)	
Missing	41 (0.2)	0 (0.0)	50	
After-school care				
No	6 093 (26.4)	5 618 (26.6)	1 582 (26.3)	0.394
Yes	16 503 (71.6)	15 528 (73.4)	4 436 (73.7)	
Missing	447 (2.0)	0 (0.0)	544	
Maternal age at recruitment				
≤ 29 years	8 961 (38.9)	8 306 (39.3)	2 802 (43.0)	<0.001
≥ 30 years	14 035 (60.9)	12 840 (60.7)	3 708 (57.0)	
Missing	41 (0.2)	0 (0.0)	50	
Maternal level of education				
High school or less	4 624 (20.1)	4 313 (20.4)	1 691 (28.5)	
University ≤ 4 years	8 904 (38.6)	8 416 (39.8)	2 305 (38.9)	<0.001
University > 4 years	8 951 (38.8)	8 417 (39.8)	1 928 (32.5)	
Missing	564 (2.4)	0 (0.0)	636	
Year of participation in the 8-year follow-up				
2011	5 148 (22.3)	4 608 (21.8)		
2012	4 002 (17.4)	3 704 (17.5)		
2013	4 922 (21.4)	4 523 (21.4)		
2014	5 896 (25.6)	5 441 (25.7)		
2015	3 075 (13.3)	2 870 (13.6)		

[a] Results from chi-square statistics comparing participants included in the analytical sample and those who were excluded in Paper III.

4.3.5 Choosing and defining the variables used in the analyses

This section details how all the variables were prepared for the statistical analyses. Table 7 gives an overview of the variables used in each paper. In addition, the table shows information about the data source and whether the variable was analyzed as an outcome, exposure, covariate or mediator. The GIS-derived variables not included in the analyses are listed as well.

Table 7. An overview of all the variables used in and excluded from Papers III and IV.

Variables	Data source	Paper III			Paper IV			
		Outcome	*Exposure*	*Covariate*	*Outcome*	*Exposure*	*Covariate*	*Mediator*
Child's gender	MoBa			X			X	
Maternal age at recruitment	MoBa			X			X	
Maternal level of education	MoBa			X			X	
Attending after-school care	MoBa			X			X	
Hours of leisure-time PA (summer)	MoBa	X						X
Hours of leisure-time PA (winter)	MoBa	X						X
Participation in organized activities	MoBa	X						X
Social activities with friends/peers	MoBa	X						X
Hours spent watching TV	MoBa			X			X	
Hours spent on screen-based activities	MoBa			X			X	
Child's moods and feeling	MoBa				X			
Total green space	GIS-derived		X			X		
Park within 800-m	GIS-derived		X			X		
Park within 5000-m	GIS-derived		X			X		
Facilities/amenities within 800-m	GIS-derived		X			X		
Facilities/amenities within 5 000-m	GIS-derived		X			X		
Playgrounds/sports fields within 800-m	GIS-derived		X			X		
Playgrounds/sports fields within 5 000-m	GIS-derived		X			X		
School within 800-m	GIS-derived		X			X		
School within 5 000-m	GIS-derived		X			X		
Population density	GIS-derived		X	X		X	X	
Golf course within 800-m	GIS-derived	Not included			Not included			
Golf course within 5 000-m	GIS-derived	Not included			Not included			
School and kindergarten within 800-m	GIS-derived	Not included			Not included			
School and kindergarten within 5 000-m	GIS-derived	Not included			Not included			

Activity outcomes and mediators

To study participation in activities among the Norwegian children, four questions from the 8-year follow-up questionnaire reported by the mothers were utilized. The questions provided data on leisure-time physical activity during the summer and winter and participation in organized activities and informal social activity with friends and peers. In Paper III, these variables were analyzed as outcome variables, whereas in Paper IV, they were considered as mediators. All these variables were constructed as dichotomous measures.

The mothers answered two questions on how much time the child spent on *leisure-time PA* outside of school hours in the summer and the winter. The response categories were "< 1," "1–2," "3– 4," "5–7," "8–10," and "≥ 11" hours/week. For the purposes of the cross-sectional studies, these responses were dichotomized into "≥5 h/week" opposed to "4≤ h/week." This threshold was selected as it closely adheres to recommendations from the Norwegian health authorities of 60 min/day of moderate to vigorous PA (The Norwegian Directorate of Health, 2014a), and it is expected that the children also accumulate PA time during recess and through PA education classes that not were captured through these measures.

A question that addressed how many days per week the child participated in any kind of organized leisure activity (e.g., sports, music, dance or theater) was used to measure *participation in organized activities* among the 8-year-olds. The mothers selected between the following five options: "never/seldom," "once a week," "2–3," "4–5," and "6–7 days/week." Only 4.6% (n = 1057) of the children in our sample never/seldom participated in organized activities. Further, a recent survey showed that Norwegian children and adolescents aged 17 or younger participate on average in 1.7 organized activities (Ipsos MMI, 2018). Thus, to obtain more comparable groups for the analyses, participation in organized activities was divided into "2 days or more/week" in contrast to "once a week or less."

Informal social activity with friends and peers was measured with a question that elicited how many days per week the child spent time with friends and peers outside school hours and organized activities. The mothers selected between the following five options: "never/seldom," "once a week," "2–3," "4–5," and "6–7 days/week." As for organized activities, only 1.6% (n = 371) of the children in our sample were never/seldom together with friends and peers. As surveys have shown that nearly 60% of Norwegian sixth-, ninth- and tenth graders spend time with their friends at least twice a week (Kolle et al., 2012), this variable was also dichotomized into"2 days or more/week" opposed to "once a week or less."

<u>Well-being outcome</u>

To examine how the built environment might contribute to strengthening the subjective dimension of children's well-being, one variable was obtained from the MoBa questionnaire. This variable considered the children's moods and feelings and was only included in Paper IV.

Children's moods and feelings were assessed through the Norwegian version of the Short Mood and Feelings Questionnaire (SMFQ) (Angold et al., 1995), which is a widely used tool for measuring moods, feelings and depressive symptoms in early childhood and adolescence. The MoBa questionnaire included the parental report version of the SMFQ. The tool consists of 13 items that are rated on a three-point Likert scale. Values are assigned to statements such as "Does your child feel miserable or unhappy" and "Does your child feel lonely" based on the following responses: "Not true (0)," "Sometimes true (1)" and "True (2)," referring to the past two weeks. The internal reliability (Cronbach's alpha) for the SMFQ was reported to be 0.85 (Angold et al., 1995). We computed Cronbach's alpha for the 8-year-olds in MoBa, and the internal consistency in our sample was found to be 0.77. A total score ranging from 0 to 26 was computed for each child. This continuous variable was used as an outcome variable in the analyses. Lower values indicated that the child experienced fewer depressed moods and negative feelings (Angold et al., 2002; Messer et al., 1995). If a child had only four or less items missing out of the total 13, the missing items were replaced with the mean of the remaining items to obtain a total score (Angold et al., 1995). If more than four items were missing, the total score was not calculated, and the child was subsequently removed from the analyses.

Built environment exposures

As described in section 4.3.2, I computed 14 different built environment variables, of which 10 were further prepared and studied as determinants of participating in activities and well-being in Papers III and IV. Due to the low number of children with golf course areas within the two radii, the measures of *proportion of golf course area* were not considered in the analyses. The reason for not including the measure *number of schools/kindergartens* was that very high positive correlations were revealed between this measure and the measure *number of schools* (Spearman's rho = 0.88 and 0.98 for the 800- and 5 000-m radii, respectively) (see Table 8).

The proportion of total green space within the 800-m radius was split into quartiles and analyzed as a categorical variable. The quartiles were derived statistically to obtain comparable groups. We dichotomized the measures of *park area* into the "presence of a park" (yes/no) within the 800- and 5 000-m buffers. The count variables of *facilities/amenities* and *playgrounds/sports fields* within the 800- and 5 000-m radii were also divided into quartiles, and were analyzed as categorical variables. We also created a binary coding for the counting measures of *schools*, which represented the "presence of a school" (yes/no) within the two buffers. The *population density* within the 800-m radius was divided into a categorical variable with four categories. These categories were also derived statistically to obtain comparable groups, but the Statistics Norway's definition of densely populated areas, which states that such areas are characterized by settlements > 200 inhabitants where the distances between houses does not exceed 50-m (Statistics Norway, 1999), was taken into account. As such, those who did not live within a densely populated area (according to the definition) were used as reference group. Table 9 presents all the established categories of the built environment determinants and their distribution in the sample.

Table 8. Matrix of correlations between the built environment measures (continuous) for the total sample (n = 23 043).

	% Green space 800m	% Park 800 m	% Park 5000m	% Golf 800m	% Golf 5000m	Density (n) 800m	Facilities (n) 800m	Facilities (n) 5000m	Playground/ sport (n) 800m	Playground/ sport (n) 5000m	School (n) 800m	School (n) 5000m	School/ kindergarten (n) 800m
% Green space 800m	1.00												
% Park 800m	-0.26	1.00											
% Park 5000m	-0.33	0.42	1.00										
% Golf 800m	0.04	-0.01	0.03	1.00									
% Golf 5000m	-0.12	0.05	0.29	0.27	1.00								
Density (n) 800m	-0.41	0.41	**0.73**	0.06	0.34	1.00							
Facilities (n) 800m	-0.29	0.25	0.36	0.06	0.17	0.53	1.00						
Facilities (n) 5000m	-0.30	0.30	**0.74**	0.07	0.37	**0.78**	0.52	1.00					
Playgrounds/sport (n) 800m	-0.31	0.28	0.58	0.07	0.32	**0.84**	0.42	0.62	1.00				
Playgrounds/sport (n) 5000m	-0.35	0.32	**0.78**	0.07	0.40	**0.85**	0.38	**0.82**	**0.80**	1.00			
School (n) 800m	-0.20	0.18	0.29	0.03	0.13	0.40	0.69	0.41	0.34	0.31	1.00		
School (n) 5000m	-0.28	0.27	**0.70**	0.06	0.35	**0.75**	0.48	**0.93**	0.60	**0.80**	0.44	1.00	
School/kindergarten (n) 800m	-0.23	0.21	0.35	0.02	0.13	0.48	**0.78**	0.49	0.39	0.37	**0.88**	0.50	1.00
School/kindergarten (n) 5000m	-0.29	0.28	0.71	0.05	0.34	**0.76**	0.49	**0.94**	0.61	**0.81**	0.43	**0.98**	0.51

Notes: Bold values indicate high or very high correlations between variables (Spearman's rho ≥ 0.7)

Table 9. Distribution of built environment determinants for the total sample of 23 043 children.

Built environment determinant	N (%)			
	Total (n=23 043)	Boys (n=11 826)	Girls (n=11 176)	P-value[a]
Total green and open spaces				0.187
≤ 13.0 % (ref.)	5 593 (24.3)	2 866 (24.2)	2 717 (24.3)	
13.1 – 29.9 %	5 664 (24.6)	2 846 (24.1)	2 811 (25.2)	
30 – 49.9 %	5 983 (26.0)	3 085 (26.1)	2 887 (25.8)	
≥ 50.0 %	5 803 (25.2)	3 029 (25.6)	2 761 (24.7)	
Missing	0 (0.0)	0 (0.0)	0 (0.0)	
Park within 800-m				0.671
No	19 279 (83.7)	9 882 (83.6)	9 362 (83.8)	
Yes	3 764 (16.3)	1 944 (16.4)	1 814 (16.2)	
Missing	0 (0.0)	0 (0.0)	0 (0.0)	
Park within 5000-m				0.517
No	8 493 (36.9)	4 384 (37.1)	4 097 (36.7)	
Yes	14 550 (63.1)	7 442 (62.9)	7 079 (63.3)	
Missing	0 (0.0)	0 (0.0)	0 (0.0)	
Number of facilities/amenities 800-m				0.325
0 (ref.)	10 837 (47.0)	5 600 (47.4)	5 220 (46.7)	
1	4 687 (20.3)	2 429 (20.5)	2 253 (20.2)	
2-3	4 542 (19.7)	2 311 (19.5)	2 219 (19.9)	
≥ 4	2 977 (12.9)	1 486 (12.6)	1 484 (13.3)	
Missing	0 (0.0)	0 (0.0)	0 (0.0)	
Number of facilities/amenities 5000-m				0.689
≤ 5 (ref.)	6 007 (26.1)	3 096 (26.2)	2 901 (26.0)	
6-14	5 512 (23.9)	2 856 (24.2)	2 647 (23.7)	
15-29	5 257 (22.8)	2 665 (22.5)	2 582 (23.0)	
≥ 30	6 267 (27.2)	3 209 (27.1)	3 046 (27.3)	
Missing	0 (0.0)	0 (0.0)	0 (0.0)	
Number of playgrounds/sports fields 800-m				0.355
≤ 1 (ref.)	3 666 (15.9)	1 928 (16.3)	1 733 (15.5)	
2-5	4 002 (17.4)	2 058 (17.4)	1 935 (17.3)	
6-10	3 748 (16.3)	1 900 (16.1)	1 846 (16.5)	
≥ 11	11 627 (50.5)	5 940 (50.2)	5 662 (50.7)	
Missing	0 (0.0)	0 (0.0)	0 (0.0)	
Number of playgrounds/sports fields 5000-m				0.176
≤ 35 (ref.)	5 845 (25.4)	3 031 (25.6)	2 805 (25.1)	
36-119	5 654 (24.5)	2 839 (24.0)	2 806 (25.1)	
120-419	5 690 (24.7)	2 965 (25.1)	2 716 (24.3)	
≥ 420	5 854 (25.4)	2 991 (25.3)	2 846 (25.5)	
Missing	0 (0.0)	0 (0.0)	0 (0.0)	
School within 800-m				
No	16 540 (71.8)	8 540 (72.2)	7 974 (71.3)	0.145
Yes	6 503 (28.2)	3 286 (27.8)	3 202 (28.7)	
Missing	0 (0.0)	0 (0.0)	0 (0.0)	
School within 5000-m				0.363
No	4 941 (21.4)	2 565 (21.7)	2 369 (21.2)	
Yes	18 102 (78.6)	9 261 (78.3)	8 807 (78.8)	
Missing	0 (0.0)	0 (0.0)	0 (0.0)	
Population density				0.072
≤ 200 (ref.)	4 747 (20.6)	2 515 (21.3)	2 227 (19.9)	
201-799	6 679 (29.0)	3 397 (28.7)	3 271 (29.3)	
800-1649	5 832 (25.3)	3 004 (25.4)	2 817 (25.2)	
≥ 1650	5 649 (24.5)	2 853 (24.1)	2 783 (24.9)	
Missing	136 (0.6)	58 (0.5)	78 (0.7)	

[a]Results from chi-square statistics comparing boys and girls.

Covariates

The theory of directed acyclic graphs (DAGs) and previous studies in the area of this research endeavor guided which covariates to include in the cross-sectional studies (Greenland et al., 1999). The DAGs served as visual and logical aids for summarizing assumptions about relations between all the variables of interest and for identifying variables for which adjustment was needed. Before performing the analyses, I created a DAG for each of the cross-sectional studies and, thus, selected and included potential confounders *a priori*. The DAGs created for Papers III and IV appear as supplemental material in each of the papers. Due to the cross-sectional nature of the MoBa data, the assumptions regarding the directions of the arrows are subject to a degree of uncertainty.

The covariates *child's gender, mother's age* and *present level of education* and *attendance at after-school care* were included to adjust for confounding in the statistical analyses in Paper III. In trying to account for a degree of urbanization in our material, the GIS-derived variable *population density* was included in some of the analyses. All these variables were also included and adjusted for in the statistical models in Paper IV. Additionally, *hours spent watching TV* and *hours spent on other screen-based activities* were included as confounders on the mediator-outcome path in Paper IV. Maternal age was treated as a dichotomous measure (≤ 29 years vs. ≥ 30 years), whereas the mother's level of education was classified as a categorical variable with three categories (i.e. high school or less, university degree ≤ 4 years and university degree ≥ 4 years). The variables hours spent on watching TV and other screen-based activities were dichotomized into "an hour or less/day" versus "> 1 hour/day." A binary coding was also applied for attendance at after-school care (attendance versus no attendance). Population density was treated as a categorical variable with four categories, as shown in Table 9.

4.3.6 Statistical analyses

The statistical analyses were performed using IBM SPSS Statistics version 25.0, and R version 3.5.2 was used to run the mediation analyses in Paper IV. The level of significance was set to 0.05, and all statistical tests were two-tailed. Preliminary analyses were carried out using descriptive statistics, such as mean, median, range, standard deviations, frequencies and percentages. I used conventional descriptive statistics to present the distribution of key variables within the total samples in Papers III and IV. The built environment exposure variables were not normally distributed (mainly positively skewed). Thus, I used pairwise Spearman correlation to examine the relations between the exposure variables to address potential multicollinearity. As already stated in Chapter 4.3.5, some of the built environment variables were extremely highly correlated and therefore excluded from further analyses. Additionally, the variance inflation factor (VIF) values of the exposure variables were inspected. The correlation coefficients revealed that population density, facilities/amenities (the 5 000-m radius) and playgrounds/sports fields (800- and 5 000-m radii) were highly correlated (rho > 0.7). Similarly, the VIF values of these variables exceeded 2.5, indicating potential multicollinearity (Midi et al., 2010). These discoveries informed the statistical analytical strategies applied in Papers III and IV.

In Paper III, differences between the genders were examined using standard chi-square statistics. The associations between the 10 built environment determinants and participation in different activities were investigated using univariate and multivariate logistic regression analyses. To remedy the problem of multicollinearity, separate models were fitted for each of the determinants. For the adjusted models, we considered only determinants that were significantly related to participation in activities in crude models. Analyses were adjusted for possible confounding of all the covariates presented in Chapter 4.3.5. However, we adjusted for population density only in the absence of multicollinearity between population density and the other particular built environment determinant of interest. All analyses were stratified by gender. All effect estimates were presented as odds ratios with corresponding 95% confidence intervals. Finally, p-values for trends were computed based on models in which the exposures were treated as continuous variables.

In Paper IV, we assessed the direct associations between the built environment and well-being and investigated participation in leisure activities as a mediating pathway in these relations. Most mediation analyses in the social sciences are inspired by the approach suggested by Baron and Kenny (1986). According to Baron and Kenny (1986), four criteria need to be satisfied for a variable to be considered a mediator: (1) the exposure variable should be significantly related to the mediator; (2) the mediator should be significantly associated with the outcome; (3) there should be a significant association between the exposure and the outcome; and (4) a significant decrease in the association between the exposure and the outcome when the mediator is added to the model. The first two conditions are considered essential for establishing mediation or indirect effects (VanderWeele, 2015), but the third requirement has been criticized by many scholars (MacKinnon et al., 2007; Shrout and Bolger, 2002; VanderWeele, 2015). The reason for the criticism is that the relationship between the exposure and outcome variable may be zero or close to zero when the direct and mediated associations have opposite signs, often referred to as inconsistent mediation (MacKinnon et al., 2000). Further, in practice, the likelihood of attaining an answer from significance testing of all four criteria will at times be quite small (VanderWeele, 2015). Based on the universally accepted necessity of fulfilling the first two requirements for establishing mediation, the results from Paper III guided which variables and models to consider in Paper IV. Significant findings between the built environment determinants and the leisure activities for the total sample in Paper III indicated that the first condition was met (i.e., significant relation between the exposure and the mediator). Thus, these significant models were further explored in the preliminary analyses of Paper IV, as described below.

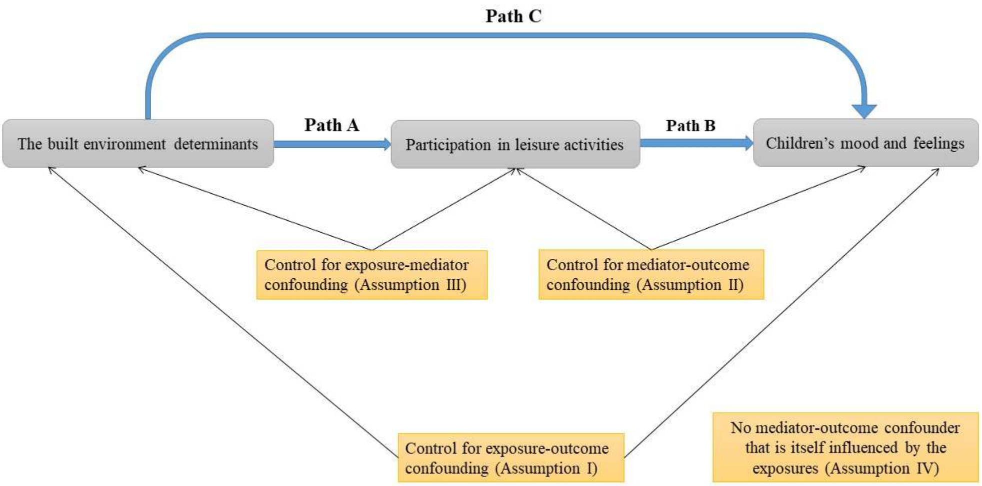


Figure 10. A conceptual mediation model showing the direct relationship on Path C and the indirect relationship though Path A and Path B, including the set of confounders on all paths.

Figure 10 shows the conceptual mediation model that formed the basis for the regression modelling approach. In the initial analyses, pathways A, B and C in Figure 10 were inspected. The relation between each built environment determinant and mediator (Path A) was examined using logistic regression. A series of general linear models were fitted to examine (1) the relationships between each mediator and children's moods and feelings (Path B) and (2) to explore the overall association between each built environment characteristic and the outcome (Path C). As described in Chapter 4.3.5, potential confounders were included and adjusted for in all models. These initial analyses revealed regression coefficients on Path B with the opposite sign of that of Path A and Path C, which seemingly indicated a presence of inconsistent mediation and suppression (MacKinnon et al., 2000; 2007). Possible inconsistent mediation seemed to be present in terms of *negative direct relations* between the built environment characteristics and the children's emotional state and *positive indirect relations* between the exposures and the well-being outcome through children's participation in leisure activities. Potential suppression was identified in some models (Path B) whereby adding the built environment determinant slightly altered the regression coefficient and increased the predictive value of the mediator, while the determinant itself was unrelated to the outcome (MacKinnon et al., 2000). For example, the regression coefficient for participating in social activities in the model without the exposure variable *school within 5 000-m* was $\beta = -0.53$, 95% CI = -0.46, -0.63. When the built environment variable was added to the model the regression coefficient increased slightly ($\beta = -0.55$, 95% CI = -0.46, -0.63), but *school within 5 000-m* was unrelated to the children's moods and feelings ($p = 0.067$). Based on the arguments raised above and our preliminary discoveries, the steps recommended by Shrout and Bolger (2002) were followed to determine which variables to enter in the models to avoid doing a type II error in the mediation analyses. Accordingly, the steps for fitting the mediation models were based on (1) significant exposure-mediator relations (Path A) and (2) significant mediator-outcome relations (Path B).

The counterfactual approach to mediation analysis formulated by Pearl (2001) and Robins and Greenland (1992) was utilized as the statistical framework for the analyses. The formal and technical notation behind the statistics rely on the assumption that the effect of an exposure can be defined as the difference between two outcomes: (i) the observed outcome in our data and (ii) what might have been the outcome if the exposure had been different from what it was, referred to as the counterfactual outcome (Imai et al., 2010; Pearl et al., 2016; VanderWeele, 2015). Based on several novel extensions of the counterfactual approach to mediation (Imai et al., 2010; Valeri and Vanderweele, 2013; VanderWeele and Vansteelandt, 2009), total, direct and indirect associations were estimated in models with categorical exposure variables and binary mediators. The methods and formulas provided within the mediation package in R developed by Tingley et al. (2014) were employed. Direct and indirect associations between the built environment determinants and well-being were estimated from fitting (1) a general linear model for children's moods and feelings (Y), which was conditional on each built characteristic (X), the potential mediator (M) and the set of confounders, and (2) a logistic regression model for the potential mediator (M), conditional on the particular built environment characteristic (X) and the set of confounders. It was assumed that the set of covariates included in the models was sufficient to control for confounding on all paths. However, the assumptions regarding no unmeasured confounding on all paths were strong, and will often be violated in practice (VanderWeele, 2016). Further, VanderWeele (2016) also stated there should be no mediator-outcome confounder that is itself influenced by the exposures. The assumptions of no unmeasured confounding on all paths may have been violated in Paper IV. Additionally, there are mediator-outcome confounders (i.e., screen-based activities) that were likely influenced by the built environment. The potential consequences for the analysis results of such violations will be discussed in Chapter 6.4.3.

In total, 15 separate mediation models were specified. We computed the direct and indirect relations for each exposure group using the reference group as the contrast. The residual plots were inspected and White's test for heteroscedasticity showed that the variance of error varied across observations. Robust standard errors were estimated to adjust for heteroscedasticity using White's heteroscedasticity-consistent estimator for the covariance matrix (Tingley et al., 2014). We report standardized regression coefficients (β) with the corresponding 95% confidence interval (CI) obtained through quasi-Bayesian Monte Carlo simulations based on normal approximation to bootstrap with 1000 resamples, which is generally considered sufficient (Imai et al., 2010).

4.4 Ethical considerations and approvals

This research project was conducted in compliance with the ethical principles for medical research involving human subjects stated in the Declaration of Helsinki (World Medical Association, 2013), which emphasizes that researchers have a duty to protect life, health, privacy and confidentiality of the personal information of human subjects. All the participants in MoBa provided written informed consent at the point of enrollment in the cohort. Furthermore, the establishment, data collection and linkage of MoBa data to other health registries was licensed by the Norwegian Data Protection Authority (ref. 01/4325) and approved by the Regional Committee for Medical Research Ethics (REK) (ref. S-97045, S-95113) and are now also based on regulations related to the Norwegian Health Registry Act.

Prior to conducting the cross-sectional studies, an application was submitted to REK. They evaluated that the study objectives were outside the scope of the Norwegian Health Research Act and that their approval was not necessary. As a result, we submitted a new application to the Norwegian Center for Research Data from which we obtained additional approval for the use of data and the linking of GIS-derived exposure variables (ref. 48426/3/AMS, 48426/6/AMS/LR). To comply with the ethical principles of protecting privacy and ensuring the anonymity of the participants, we had to use distributed linkage as the procedure for linking data (described in Chapter 4.3.3). SSB was the entrusted coordinator of the data and performed the linkage. Additional approvals and agreements were obtained from the Norwegian Institute of Public Health, as the owner of the data, and from SSB. Decision letters, approvals and agreements are appended.

5 Presentation of the papers

5.1 Paper I

"GIS-derived measures of the built environment determinants of mental health and activity participation in childhood and adolescence: A systematic review."

Studies increasingly use GIS to measure the environmental features of relevance for children and adolescents. Significant uncertainty is involved in delimiting the spatial areas of exposure. Furthermore, a wide array of GIS measures, techniques and operational definitions exists. Thus, using GIS technology for public health and research purposes requires great methodological awareness. Greater informativeness and a synthesis of the ways to operationalize built environment determinants are needed, and this paper intended to contribute to such efforts. The study aimed to identify, systematize and evaluate (1) the operational definitions of GIS-derived built environment measures and (2) the geographic areas of exposure applied in studies examining the impact of built environments on the mental health of children and adolescents and their participation in activities.

A systematic literature review was designed and conducted. Peer-reviewed articles were acquired through stepwise searches in the following databases: Web of Science, PubMed, Medline, PsychINFO and SweMed+. The extracted material was analyzed and synthesized using descriptive statistics, content analysis and a narrative synthesis approach.

We identified a multitude of operational definitions of different built environment features across the 90 included studies. These operational definitions were grouped into seven main and 18 sub-content categories of built environment measures (Table 10). There was large variability in the measures applied, and some studies lacked precise operational definitions. Most studies used ego-centered definitions to delineate the geographic areas of exposure. Circular and network buffering techniques were almost equally applied, but the distances ranged widely from 50 to 8 050 meters.

This comprehensive review contributes to the ongoing methodological discussions of applying GIS-derived measures for investigating relations between the built environment and health among children and adolescents. We suggest that the identified categories of measures represent an initial step toward establishing consensus about which determinants are important to measure. The categories of built environment measures are viewed as valuable and relevant to assess and monitor in research, policy and practice. However, we revealed several remaining methodological issues and challenges, and consistency in operational definitions is urgently needed. Findings from this systematic review could be informative in both research design and review processes as well as in planning practice. The informativeness of the synthesis could provide a basis for refining and further developing existing operational definitions, which eventually can ensure targeted use of and consistency in measures applied across future studies and lead to joint operational definitions applied across research and practice. As such, this paper facilitates and points to the crucial role of methodological discussions of operationalizing appropriate measures in consistent manners within this continuously evolving research area.

Table 10. The main and sub-categories of built environment measures identified.

Main categories identified	Sub categories identified
Population measures	1) Population density
Built form measures	2) Residential density
	3) Total building density
	4) Urban-rural status of home address
Land-use measures	5) Land-use or land-cover
	6) Land-use mix
Road/street environment measures	7) Road/street patterns and connectivity
	8) Traffic exposure and safety related features
	9) Pedestrian infrastructure
Facility and amenity measures	10) Distance to facilities and/or amenities
	11) Count or proportion of facilities and/or amenities
	12) Topography connected to accessibility of facilities and/or amenities
Neighborhood green and open space measures	13) Distance to green and open space
	14) Count or proportion of green and open space
	15) Type of green and open space
	16) Structures surrounding park
Composite measures	17) Walkability index
	18) Facility and amenity index

5.2 Paper II

"Promoting activity participation and well-being among children and adolescents: A systematic review of neighborhood built environment determinants."

Neighborhoods are considered key settings for health-promoting actions and efforts. Such efforts and initiatives should essentially originate from evidence-based knowledge. Hence, it is crucial to advance our understanding of potential health-promoting built environment determinants within neighborhoods and local communities. There is a need to comprehensively and critically review the existing evidence of the relations between the built environment and health in childhood and adolescence. Such evidence syntheses can contribute to ensuring informed decision-making, policy changes and spatial planning. Thus, the aim of this review was to identify, evaluate and synthesize the findings of the built environment determinants and their relation to participation in different domains of activities and well-being among children and adolescents from a broader public health perspective.

A four-step search strategy was utilized. Relevant peer-reviewed studies published since January 2010 were identified through tailored searches in PubMed, Medline, Web of Science, Embase, CINAHL and PsychINFO. The reviewers assessed the methodological quality of the included studies independently in pairs using standard critical appraisal tools. The extracted data were narratively synthesized using textual descriptions, grouping and vote counting. We generated six mutually exclusive outcome categories: unspecified PA, leisure-time PA, active travel, outdoor play/activity, organized sports and well-being outcomes. The associations between these outcome categories and the built environment were synthesized using the content sub-categories developed in Paper I (Table 10). We added aesthetics to the list of sub-categories to facilitate the interpretation of findings, resulting in 19 built environment determinant categories.

Evidence from 127 studies were reviewed, of which the majority (78.7%) were from North America and Europe. The study designs were mainly cross-sectional (87.4%). The quality assessment revealed that the quality of the studies was quite good. Just over half of the studies was rated as fair (57.4%), and 27.6% of the studies were of good quality. Active travel was the most studied outcome (n = 54), followed by unspecified PA (n = 46), whereas 11 studies examined the built environment determinants of organized sports and well-being. A novel finding of the review was that the composite determinant denoted as the facility and amenity index was most consistently related to unspecified PA and to some extent leisure-time PA. The associations between the rest of the built environment determinants, unspecified PA and leisure-time PA lacked consistency across the studies. In contrast, neighborhoods with low traffic, high safety, pedestrian infrastructure for walking/biking, short distance to facilities and high walkability were consistently found to be beneficial in terms of promoting active travel. Limited evidence existed for the relationship between the built environment and well-being in the younger population.

This systematic review considered a broad range of built environment determinants and health-related outcomes from recently published studies and provided a determinant- and outcome-specific synthesis of associations. There are several remaining research gaps to address before a more robust conclusion can be drawn. However, we suggest that policy and planning should consider the identified health-promoting determinants low traffic and high safety, short distances to facilities, pedestrian infrastructure for walking and cycling and high walkability to promote active travel to and from daily destinations among children and adolescents.

5.3 Paper III

"Neighborhood Green Spaces, Facilities and Population Density as Determinants of Activity Participation among 8-year-olds: A Cross-Sectional GIS Study Based on the Norwegian Mother and Child Cohort Study."

Participating in activities is vital for children's health and well-being, and research confirms the importance of doing meaningful activities in everyday life. Since the neighborhood is a key arena for many activities that children enjoy, it is necessary to possess substantial knowledge about the built environment determinants within such contexts. We see several deficiencies in the exciting evidence. Hardly any empirical studies address the built environment determinants of participation in organized and social activities, and children aged 8-years and younger have received less attention in previous research. This study makes efforts to address these gaps.

The objective of this study was to examine whether the built environment determinants population density, green spaces and facilities are associated with participation in leisure-time PA across seasons, organized activities and social activities with friends in a large and geographically diverse sample of Norwegian 8-year-olds.

A cross-sectional study design was applied. Data from 23 043 Norwegian 8-year-olds in MoBa were linked to geospatial data about the built environment calculated within 800- and 5 000-m buffer zones around the participants' home addresses. We derived the exposure variables using GIS, and these included population density and access to green spaces and facilities. Questionnaire data reported by mothers provided information on the children's leisure-time PA in the summer and winter (hours/week), participation in organized activities (days/week) and social activity with friends and peers (days/week). Logistic regression models were fitted to estimate the odds of participating in different activities depending on the built environment determinants.

Children having a park in their neighborhood were more physically active in the summer than those without such access. Moreover, children who resided in neighborhoods with higher proportions of green space undertook more PA during the winter. More densely populated areas and access to facilities promoted participation in organized and social activities. Greater access to playgrounds/sports fields in the neighborhoods was the strongest correlate of activity participation among Norwegian 8-year-olds by supporting socialization with friends and peers. These findings underscore the importance of access to diverse venues and opportunities for a range of activities in the neighborhood and in the greater community to support activity participation in childhood.

5.4 Paper IV

"Disentangling how the built environment relates to children's well-being: Participating in leisure activites as a mediating pathway among 8-year-olds based on the Norwegian Mother and Child Cohort Study."

Promoting well-being in childhood is crucial because experiencing positive emotions and feelings and having the ability to realize one's own abilities and thereby thrive provide grounds for maintaining health across the life span. A supportive built environment might enhance children's well-being, but to date, few studies have investigated this relationship. This paper offers empirical findings that contribute to bridging this knowledge gap by examining whether population density, green spaces and facilities are related to children's moods and feelings and if the participation in different leisure activities acts as a mediator in such relations among Norwegian 8-year-olds.

We applied a cross-sectional data linkage design in which data from 23 043 children in MoBa were linked to geographic data about built features surrounding a child's home address. Information on the 8-year-olds' leisure activities and moods and feelings, assessed with the SMFQ, were obtained from the questionnaire data reported by mothers in the cohort study. We utilized geographic information systems to compute exposure to green spaces, facilities and population density within 800- and 5 000-m radii of the home addresses. We estimated direct and indirect relations between the built features and children's well-being through a series of regression analyses based on the counterfactual approach to statistical mediation.

Although the 8-year-olds experienced few depressive and emotional symptoms, we found that children with access to a park and more playgrounds/sports fields in the neighborhood had significantly more negative feelings compared to those without such access. We also found that living in more densely populated areas was associated with poorer emotional states. However, engagement in leisure-time PA, organized activities and social activity with friends mediated these relationships and counteracted some of the negative associations observed between all these built environment characteristics and the Norwegian 8-year-olds' moods and feelings.

Despite the overall negative associations between the built environment and children's emotional state, these findings indicate that strategies to attain high well-being in childhood should include access to neighborhood facilities and green space that support participation in leisure activities. However, developing a better understanding of these complex relations is necessary.

6 Synthesized discussion

This thesis has investigated neighborhood and local community built environment determinants and their potential to support participation in activities and strengthen the well-being of children and adolescents. All four papers included in this thesis concern built environment determinants. In Paper I, the built environment characteristics were investigated methodologically by appraising how we can operationalize them objectively by means of GIS technology and related methods. In Papers II, III and IV, the health-promoting potential of the built environment characteristics was examined empirically (1) through a synthesis of existing evidence of their relations with activity participation and well-being, (2) by assessing their relations with involvement in leisure activities among Norwegian children, and (3) by exploring mediation mechanisms and pathways between the built environment characteristics and children's subjective well-being. The following sections are devoted to providing a synthesized discussion of the results and to considering methodological issues related to this research endeavor. The discussion will unfold in three parts. The first part focuses on this thesis' results at a methodological level and discusses the findings from Paper I. In addition, relevant findings from Paper II will be reflected upon in the first part, as they closely relate to the methodological issues and limitations addressed in Paper I. The second part discusses the empirical results and elaborates on the health-promoting potential of the built environment. This part draws on findings from Papers II, III and IV, as well as perspectives from salutogenic theory, occupational science and the concept of affordances. The third and final part considers the methodological issues and limitations of this thesis. The emphasis throughout the discussion is on aspects linked to health and well-being, which mirrors my grasp of the topic as predominantly from a public health and health-promoting perspective.

6.1 Using GIS to measure the built environment for public health and research purposes

6.1.1 Holistic consideration of characteristics that facilitates everyday activities

Being aware of the built environment determinants is central for considering the investment that should be made in creating health-promoting environments (WHO, 2018). The informativeness of the systematic reviews undertaken are important, as they contribute to raising our notions about which built environment characteristics need to be considered with respect to health and well-being in childhood and adolescence. The synthesis of existing evidence linking the built environment to participation in activities and well-being revealed that our neighborhoods and local communities are tremendously complex. These complexities have major implications for studying relations between the built environment, health and well-being and for creating supportive environments.

As stated earlier, about 55% of Norwegian municipalities currently include public health and related efforts as objectives in their planning strategies (Hofstad, 2018; Thoren et al., 2018). Yet, there are still areas of improvement, particularly with respect to spatial planning (Hofstad, 2018). If we intend to progress on how we exert cross-sectoral collaboration, advanced integration and consideration of the built environment characteristics relevant to public health will be essential to circumvent silo-based approaches. Integrative approaches to planning have also been stressed by others as critical to addressing the complex challenges of realizing the sustainable development goals (United Nations, 2015; WHO, 2018), of which the promotion of health and well-being at all ages is an integral part (United Nations, 2018). One issue raised in Norway making knowledge about public health more accessible and transferring it to spatial planning seem challenging. Public health goals need to be more operationally relevant (Hofstad, 2018). For such purposes, GIS-based measures could represent a cornerstone if geographic information is attached to health surveillance data or people's own perceptions and use of the built environment.

GIS technology has become an invaluable tool for public health (Cromley and McLafferty, 2012) and the investigation of built environment determinants (Diez Roux and Mair, 2010; Thornton et al., 2011). Importantly, GIS-derived measures and research of their links to health and well-being can be used to better inform planning policies in context-sensitive manners (Badland et al., 2014). Researchers have also suggested that GIS-derived measures of the built environment could be useful as public health surveillance indicators to monitor our progress in creating health-promoting environments (Brownson et al., 2009b; Elmore et al., 2010). Such surveillance efforts could also be successively and operationally relevant for policy and spatial planning in itself, but that potential seems unrealized (Brownson et al., 2009b; Giles-Corti et al., 2014). Important reasons for this could be that limited attention has been paid to assessing the feasibility and validity of different GIS-derived measures of the built environment for public health purposes (Badland et al., 2014; Elmore et al., 2010; Giles-Corti et al., 2014), although exceptions exist (Annerstedt van den Bosch et al., 2016; Badland et al., 2015; Buck et al., 2011; Frank et al., 2010; Rhew et al., 2011). Limited investment in and prioritizing the appraisal of the feasibility and validity of GIS measures are visible through the results of the review, showing large variability and a lack of consistency in the operational definitions applied. Do we need all these measures? Which measure are most useful and applicable for public health policy and planning purposes concerning the health and well-being of children and adolescents? Such questions and facets will be essential to contemplate in upcoming discussions and future research. Built environment characteristics that enhance well-being in adulthood do not necessarily promote health and well-being in the younger population. This underscores the importance of capturing the determinants that in momentous ways comply with the activities of children and adolescents (Oliver et al., 2016). As such, the synthesized, hands-on overview of GIS-derived measures that this research has provided could be used to initiate fundamental discussion among researchers, policy makers and practitioners.

Establishing consensus about which built characteristics to monitor in research, policy and planning represents an important step toward developing more valid and applicable measures. As suggested by Brownson et al. (2009b), redundant measures with limited utility could be removed. However, this requires systematic attention and dedicated long-term dedicated efforts. The findings detailed in Paper I demonstrate a need for such systematic effort, and the synthesis represents an initial step in that direction. A crucial question then is how do we continue from here? Brownson et al. (2009b) said that the majority of measures in their overview captured built characteristics mostly relevant for active travel. However, they did not focus on measures typically applied among children and adolescents, as we did. Additionally, Brownson et al. (2009b) mainly paid attention to physical activity, while our focus was made broader in scope by considering measures of relevance to different meaningful everyday activities that take place within built environments. Importantly, we identified that several facility/amenity and green/open space measures were frequently applied, closely followed by road/street environment measures. These categories of measures seem to capture key characteristics and venues that matter for the promotion of participation in activities in childhood and adolescence (Badland et al., 2015; Christian et al., 2015; Kyttä et al., 2018; Loebach and Gilliland, 2016). Further, Paper II revealed that several built environment measures of facilities/amenities, green/open space, and the road/street environment were consistently associated with active travel and, to some extent, physical activity among children and adolescents. According to this, and the wealth of existing research on supportive built environments for children and adolescents (Bird et al., 2018; Christian et al., 2015; Ding et al., 2011; MacMillan et al., 2018), it seems evident that facilities/amenities, green/open space and several aspects of the road/street environment, such as pedestrian infrastructure, traffic exposure and safety, are central factors to assess in research, policy and planning. This supports the applicability of measures capturing these key characteristics as core indicators for public health surveillance and research targeting children and adolescents. In that respect, a promising starting point for developing more applicable and valid indicators of health-promoting environments could be revisiting these three categories of measures (i.e., facility and amenity measures, green and open space measures and road/street environment measures) and the related operational definitions that were identified in Paper I.

It must be emphasized that a plurality of built environment characteristics seems to play a key role for the younger population. Thus, from an *objective-list account perspective of well-being* (Barstad, 2016; Nussbaum, 2000) and the *occupational perspective of health* (Wilcock and Hocking, 2015a), a holistic consideration of the multiple built characteristics that influence the possibilities of children and adolescents to attain high levels of well-being through meaningful everyday activities would be essential. Solely focusing on one aspect of the built environment restricts our possibilities to create health-promoting environments. As such, a basic idea and an attainable goal should be to come forward with several key GIS-derived indicators of importance for well-being that can help us to assess and monitor the everyday environments of children and adolescents in an expedient manner.

6.1.2 The essentials of valid and applicable measures for evidence-based public health

Adopting evidence-based strategies to achieve the current national goals within public health policy has been recommended (Ministry of Health and Care Services, 2019; The Norwegian Directorate of Health, 2017). A key component of evidence-based public health includes making decisions based on the best available scientific evidence. Systematic reviews or evidence syntheses are used to support the development of public health initiatives and to inform policy changes (Brownson et al., 2009a; Lhachimi et al., 2016). Additionally, systematic reviews represent the standard for synthesizing evidence in the health sciences, including public health science, because of their methodological rigor (Moher et al., 2015). To identify research gaps and address methodological limitations of past syntheses, a systematic review of quantitative evidence was conducted as a part of this thesis. The included and appraised studies were very methodologically heterogeneous. Other researchers undertaking the task of reviewing the literature in this area have emphasized this as well (D'Haese et al., 2015b; MacMillan et al., 2018). One of the heterogeneities relates to the issue of defining and operationalizing the built environment using GIS. As such, the methodological issues identified in Paper I entailed consequences for the synthesis in Paper II. This also pertains to previous systematic reviews on health-promoting environments for children and adolescents (D'Haese et al., 2015b; Ding et al., 2011; Tillmann et al., 2018). Since the methodological quality of the included studies was appraised (Paper II), the synthesized findings account for some of the methodological weaknesses (e.g. the absence of operational definitions). However, without clearer and more consistent operational definitions, meta-analysis approaches will remain less applicable. Even without aiming for meta-analysis techniques, this heterogeneity diminishes the possibilities for detailed comparisons across studies. Thus, progress on GIS-derived measures and establishing consensus about which operational definitions to apply are also essential for providing a more robust synthesis of evidence, which will add strength to our knowledge on health-promoting environments for children and adolescents. The review of GIS-derived measures (Paper I) elucidates that great methodological awareness is required when deciding upon which measures to apply in research. By highlighting and discussing these methodological aspects, this research contributed to raising such awareness and putting these methodological issues on agendas for future research. Adding to what has been discussed in the preceding part of this chapter, this remains crucial for evidence-based public health.

So far, the discussion has revolved around the operationalization of built environment characteristics. However, there is another issue identified in Paper I that also has implications for the interpretation of findings, comparison across studies and the risk of bias in results, namely how we delineate and operationalize the geographic areas of exposure (Chaix et al., 2009; Kwan, 2012; Spielman and Yoo, 2009). As identified in Paper I, there was considerable variation in how the exposure areas were defined. Both territorial definitions, based on postal code areas or census tracts, and ego-centered definitions, relying on different buffering techniques around residential addresses, schools or other individual centroids, were utilized. Additionally, the size of the buffer zones around the different centroids varied considerably. This is problematic because relations between the built environment characteristics, health and well-being could be influenced by how we delineate the exposure areas (i.e., neighborhood). This issue is denoted as the Uncertain Geographic Context Problem (UGCoP) (Kwan, 2012). The UGCoP arises because of the uncertainty about which actual spatial areas individuals use. Erroneously specifying the true geographic context could lead to inconsistent results between studies and mask consistencies in the evidence (Frank et al., 2017; Kwan, 2012). This could also explain the inconsistent associations identified in Paper II. Recent studies have carefully considered the issue of UGCoP by exploring how exposures vary between territorial units, different buffer zones, perceived neighborhood areas and activity spaces (Perchoux et al., 2016) and if the units yielded different associations between the built environment, health and well-being in the adult and older populations (Laatikainen et al., 2018; Zhao et al., 2018). Both Laatikainen et al. (2018) and Zhao et al. (2018) showed that the spatial units of analysis resulted in different associations between the built environment, obesity and well-being. Hence, it is crucial to be aware that delineating geographic areas differently can provide distinct results and lead to inconsistencies in the syntheses of evidence. This should be addressed in future systematic reviews. It would be interesting to synthesize results of associations between the built environment, health and well-being for different spatial units to explore if this altered the findings and conclusions.

As pointed out in Paper I, none of the reviewed studies used activity spaces to delineate the exposure areas. By considering activity spaces we can define spatial areas based on where our target groups perform their daily activities (Thornton et al., 2011). Some studies in the research area of health-promoting environments have used global positioning systems (Chaix et al., 2013; Kestens et al., 2018) and public participatory GIS approaches (Hasanzadeh et al., 2018; Laatikainen et al., 2018) to capture an individual's activity spaces and the related built environment exposures. This allows for GIS-based analyses of people's activities in a known geographic context, which could contribute to overcoming some of the limitations associated with static buffers (i.e., ego-centered definitions) in which the true geographic context remains unknown. Using activity spaces is regarded as a promising approach for capturing the essential neighborhood areas that children and adolescents use and are exposed to (Loebach and Gilliland, 2014), and this should be considered more extensively in future research.

6.2 Health-promoting built environment characteristics – which and how

The everyday lives of children and adolescents proceeds through a myriad of activities that are vital for their health and well-being (Desha and Ziviani, 2007; Law, 2002; Mahoney et al., 2005; Passmore, 2003), and a great amount of their time over the course of a day is devoted to leisure activities (Desha and Ziviani, 2007). This pertains to the younger population in Norway too

(Vaage, 2013), and Norwegian children and adolescents are involved in many activities in diverse arenas during their leisure time (Bakken, 2018; Kolle et al., 2012; Samdal et al., 2016). Thus, through a health-promoting and salutogenic lens, the focus of this thesis has been to study the built environment determinants as potential resources for activity participation and well-being. Focusing on a variety of activities that children and adolescents engage in on a daily or regular basis seemed to be a valuable entering angle for studying health-promoting environments in light of *affordance theory* (Gibson, 1979; Kyttä, 2003) and the *occupational perspective of health* (Wilcock and Hocking, 2015a). The concept of affordances added insights to recognize neighborhoods and communities as comprehensive settings filled with activity-related properties or potential affordances, as referred to in this thesis. Through an *objective-list account perspective on well-being*, opportunities to take part in activities, as well as pursuing meaningful activities, represent essential aspects of well-being and are main outcome in themselves. Simultaneously, leisure activities are understood as potential resources for health and the subjective dimensions of well-being. Leisure activities could provide a child or an adolescent with meaningful and coherent life experiences important for developing a strong *sense of coherence* (Lindström and Eriksson, 2005; Wilcock and Hocking, 2015c). Although sense of coherence was not assessed in the studies, elaborating on the findings in light of this concept and the related resources assists in understanding the health-promoting potential of the built environment. What, therefore, does this thesis add to our knowledge on health-promoting environments seen through this theoretical and interpretive framework?

Despite the wealth of research in the area of health-promoting environments for children and adolescents (Christian et al., 2015; D'Haese et al., 2015b; Ding et al., 2011; MacMillan et al., 2018; McGrath et al., 2015; Smith et al., 2017; Tillmann et al., 2018; Twohig-Bennett and Jones, 2018), there were scant investigations of the built environment determinants of organized and social activities and well-being. Furthermore, it was believed that this area of research inquiry could benefit from a more detailed synthesis of the existing evidence in terms of activity outcomes and built characteristics to provide a clearer picture of the health-promoting potential of the built environment. Moreover, whether any associations existed between the neighborhood and local community built environment, activities and well-being of younger children in Norway was mainly unknown when this project commenced. At the empirical level, this thesis contributes to addressing these knowledge gaps. Given the findings of Papers II, III and IV, this thesis offers both confirmatory support and novel insights into the notion that a health-promoting environment is characterized by the presence of versatile built environment resources and venues that can facilitate participation in different activities. This is in harmony with a recent in-depth study using global positioning system monitors, activity diaries, annotated maps and Google Earth-enabled interviews among children aged 9-12 years from London, Ontario, in Canada (Loebach and Gilliland, 2019).

Potential built environment resources for active travel were only investigated in Paper II. The synthesized results based on 49 cross-sectional and five longitudinal studies from 11 countries and four continents revealed that low traffic, more safety features, proximate facilities, high walkability and well-established infrastructure for walking and cycling were consistently related to active travel among children and adolescents. Similar results have been reported previously (D'Haese et al., 2015b; Panter et al., 2008; Pont et al., 2009). The majority of the included studies were cross-sectional, and none of them was carried out within the Norwegian context. However, at present, this represents the best available knowledge, and the broad scope of the evidence cannot be ignored. In Norway, there seems to be a potential for promoting active travel among children and adolescents (Steene-Johannessen et al., 2019), and, importantly, almost 40% of parents in Norway think the route to school is unsafe for their children. This number has remained unchanged since 2005, and those living in low-density areas experience most traffic safety problems (Hjorthol and Nordbakke, 2015). As such, the built environment characteristics found to support active travel could have great health-promoting potential and the findings ought to inform emerging policies.

There were few evident findings and associations between the built environment and both unspecified PA and leisure-time PA in Papers II and III. This could partly be attributed to heterogeneity between studies with respect to methodology applied and how the built environment determinants are operationalized, as discussed earlier. Interestingly, some support for a positive association between the facility and amenity index and physical activity was identified in the systematic review. This means that neighborhood areas characterized by for example mixed land-use, connected streets with direct access for pedestrians and cyclists and a variety of facilities could support physical activity among children and adolescents. Examples of composite measures are the Neighborhood Destination Accessibility Index (Badland et al., 2015) and the Movability Index (Buck et al., 2015). As shown in Paper I, these composite indexes are inconsistently defined across studies. Accordingly, it is very challenging to give a clear interpretation of the results. Still, the finding could point to the significance of considering the sum of built resources. A positive feature is that the composite indexes account for several potential facilitators and barriers within the built environment, but there is a need to refine and further develop these operational definitions for the indexes to be widely applicable and commensurable. First, establishing consensus about which elements should be included in a composite measure is essential. Then, each of the elements should be operationalized in the same manner across studies. This needs further attention and exploration, especially since the indexes so far have been less applied compared to other GIS-derived measures of the built environment.

Within the Norwegian context, only neighborhood green space was positively related to leisure-time PA among the 8-year-olds (Paper III). These positive findings as well as the many non-significant results add to the body of ambiguous evidence reviewed in Paper II (Kowaleski-Jones et al., 2016; Magalhães et al., 2017; Markevych et al., 2014; Roemmich et al., 2006). In comparison to foregoing studies, the consideration of seasonality in the leisure-time PA measure adds strength to this research. Interestingly, access to a park was related to leisure-time PA during the summer whereas greater proportions of total green space (i.e. forests, marshland, golf courses and parks) were associated with more leisure-time PA in the winter. In view of affordance theory (Gibson, 1979; Kyttä, 2003), it is believable that parks act as an affordance for the usual summer activities, such as biking, ball games, roller-skating and skateboarding, while other green spaces might afford additional opportunities for winter activities, such as skiing and tobogganing. Bjørgen (2016) observed that green and open space afforded opportunities for and actualized activities such as skiing and tobogganing during winter, which contributed to greater PA among Norwegian children in kindergarten. While these are exciting discoveries, this thesis simply provides a tiny glimpse into how built environment characteristics might relate to children's participation in PA across seasons. As climate and weather depend on location and seasonality in Norway, further and more thorough investigation into these aspects is recommended.

The findings of Paper II show that associations between built characteristics, participation in other activities (i.e., outdoor play/activity or organized sports) and well-being were either mostly non-significant or highly inconsistent. As stated, methodological issues and challenges remain to be resolved. Thus, it would be premature to dismiss the potential of built environments to support participation in such activites, nor is it appropriate at present to make strong recommendations to inform policy about these outcomes. However, as found in Paper II, traffic and safety concerns seem to be important for outdoor play/activity, particularly among children. This indicates that built environment characteristics of importance for active travel and physical activity also have potential to support other activity outcomes, such as outdoor play, which has to be communicated to policy makers and planners. Additionally, this fast-growing body of research requires systematic reviews to be regularly updated, especially since the studies are very heterogeneous with respect to measurement approaches and operational definitions (Gebel et al., 2015; Shojania et al., 2007). Reconsolidating the evidence and disseminating the findings on a regular basis will be important in informing the scientific community as well as public health and planning policies about the present potential of built environment characteristics to promote health and well-being.

The inclusion of a united measure of organized activities and social activity with friends represents novel contributions to the evidence. The consideration of these leisure activities, and the related efforts of this thesis to provide knowledge about which built environment characteristics could support participation in such activities, signifies a more holistic approach to examining health-promoting environments stemming from an *occupational science perspective*. It was observed that living in neighborhoods with more playgrounds/sports fields and higher population density was associated with greater involvement in organized activities among the 8-year-olds. Although few studies have examined such relations, our findings stand in contrast to both Buck et al. (2011) and Galvez et al. (2013), who did not find any links between access to facilities and participation in organized sports among children. Research has shown that schools located in town centers, close to amenities and with a fairly equal radius to housing areas are likely to support active school travel (Kim and Lee, 2016). Among the Norwegian children, access to a school within the neighborhood was associated with participation in organized activities. One hypothetical reason is that schools in Norway represent central local community venues commonly used for many activities. Hence, considering school localization in relation to housing areas might be relevant for promoting various activities, and proximate facilities, including schools, were consistently related to active travel in Paper II.

The positive relations between facilities, higher population density and socialization with friends and peers were notable findings in Paper III. Interestingly, more densely populated areas and shorter distances to facilities were recently found to facilitate socialization among Norwegian adults (Mouratidis, 2018a). The health-promoting potential of these built characteristics seems favorable, especially since social activity with friends was the leisure activity most strongly related to fewer depressive moods and feelings among the 8-year-olds (Paper IV). A recent study revealed that children find their meaningful places for activities across multiple settings in both educational, commercial and recreational land-uses (Kyttä et al., 2018). Based on the thesis' holistic approach to children's participation in activities, the GIS-derived total facility measure included a wider range of facilities, such as libraries, churches, indoor pools, ice-skating arenas, cultural venues, community centers and shopping malls compared to the facility measures applied in prior studies (Paper I). The exception is Villanueva et al. (2012), who assessed associations between access to local destinations and children's independent mobility. Assuming that more facilities are linked to a greater mix of facilities, results from Paper III suggest that a variety of facilities could be essential to support socialization with friends. That a range of built environment resources could potentially facilitate children's spending time with their friend represents a valuable finding in this body of work that deserves additional in-depth investigation. Importantly, future studies should have a holistic perspective on what kind of facilities in the built environment can afford meaningful activities for children. Examining different facilities, and whether each facility can support engagement in a variety of activities, could yield valuable insight into how access to facilities can enhance well-being through participation in meaningful everyday activities.

What was most surprising was that although many of the built environment determinants were positively related to participation in leisure activities, which in turn exerted positive influences on children's moods and feelings, the overall association between the built environment and subjective well-being was negative (Paper IV). Specifically, the negative relations found between neighborhood green spaces and poorer moods and feelings were unexpected, since these resources are commonly considered beneficial for well-being (Hartig et al., 2014). However, unmeasured confounding and contextual differences could explain the negative associations observed in Paper IV. I speculate that the unmeasured characteristics of the built environment, such as traffic exposure, might provoke overwhelming experiences and unpredictable situations that trigger stress in young children.

This thesis' efforts to disentangle the relations observed between the built environment and children's moods and feelings signify an original input to existing knowledge on health-promoting environments for children. Through this work, it appears that built environment determinants are not in themselves positively associated with children's well-being. However, by acting as positive resources for leisure activities, they might contribute to providing participative and outbalanced experiences through the promotion of participation in leisure activities. Involvement in activities is shown to enhance the notion of *comprehensibility, manageability and meaningfulness* (Eriksson and Lindström, 2007; Lindström and Eriksson, 2005) and thereby serves to shape a *sense of coherence* and strengthen well-being (Honkinen et al., 2005; Løndal, 2010). The perception of having good neighborhood places to spend leisure and a safe living environment has been positively associated with a stronger *sense of coherence* (García-Moya et al., 2013). Thus, it appears essential to provide neighborhood built environment recourses relevant for children and adolescents. In this thesis, the children did not identify their use of resources nor how they benefit from them. These aspects, however, would be important to gain more knowledge about. Adopting the salutogenic framework and the concept of *sense of coherence* more thoroughly within this research area might offer additional insight into these perspectives because substantial knowledge gaps remain in clarifying such potential mechanisms.

A whole spectrum of determinants exert influence on health and well-being (Bentley, 2013; Helliwell et al., 2017; Viner et al., 2012; WHO, 1986). While I acknowledge this multidimensional influence, it would be beyond the scope of a PhD to account for them all. However, future research on the built environment determinants of well-being among children and adolescents would likely benefit from scrutinizing more complex models and relations and identifying the relative importance of the built environment. Taking into account aspects such as personality traits, community networks, social cohesion, traffic, fear of crime and neighborhood deprivation might provide a clearer picture, since these factors seem to represent important pieces in this very complex puzzle (Lucas and Diener, 2009; Sellström and Bremberg, 2006). Additionally, it cannot be unstated that the children studied in Papers III and IV were both healthy and happy in general. Relationships between built environment characteristics and well-being were marginal, and some estimates for associations with leisure activities were quite small in magnitude, as well. Age, sex and hereditary factors are posited to represent the core influences on health and well-being (Bentley, 2013). Besides these factors, parental income, employment and health, as well as schooling and an individual's own health status, are considered the strongest influences on well-being in childhood and adolescence (Helliwell et al., 2017; Viner et al., 2012). As such, larger estimates might not be expected from the built environment and participation in leisure activities. However, it is essential to bear in mind that the built environment interacts with other determinants through a dynamic interplay (Naidoo and Wills, 2009). Neighborhood environments that could add positive figures to the health and well-being equations by supporting participation in activities may increase the likelihood for a total sum of influences that promotes instead of threatens the health and well-being of our emerging generation.

6.3 Methodological considerations

An in-depth discussion of methodological issues related to this body of work is provided below. First, I will give a brief discussion of the research strategy and the theoretical assumptions that underpins this work. Then, I will elaborate on the methodological issues related to the systematic reviews and the cross-sectional studies. Finally, I offer some considerations about generalizability.

6.3.1 The overall research strategy and theoretical assumptions

Using a pragmatic multi-methodology research strategy was useful in addressing the overarching aim of this thesis, taking into account the nature of the research process and the available resources. The idea behind applying both systematic review designs and a cross-sectional epidemiological design was that the studies could complement each other in the sense that they all addressed an integrated part of a whole. The different methodologies and methods applied were suitable in addressing the group of research questions related to the specific objectives of this thesis. Additionally, the way the research process unfolded, from reviewing methodological issues and synthesizing existing evidence to the empirical studies within the Norwegian context, ensured informed decision-making along the way. Commencing the process with reviewing the literature also provided a better sense and overview of the topic. Linking GIS-derived exposures to substantial health survey data represents an original approach. However, the data-linkage design involved several issues (see Chapter 6.4.3) that need to be addressed in future research. However, despite these issues, the linking of existing health survey data and GIS-derived measures is a promising strategy with great potential owing to technological advancements.

The methodologies and methods were based on quantitatively driven approaches and represent adult-centric research on children and adolescents (Clavering and McLaughlin, 2010). The voices of the target groups are not visible in this work, although the review in Paper II included studies in which the environmental perceptions of children and adolescents were assessed. Adult-centric research herein limits an in-depth understanding of environmental experiences and perceived opportunities to engage in activities among Norwegian children. Moreover, this has implications for the overall theoretical assumptions of the thesis. Through an objective-list account perspective on well-being, I claim that supportive environments and participation in activities are essential for the well-being of children and adolescents even if children and adolescents do not agree or even want to be involved in activities. However, this does not necessarily mean that my assumptions are wrong (Crisp, 2017).

6.3.2 Trustworthiness and the risk of bias in the systematic reviews

Conducting a systematic review is regarded as an efficient way to identify focal studies to ascertain informed approaches to future research (Moher et al., 2015). Herein, the reviews contributed to an enhanced understanding of the methodological issues and empirical knowledge of the phenomenon under study. They also provided the grounds for the cross-sectional studies. Both reviews followed rigorous recommended methodologies, and the search strategies were comprehensive. This, and the exhaustiveness and transparency in the reporting, added to the trustworthiness of the syntheses. Further, the critical appraisal of the included studies contributed to ensuring that the findings of Paper II were credible and useful in informing future research, policy and practice (Aromataris and Munn, 2017). Despite these strengths, there were possible threats to the validity of the reviews.

First, only English language literature was included in both reviews. Based on the language skills of the authors, we could have reviewed studies written in Norwegian, Swedish and Danish. Not considering such studies may have introduced language bias. However, English seems to be the universal language of science in Scandinavian countries, and researchers often end up publishing in international peer-reviewed journals. Thus, the risk of bias due to restriction on language seems less likely. Additionally, Morrison et al. (2012) found no evidence of systematic bias from the use of English language restrictions in systematic reviews of health research. Second, publication bias potentially distorted the findings of Paper II. Investigators may have been inclined to report significant rather than null findings. Thus, studies with no associations could have been underrepresented, leading to a type I error in the results. Nevertheless, in recent years there has been an increased focus on publishing non-significant results. Further, by counting all positive and negative findings and non-significant results from the articles, we tried to minimize such bias in the analysis and synthesis of the review results. Additionally, not considering grey literature was a limitation of both reviews. The inclusion of grey literature could have broadened the scope to other relevant studies (Mahood et al., 2014). However, the focus remained on published evidence due to the wealth of literature on this topic. We could not stick to the recommendation of using two independent reviewers throughout the entire review process of Paper II due to time and resource constraints. Yet, we tried to reduce the risk of bias at all stages in the review process as detailed in Paper II. Specifically, we strived to provide a rigorous quality appraisal of the included studies. Lastly, the broad scope, in terms of age groups, outcome measurement methods and the merging of perceived and GIS-derived measures of the built environment characteristics, might have led to inconclusive results. This methodological heterogeneity and its consequences have been deliberated in preceding parts of the discussion. More confined syntheses could clarify some of these inconsistencies. On the other hand, a too narrow focus on specific groups, in particular activities or built environment determinants, might restrict our understanding from the holistic public health perspective that lies at the core of this thesis.

6.3.3 Reliability and validity of the cross-sectional studies

There were wide-ranging potential threats to the reliability and validity of the cross-sectional studies that have accumulated over an elongated period, from the recruitment to the cohort to the statistical analyses in Papers III and IV. To what extent are the estimates in the cross-sectional studies reliable? Is the study sample representative? Are the results valid? These questions will be assessed below. A brief discussion of the limitations of the cross-sectional design will be given before I consider whether the results could be due to chance (precision and random errors), bias (systematic errors and internal validity) or issues of confounding (Webb and Bain, 2011).

Limitations of the cross-sectional design

The cross-sectional epidemiological design has several drawbacks. It is not possible to infer any causal relations between the built environment determinants and the 8-year-olds' participation in activities or well-being. A common problem in cross-sectional studies is the likelihood of reverse causality. Herein, it is unlikely that children's engagement in leisure activities and their well-being result in built environment characteristics of a particular quality, especially since the determinants were objectively measured with GIS, eliminating the risk of single source bias and reverse causation. However, other potential causal pathways might be a problem. As such, whether the built environment causes increased participation in activities or whether children who are more involved in leisure activities live in certain neighborhoods remains unknown due to the cross-sectional nature of the data. It is less plausible that these young children's activity patterns exert great influences on where the family choose to live. Still, it is well known that the activity behaviors of parents influence children's activity levels, and the parental preferences of where to live could indicate reverse causality. This issue closely relates to the problem of selection into neighborhoods, which will be discussed as a source of bias in the coming pages.

Random error and precision – could the results be due to chance?

There are many people involved in the registration of geographic map data in municipalities across Norway. Based on the amount of geographic data downloaded and utilized in Papers III and IV, quality and accuracy problems leading to random errors in the exposure variables were expected. However, the Norwegian Mapping Authority has strict routines for quality control and clear guidelines for data registration, which minimize the extent of such errors. Further, the aim of the methods applied in this thesis were to reduce the influence of such random error or chance, which depend on the number of participants, the proportion of exposed and unexposed children and the occurrence of the outcome (Webb and Bain, 2011). The sample of participants in the cross-sectional studies was fairly large. Further, the distribution of children within the exposure and outcome categories was sufficient to compare the groups. As described in Chapter 4.3.5, the ensuring of comparable groups was considered when the thresholds for binary outcomes and mediators were decided. When comparing boys and girls, the sample size was reduced, with the smallest sample size for the access to park determinants (n =1 814) and the reference group for the social activity outcome (n = 1 684), both among girls. As such, the stratified odds ratios in Paper III may be less precise. However, in all analyses, 95% confidence intervals were used as measures of precision. These confidence intervals were quite narrow, which indicates high precision.

One can never know for sure whether the identified associations between built environment determinants and the outcomes of interest are true or by chance. The level of significance (α value) for each statistical test was set to 0.05. This indicated a 5% probability of detecting a spurious association and wrongly concluding that there was a relation between the variables of interest. The large set of tests in both Papers III and IV could indicate that more than 5% of the associations identified were caused by chance, particularly since the sample sizes were large. One way to solve this is to use a more conservative significance level, such as the Bonferroni correction. However, the Bonferroni correction is often considered very conservative, and making such adjustment increases the likelihood of type II errors (Perneger, 1998). Although power calculation was not performed, the large sample likely had enough power to detect a true association.

Systematic errors and internal validity

Selection bias

There are six major sources of possible selection bias in the cross-sectional studies. These relate to the recruitment of participants, loss to follow-up, geocoding, criteria for inclusion, residential self-selection and missing data. All these mechanisms for bias are relevant in this thesis and will be discussed in the pages that follows.

The MoBa sampling strategy consisted of inviting all pregnant women from across Norway who attended routine ultrasound examinations during week 17 of their pregnancy, except for those from two hospitals (one in Oslo and one in Tromsø) (Magnus et al., 2006). Although the sampling strategy was broad in scope, it is well known that those who agree to participate in epidemiological studies differ from those who refuse to participate (Galea and Tracy, 2007; Webb and Bain, 2011), producing a risk of selection bias. Analyses have revealed that young and less educated mothers living alone were underrepresented in MoBa compared to the rest of the population of pregnant women (Nilsen et al., 2009). Next, the response rate for the 8-year follow-up survey was 47% of the initial sample. As such, the findings of the cross-sectional studies are prone to attrition bias. Further, 13.6% of the participants in the data material could not be geocoded by Statistics Norway. Loss of participants attributable to geocoding were most pronounced for those followed up in 2011, indicating that tracking and identifying addresses back in time could be difficult because of, for example, changes in the property register. Additionally, excluding children with chronic or severe conditions, those living in post-separation families and those whose year of participation in the follow-up was unknown may have led to even more biased results. However, it was necessary to exclude children living in post-separation families and children with unknown year of participation in the follow-up to reduce the risk of measurement error and information bias (see further down in this section). Additionally, when comparing participants in MoBa with data on mothers in the Medical Birth Registry in Norway, Nilsen et al. (2009) identified bias in outcome prevalence but no bias in other outcome-exposure associations. If the same mechanism is valid for our exposure and outcome variables, selection bias due to the issues raised above may not be a serious problem in the studies presented in Papers III and IV.

Still, the cross-sectional design makes the findings prone to residential self-selection bias. Such bias stems from non-random selection of children into neighborhoods based on, for example, their parents' activity behaviors and related preferences for facilities in close vicinity to their residences (Boone-Heinonen et al., 2010b). The MoBa data did not allowed for the consideration of activity-related residential preferences. However, Næss (2009) examined relationships between residential location and travel patterns while accounting for travel-related residential preferences among Norwegian adults. Significant relations between residential location and travel existed regardless of travel-related residential preferences. Additionally, Næss (2009) raised an interesting thought regarding residential self-selection: if families select into neighborhoods that accommodate their preferences, it seems somewhat evident that the built environment matters. Accounting for this will be important in the future to clarify if relations persist regardless of preferences.

The levels of missing data for the exposure variables were minimal (only 136 children with missing values for population density), which is considered a strength in Papers III and IV. There were smaller numbers of missing data for the majority of the variables from MoBa (see Table 6 in this thesis as well as Tables 1 and 2 in Papers III and IV), which added up to a larger total when the variables were considered for statistical modelling. There is no established cut-off for acceptable levels of missing data for valid statistical inferences (Dong and Peng, 2013). It has been stated that statistical analyses are likely to be biased when more than 10% of the data are missing (Bennett, 2001). However, the types of mechanisms producing missing data could have greater impact on results than the proportion of missing data itself (Dong and Peng, 2013). Although the missing data mechanisms remain unknown, the comparison performed between included and excluded children, as referred to in the preceding paragraph, might indicate that the data were not randomly missing. Despite this, the analyses in Paper III were run on complete case data, as the proportion of missing subjects was 8.2%. A higher number of missing was observed in Paper IV. To account for some of the missing data, we imputed values for children with less than four missing items on the SMFQ following the procedure suggested by Angold et al. (1995). This resulted in a total proportion of missing data of 10.4% in Paper IV. Multiple imputation techniques were not included in this thesis.

Potential systematic measurement error and information bias

Information bias can arise from measurement errors in all the variables of interest. When dividing participants into discrete groups, there is always a risk of aligning them into the wrong groups (misclassification). If the probability of being misclassified is the same for all groups and subjects and does not depend on the outcome the misclassification is nondifferential. Such bias is more predictable and usually leads to attenuated estimates (i.e., toward null). Conversely, if the probability of being misclassified depends on the outcome, differential misclassification could occur, causing more unpredictable bias (Webb and Bain, 2011). There are sources of systematic measurement errors that may have led to information bias in the cross-sectional studies.

First, considering the data-linkage design, it was impossible to compute the children's actual exposure to the built environment or identify their movement patterns within a specific area. Accordingly, GIS-derived buffer zones around the geocoded residential addresses were used as proxies to capture the exposure areas. The use of GIS-derived buffer zones is a limitation of this work and represents a potential source of information bias. The problem related to applying such proxies is denoted the uncertain geographic context problem (discussed in Chapter 6.2). Despite current debates, the purpose of delineating a neighborhood and local community was to allow computation and aggregation of built environment determinants. The use of buffering techniques and ego-centered definitions seemed well established in research investigating health-promoting childhood environments, as identified in Paper I. Furthermore, Laatikainen et al. (2018) found that several spatial units could be appropriate for capturing exposures and associations, as well as the ego-centered units, and it is hard to argue about the accuracy of a particular unit of analysis. Still, it is obvious that the actual exposure areas remain unknown for the children in Papers III and IV. Nevertheless, the delineation of exposure areas in this body of work was guided by findings from Paper I as well as theoretical knowledge. In addition, we made several efforts to reduce the risk of error. Children living in post-separation families were excluded to increase the likelihood that a child lived at the specific geocoded address. In addition, we adjusted for after-school care to account for leisure time spent in other settings. Lastly, the exposure areas were delineated using identical procedures for all participants and do not depend on the outcomes, which suggests nondifferential misclassification.

Another major limitation of the cross-sectional studies is the temporality issues. Outcome data were obtained from children who turned 8-years old in 2011, 2012, 2013, 2014 and 2015, and the mothers responded to the questionnaires during these years. The exposure measures were based on geographic data and population statistics from 2016 and January 2017 for the address at which the children resided in 2011, 2012, 2013, 2014 and 2015. Historical map data were not available for all the data-sets and were not used. There was a gap in time from outcomes to exposures, and temporal sequencing could not be established. This issue also represented a potential source of exposure misclassification. Changes to the built environment may have occurred over these years, and the risk of error was higher for children participating in 2011 than for those questioned in 2015. We are aware that the built environment changes, but it is posited to do so slowly (Duncan et al., 2011). As such, vast infrastructural alterations, both in terms of green infrastructure and facilities, were less likely during these years. As the risk of environmental changes is smaller for the children followed up on in later years, we explored the estimates in separate analyses of children participating in 2014 and 2015. There were marginal changes to the ORs. Even though this issue seemed to minimally influence the estimates in the studies, accounting for temporality issues in the future will be important to strengthening the rigor of the research and our abilities to draw inferences that are more valid.

There are potential sources of bias for outcome measures and covariates as well. All the activity outcomes and covariates were based on parental reports. The mothers may have answered questions in a way that could be viewed more favorably by others, which increased the risk of social desirability bias. The extent to which the results are influenced by such bias remains unknown.

Issues of confounding

Confounding arises when an exogenous factor is associated with both the built environment exposure and the activity or well-being outcomes of interest. Not controlling for confounding in statistical analyses threatens the validity (Webb and Bain, 2011). The theoretical framework of DAGs guided which covariates we considered (Greenland et al., 1999). The intention was to adjust for relevant confounders and simultaneously avoid overadjustment, which can also lead to biased estimates (Schisterman et al., 2009). Although we identified and adjusted for what we considered to be the most important confounders (i.e., maternal age and level of education), other variables not included in MoBa could confound the associations observed. Additionally, area-level factors, such as traffic exposure and safety aspects, could have confounded the results. Hence, residual confounding represents a threat to the validity of the findings. In the analyses, we tried to account for urban/rural differences by adjusting for the GIS-derived population density measure. However, this was problematic in several models due to multicollinearity issues. This may have distorted the results.

The issue of residual confounding may have seriously influenced the mediation analyses in Paper IV. The estimation of direct and indirect relations required no unmeasured confounding on all paths (VanderWeele, 2015). This assumption was likely violated and may never be satisfied using an observational study design (Sheikh et al., 2016). Further, as mentioned in Chapter 4.3.6., the assumption of no mediator-outcome confounder being influenced by the exposure was likely violated because the built environment could influence the amount of screen-based activities (Christian et al., 2017). Sheikh et al. (2016) explored the consequences of such violations. They reported that the total and direct associations were overestimated, while the indirect relations were underestimated. Sensitivity analysis techniques should have been used to explore this in Paper IV, as well. However, based on what Sheikh et al. (2016) showed, the negative direct associations observed in Paper IV could have been smaller, whereas the indirect relations through the activity mediators might have been greater. Addressing the research objectives of Paper IV in other settings could clarify relations between built environment determinants and children's moods and feelings and help determine if participating in activities mediates such relations. Further, the significant direct associations could point to the possible existence of other mediators (Zhao et al., 2010). This should be pursued in future research.

6.3.4 Generalizability

Based on the scope of the existing evidence presented in Paper II, it is reasonable to assume that the characteristics found to promote active travel among children and adolescents are generalizable to other settings and countries, particularly within Northern Europe, North America and Australia, as a considerable amount of the studies originated from these areas. Although none of the studies was from Norway, I assume the findings are applicable to the Norwegian context, as discussed earlier, especially since traffic safety issues are major concerns among parents in Norway (Hjorthol and Nordbakke, 2015). Likewise, in other countries, concerns about traffic safety are common reasons why parents restrict children from using their neighborhood surroundings (Carver et al., 2010; Kyttä, 2004). It seems that a supportive environment for active travel comprises low traffic or more safety features, high walkability, well-established infrastructure for walking and cycling, and nearby facilities and that it does so in multiple settings. However, generalizing the findings to the entire group of young people must be done with care, as the review did not focus on exploring the age and sex dimensions in-depth. In regard to the GIS measures of the built environment determinants identified in Paper I, these measures can be used in different settings given that the geographic data needed are available.

The context of the cross-sectional studies, on the other hand, was Norway, representing one of the richest and most developed countries in the world, where the health and well-being of the younger population is good (Norwegian Institute of Public Health, 2018). Considering this, to what extent is it possible to generalize the findings from these two studies? Participation in leisure-time PA across seasons, organized activities as well as children's well-being and the relations between these outcomes and the built environment likely differ among populations. The particularities of the Norwegian context, some of which were presented in Chapter 2.7, must be carefully considered, including climate and related seasonal variations. Additionally, the study samples were quite selective, representing a group of more privileged children in Norway. Still, there are reasons to believe that the findings of Papers III and IV may apply to the Norwegian context and the group of younger children. Exceptions may be other ethnic minorities, as the ability to read Norwegian was required for participating in the cohort study. This indicates that children in other ethnic minority groups were underrepresented. As such, at first glance, the findings do not seem to be widely generalizable. However, when also considering the scope of research across the world revealing positive associations between the built environment and participation in activities (Christian et al., 2015; D'Haese et al., 2015b; Ding et al., 2011; McGrath et al., 2015) and the essentials of involvement in activities for the well-being of children and adolescents (Badura et al., 2015; Goswami, 2012; Janssen and LeBlanc, 2010), it is reasonable to assume that the findings could be applicable outside the country boarders.

7 Conclusion and implications

7.1 Contribution to knowledge

This body of work, embedded in a salutogenic perspective of public health and health promotion, has generated both systematically synthesized and empirical evidence representing an original contribution that broadens our understanding of health-promoting environments. The systematic reviews, alongside the empirical studies within the Norwegian context, address several research gaps and provide both confirmatory support and novel insights into the health-promoting potential of the built environment.

At the methodological level, the thesis contributes to ongoing discussions concerning how to operationalize the geographic areas of exposure and their built environment characteristics. This thesis adds greater informativeness regarding GIS-derived measures utilized in previous research by providing the first comprehensive and synthesized overview of operational definitions of the built environment determinants applied when studying participation in activities and well-being in childhood and adolescence. By discussing methodological facets of applying GIS measures to assess the built environment for research purposes, this research endeavor contributes to raising awareness among researchers and putting these methodological issues on the research agenda.

At the empirical level, the systematic review of the quantitative results assessed evidence from recently published studies (January 2010 to June 2018). The collation of evidence offers researchers an overview of studies conducted within the field, which facilitates the identification of the remaining knowledge gaps. This research work has provided an even more comprehensive outcome- and determinant-specific synthesis of findings than what already existed. Through the systematic review, gaps related to the scarcity of syntheses considering well-being outcomes and the absence of critical appraisals were addressed. The cross-sectional studies and their data-linkage designs represent an important approach for acquiring knowledge on relations between the built environment and children's leisure activities and well-being. Further, utilizing the counterfactual approach to examine mediation mechanisms represents a novel contribution to the evidence. Accordingly, this thesis has provided intriguing findings into the health-promoting potential of the built environment determinants of leisure-time PA across seasons, organized activities and social activity with friends among children. Further, this thesis delivers interesting insights into the potential pathways through which the built environment relates to children's well-being.

7.2 Implications for policy and practice

The findings of this thesis have some implications for policy and practice, which will be discussed in brief below. These implications can be summarized in five main points:

- A reinforcement of holistic and integrative approaches to public health and planning
- Closer collaboration between public health and planning professionals
- The discussion and establishment of GIS-derived measures to be monitored in public health and planning
- Improvement and specification of relevant policies
- Support for existing health-promoting efforts

First, the findings strengthen the argument for holistic and integrative approaches to public health and planning to address the key built environment determinants of health and well-being in childhood and adolescence, as emphasized in public health policy (Ministry of Health and Care Services, 2019). This requires reinforced efforts to ensure that the built environment determinants of health and well-being are carefully considered in planning processes. Essentially, policy makers and practitioners should grasp and utilize the results of this thesis as a whole, which can provide a broad overview of the evidence and encourage holistic thinking that extends beyond one public sector.

Based on the legislative anchoring of cross-sectoral public health work in Norway, closer collaboration and communication between public health and planning professionals are essential. The methodological findings of this thesis ought to be used to initiate discussions about making knowledge about public health and related issues more relevant and accessible for spatial planning. This would be important in ensuring the evidence-based planning of neighborhoods and local communities that can promote healthy, thriving and resilient children and adolescents. Moreover, integrating GIS-derived measures of the built environment and their relative importance to the design and planning of infrastructural changes may assist planners in developing health-promoting environments. According to the Public Health Act §5 (2012), Norwegian municipalities are obliged to have an overview of their inhabitants' health, including the positive and negative factors of influence. As such, a consensus on some key GIS-derived measures of the built environment to be monitored would be relevant in the future environment. However, this requires arenas for networking. How fruitful discussions among researchers, public health professionals and planners could be facilitated has yet to be discussed. However, it is hoped that the syntheses of evidence can promote better engagement between public health and planning professionals so that public health and related issues can be made more relevant and accessible for spatial planning.

Considering the results of the health-promoting potential of built environments, policies and planning practice emphasizing the role of low traffic exposure, more safety features, well-established infrastructure for walking and cycling, high walkability, proximate facilities, such as schools and playgrounds/sports fields, and access to green space would likely play a central role in promoting active travel and leisure activities in the younger population. Some of these aspects have been highlighted in the current public health policy (Ministry of Health and Care Services, 2019). Accordingly, the results of this thesis should add evidence-based strength to present policies, while its findings also ought to be used to specify which determinants are most relevant for children and adolescents. As the cross-sectional studies only provide some very initial insights and suggestions, additional research within the Norwegian context is needed to produce more rigorous evidence to inform policies and planning.

Lastly, the evidence-based knowledge provided herein offers support to existing efforts related to active travel and safety. Such an example is *Hjertesoner*, which attempts to establish zones or areas outside the school or along the route to school that are safe and suitable for children.

7.3 Moving forward – avenues for future research

The complexity of built environment determinants and their intertwined links to other factors that influences well-being and opportunities to take part in activities clearly demonstrates a need for more research, as underscored throughout the discussion. Moreover, this thesis raises new questions and additional issues to be answered by an evolving field. More research assessing the applicability and validity of GIS-derived measures is needed to unravel the methodological issues and limitations of quantifying the built environment. Further, consolidating the evidence regularly is important in providing researchers and policy makers with convenient overviews of the evidence. Due to the heterogeneities, highly inconsistent results and the limitations in the systematic review provided in this thesis, future reviews should distinguish between children and adolescents and provide stratified results for these age groups. Further, synthesizing objective and perceived environmental measure separately could add more insight. Moreover, a detailed systematic review of studies using GIS-derived measures that takes into account the multiple ways geographic areas of exposure are delineated could be relevant in examining whether the inconsistencies become less pronounced. This could also give a better sense of which specific spatial units capture different associations. Other researchers have mentioned some of these aspects, as well (McGrath et al., 2015; Smith et al., 2017). All future systematic reviews should follow recommended methodologies, and the undertaking of proper quality assessments is important in ensuring the usability of the review findings.

We have only begun to scratch the surface of intriguing questions concerning how the built environment alone, and through the interplay with other determinants, could be important for the well-being of children. The limitations of the cross-sectional data-linkage design suggest a need for more rigorous study designs, and longitudinal studies have been repeatedly requested (D'Haese et al., 2015b; Gascon et al., 2015; Smith et al., 2017; Tillmann et al., 2018). Future research should consider other individual demographic and psychological factors, such as residential preferences, in examining the relative importance of the built environment and trying to account for residential self-selection. For causal inferences, it would be important to distinguish whether it is the built environment that supports the activities of children or if it is just that certain families who appreciate active living tend to reside in neighborhoods with a greater variety of resources.

Applying holistic perspectives to meaningful activities and to the built environment that could support such activities is essential. Future studies could investigate how seasonal variations influence any relations between the built environment and the leisure activities of children and adolescents. Further, the promising results regarding the potential of the built environment in supporting socialization with friends deserve additional attention and in-depth investigations both within the Norwegian context as well as abroad. More knowledge of factors that enable children and adolescents to use the resource would be equally important to ensure they gain from them. Future studies investigating the built environment determinants of well-being would benefit from examining relations and models that are more complex, and this has to be considered when new studies are conceived. Continuing to scrutinize potential mediators and pathways through which built environment determinants influence children's well-being is vital to understanding potential mechanisms. Additionally, more refined methods to assess exposure in spatially context-sensitive manners, such as by defining activity spaces, are also necessary to overcoming the limitations of this body of work as well as earlier research on health-promoting environments. Lastly, careful consideration of GIS-derived measures is essential to ensure that the results could be more easily translated to planning practices.

7.4 Concluding remarks

The study of potential resources for health and well-being symbolizes the very core of this research endeavor. This thesis places the promotion of health and well-being in childhood and adolescence at the forefront of public health efforts and represents an original contribution towards ascertaining built environment resources for health and well-being within neighborhoods and local community settings. The prominent focus on and legislative anchoring of cross-sectoral public health work in Norway make this research inquiry relevant for a wide audience (Ministry of Health and Care Services, 2019). Although many methodological issues and research gaps remain, planning for public health cannot wait. Using the best available evidence at this very moment, the scope of the findings suggests that children and adolescents who live in neighborhoods with versatile built resources and activity venues likely engage more in leisure activities that in the long run may contribute to strengthening their health and well-being. I conclude that low traffic exposure, high walkability, more safety features, access to green space, well-established infrastructure for walking and cycling and proximate facilities, such as schools and playgrounds/sports fields, seem to represent focal aspects in planning health-promoting environments for children and adolescents. Accordingly, holistic approaches to public health and spatial planning within the settings of everyday life are essential. Different stakeholders, including policy makers, public health professionals and planners, who request evidence-based knowledge for emerging strategies can utilize the findings. These stakeholders should acknowledge multifaceted determinants and appreciate that a variety of resources for health and well-being could be found within our built environments.

Epilogue

With these words written,
a fulfilling and rewarding journey is about to end.
With my knapsack full of additional experience,
I look forward to new and exciting adventures with eagerness.
Hopefully,
these future adventures give me opportunities to explore further in our world,
which has the potential to promote health and well-being in the population because…

…"[h]ealthy citizens are the greatest asset any country can have."

(Winston Churchill)

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Errata

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Table 11. Errata list

Page	Line	Original text	Corrected text
xiii	10	A systematic seview of neighborhood built environment determinants.	A systematic review of neighborhood built environment determinants.
2	12	achieving high levels well-being in the population.	achieving high levels of well-being in the population.
8	Fig. 1	Presence of pleasant positive, positive emotions	Presence of pleasant, positive emotions
14	20	The physical environment include built attributes	The physical environment includes built attributes
23	16	(i.e. persons perceive,	(i.e., persons perceive,
25	12	(e.g. a neighborhood)	(e.g., a neighborhood)
30	29	were synthesized, the second objective	were synthesized, and the second objective
35	4	activities (e.g.	activities (e.g.,
49	Fig. 9	unkown (n = 432).	unknown (n = 432).
67	30	is necessary	is necessary.
73	19	an individuals'	an individual's
76	18	such as biking, ball games roller-skating	such as biking, ball games, roller-skating
87	10	was less likely during these years.	were less likely during these years.

Paper I

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Review Article

GIS-derived measures of the built environment determinants of mental health and activity participation in childhood and adolescence: A systematic review

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A R T I C L E I N F O

Keywords:
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A B S T R A C T

Studies increasingly use geographic information systems (GISs) to assess the impact of built environments on health in childhood. The extensive range of GIS measures and operational definitions of the built environment determinants, as well as definitions of the geographic areas of exposure, entail methodological challenges that need to be addressed. We aimed to identify, systematize and evaluate (1) operational definitions of GIS-derived built environment measures and (2) the geographic areas of exposure applied in studies examining the impact of built environments on mental health and activity participation among children and adolescents. A systematic literature review was conducted. We searched for peer-reviewed articles using Web of Science, PubMed, Medline, PsychINFO and SweMed+. The material was systematized using descriptive statistics and a synthesis approach. Numerous operational definitions were identified, which we grouped into the following categories of measures: population, built form, land-use, road/street environment, facility and amenity, neighborhood green and open space and composite measures. There was a large variability in the measures applied, and some studies lacked precise operational definitions. Most studies used ego-centered definitions, based on circular and/or network buffers with distances that ranged from 50 to 8050 m, to define the areas of exposure. This review elucidated that consistency in operational definitions is urgently needed. We suggest that the identified categories of measures represent an initial step towards establishing consensus about which determinants are important to measure. This could provide a basis for refining operational definitions, which eventually can ensure targeted use and consistency in measures applied across future studies.

1. Introduction

Children's heath and well-being are profoundly important for society, and are known to be related to multiple determinants at different levels (WHO, 1986). Moving beyond individual-based explanations, the built environment is suggested as an important determinant of influence (Sallis et al., 2006). Accordingly, increased interest in *how* local communities and neighborhoods may affect health and well-being has been evident within public health and epidemiological research (Diez Roux & Mair, 2010). Environmental determinants of public health are also given more attention in political agendas, which emphasize that concerns for people's health and well-being must be prioritized when creating healthier environments for sustainable development (UNICEF, 2004; WHO, 2014).

Investigating the impact of the built environment on health and well-being in childhood and adolescence raises questions about how to measure and operationalize the environmental determinants. For such purposes, geographic information systems (GISs) are a major advance (Diez Roux & Mair, 2010). However, using GIS is challenging as a multiplicity of measures and GIS-related operations, such as geocoding, buffering techniques, network analysis and cluster mapping, exist (Brownson, Hoehner, Day, Forsyth, & Sallis, 2009). To raise methodological awareness that can facilitate choices and computation of relevant GIS-derived measures, greater informativeness, systematization and evaluations of ways to operationalize the built environment determinants of health are needed. This study aims to address these issues.

1.1. Built environment determinants of health in childhood

A growing body of evidence has identified different characteristics of the built environment that promote active living, health and well-being among children and adolescents (Christian et al., 2015; Davison &

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Lawson, 2006; Ding, Sallis, Kerr, Lee, & Rosenberg, 2011). Structural features shown to promote an active lifestyle include mixed land-use, higher residential density and accessibility to versatile places, such as recreational and commercial areas (de Vries, Bakker, van Mechelen, & Hopman-Rock, 2007; Frank, Kerr, Chapman, & Sallis, 2007; van Loon, Frank, Nettlefold, & Naylor, 2014). A recent review concluded that safe neighborhoods, along with green space to be active, facilitated behaviors promoting child health and development. Furthermore, the presence of neighborhood facilities (e.g. recreation center) for children has been linked to their physical health, well-being and social competence (Christian et al., 2015). Kyttä, Broberg, and Kahila (2012) found that more densely built areas were associated with active travel to school and shorter distances to meaningful places for activities, whereas Broberg, Salminen, and Kyttä (2013) demonstrated that areas dominated by single-family housing promoted independent mobility and active transportation. Moreover, several road environment characteristics have been found to be associated with active living, such as higher intersection density (Frank et al., 2007; van Loon et al., 2014), traffic safety, and safe and diverse walking and cycling infrastructure (Carver, Timperio, Hesketh, & Crawford, 2010; de Vries et al., 2007; de Vries, Hopman-Rock, Bakker, Hirasing, & van Mechelen, 2010).

Neighborhood green space has also been found to influence health and well-being through different explanatory mechanisms (de Vries, 2010; Hartig, Mitchell, de Vries, & Frumkin, 2014; Lachowycz & Jones, 2013). In early childhood, more densely vegetated neighborhoods have been associated with increased playtime outdoors (Grigsby-Toussaint, Chi, Fiese, & Group, 2011). Larger proportions of neighborhood green space have been associated with higher levels of physical activity among older children and adolescents (Almanza, Jerrett, Dunton, Seto, & Pentz, 2012; de Vries et al., 2007). Access or proximity to green spaces, such as gardens and parks, and their relationship to physical activity has been widely investigated, and several studies have demonstrated positive associations (Boone-Heinonen, Popkin, Song, & Gordon-Larsen, 2010; Davison & Lawson, 2006; van Loon et al., 2014). In addition to physical activity and play, larger proportions of green space have been linked to better self-perceived health (Kyttä et al., 2012). Furthermore, emotional well-being has been positively associated with larger proportions of natural space among children and adolescents living in small towns compared to rural and metropolitan areas. However, the overall associations were weak and inconsistent (Huynh, Craig, Janssen, & Pickett, 2013).

1.2. Methodological issues and challenges with GIS-derived measures

The emergence of GIS has enabled public health researchers to quantify and analyze potential health-promoting determinants of the built environment (Diez Roux & Mair, 2010). Called one of the foremost scientific innovations (Butz & Torrey, 2006), GIS has the potential to increase our understanding of the importance of the built environment for health and well-being (Thornton, Pearce, & Kavanagh, 2011). Several definitions of what constitutes GIS exist in the literature (Burrough & McDonnell, 1998). From a user perspective, Burrough and McDonnell (1998) define GIS as "a collection of software modules for map systems, geographical data, procedures, and human knowledge and experience, which makes it possible to analyze and present the physical environment with digital technology". GIS methods have important applications to population-level studies assessing the impact of the built environment on health, due to the ability to provide objective environmental measures in studies involving individuals spread across large geographic areas (Brownson et al., 2009). However, the processes of producing, analyzing and presenting geographic data involve making conceptual and formal abstractions of the reality (Burrough & McDonnell, 1998), and before data acquisition and analyses, researchers encounter challenges in terms of defining and operationalizing determinants relevant for the target group and the health outcomes of interest. Furthermore, the geographic area of exposure has to be defined (Diez Roux, 2007). Analyses of the built environment are conducted at several scales (national, regional, community, city and neighborhood) whereas decision-making mainly occurs at a regional or local level (e.g., municipality) and is highly context dependent. Discrepancies between the scales of analysis and decision-making may result in difficulty integrating research findings into planning and decision-making. Concerning these matters, several important methodological issues and challenges remain (Diez Roux & Mair, 2010; Matthews, Moudon, & Daniel, 2009; Oakes, Masse, & Messer, 2009).

1.2.1. Operationalization of determinants

Although there is a broad theoretical consensus that the built environment influences health and well-being (Sallis et al., 2006), the issues of precisely defining and documenting GIS-derived measures have been given little attention in the literature (Forsyth, Schmitz, Oakes, Zimmerman, & Koepp, 2006). Each built environment determinant has to be clearly defined and operationalized to obtain high-quality measures, which can be replicated and assessed for reliability and validity (Forsyth et al., 2006). A comprehensive review, addressing GIS-derived built environment measures for physical activity, showed large variability and a lack of clarity about operational definitions (Brownson et al., 2009). Furthermore, the interdisciplinary nature of built environment research implies that not all measures are relevant for every target group or health outcome of interest (Forsyth et al., 2006). This demonstrates the importance of identifying and systematizing the measured determinants and their operational definitions. Additionally, an overview of the determinants typically measured in studies investigating the impact of the built environment on health in childhood and adolescence does not exist to our knowledge. Such an overview could be important to ensure that researchers who aim to use GIS-derived measures make informed choices.

1.2.2. Defining the geographic area of exposure

How to define the geographic areas of exposure, in which built environment measures will be computed, is another important question (Diez Roux & Mair, 2010; Kwan, 2012; Spielman & Yoo, 2009). We distinguish between territorial and ego-centered definitions. Territorial definitions imply using predefined spatial units or administrative areas, whereas ego-centered definitions consider the geographic context from the residence of each individual (Chaix, Merlo, Evans, Leal, & Havard, 2009). GIS can be utilized to integrate spatial data from diverse sources to compute measures of the built environment surrounding each home (Thornton et al., 2011) or other locations, such as schools (Oliver, Schuurman, & Hall, 2007), by geocoding addresses and using buffering techniques. Different buffer types and varying distances are applied in studies (Brownson et al., 2009), and selecting inappropriate buffer distances can cause severe bias in associations of interest (Spielman & Yoo, 2009). This lack of agreement and considerable uncertainty in defining the geographic areas of exposure make buffering difficult (Diez Roux & Mair, 2010), which has been acknowledged in several studies (Colabianchi et al., 2007; van Loon et al., 2014).

1.3. Objectives and delimitation

We aimed to identify, systematize and evaluate (1) operational definitions of GIS-derived built environment measures and (2) the geographic areas of exposure applied in previous studies, assessing the impact of the built environment on the mental health of and activity participation by children and adolescents.

The terms health and well-being are broad concepts, covering large aspects of life. We focus on mental health and include a holistic perspective of health, in which mental health is an integral part of the definition. Mental health is defined as encompassing mental illness and a positive state of well-being, where an individual is able to realize his or her abilities and attain the fullest potential of health (WHO, 2004). Furthermore, mental health and well-being are related to the competencies and experiences needed to promote health (Fauth & Thompson, 2009). Participation in meaningful activities, such as play and organized activities (Ginsburg et al., 2007; Wilcock & Hocking, 2015), in addition to children's and adolescents' independent ability to reach arenas for such activities (Kyttä, 2004; Schoeppe, Duncan, Badland, Oliver, & Browne, 2014), are important. For this reason, studies using GIS-derived measures of the built environment for studying participation in activities are highly relevant for the objectives of this study.

2. Methods

2.1. Search strategies

We conducted a systematic search of the literature for combinations of keywords related to the categories environment, GIS, activity, mental health and the target group of children and adolescents. A total of 67 keywords were included in the queries. The following strategies were used to find relevant search terms: (1) We screened papers and previously published review articles on the topic to identify free-text words and authors' keywords, (2) we searched electronic dictionaries to ensure that relevant synonyms were captured, (3) and we added keywords based on the researchers' experience and familiarity with the field. Fig. 1 shows the flow chart of the review process. Searches were carried out during October 2016, within the following databases: Web of Science, Medline, PubMed, PsychINFO and SweMed+. We systematized the search by combining all keywords (shown in Fig. 1) within each category with the logical operator OR. We then assembled keywords across the categories with AND. We executed two queries in each database. The first query involved the categories environment, GIS, target group and activity, whereas the second query consisted of keywords from the categories environment, GIS, target group and mental health.

2.2. Systematic review process

The combined search identified 1062 records. After we removed the duplicates, we ended up with 597 records. Based on the screening process listed below, we retrieved 71 full-text articles and assessed each for eligibility. Through the eligibility assessment, 30 additional articles were identified during the reading process, based on the references cited in the initial 71 articles retrieved. Criteria for inclusion were the following:

- Peer-reviewed original articles, written in English.
- Study population was children and/or adolescents aged between 0 and −18 years.
- At least one GIS-derived measure of the built environment as an independent variable.
- Activity and/or mental health as one of the outcomes.

We excluded articles that did not fulfill these criteria from the review. This resulted in 90 studies included in this review, which are numbered from 1 to 90 (Appendix A).

2.3. Data extraction

The processes of data extraction and analyses were driven by the data, as well as the objective of providing a useful overview for researchers and planners dealing with built environments for children and adolescents.

In Appendix A, we list information on the age, health outcomes, built environment determinants and geographic areas of exposure from each study. For consistency, we converted grades into age groups, for the studies that reported grades, and we named the health outcomes in generalized terms, such as physical activity or active travel. We used the term *active travel* to refer to active transport, active transportation, and walking, cycling and bicycling to and/or from destinations. More specific information was entered along with these generalized terms. We retained the wording of the built environment determinants applied in the individual studies to show the diversity of expressions. Finally, we sorted the geographic areas of exposure based on whether the definitions applied were ego-centered or not. This distinction was chosen primarily for practical reasons related to the space and length of the paper, as well as to ensure readability of the Appendix. We extracted information on buffer types and distances. All buffer distances were reported in the metric system.

2.4. Data analysis

We systematized and analyzed the built environment determinants, their operational definitions and the geographic areas of exposure. To begin, we entered all buffer distances, listed in the sixth column (Appendix A), into SPSS Statistics version 24. Descriptive statistical analyses were conducted to assess the frequency of the different buffer distances applied in studies with ego-centered definitions.

Further, we carried out a content analysis, based on the meta-synthesis approach (Murray & Stanley, 2015), of the built environment determinants and the operational definitions used in the individual papers. Unlike a standard meta-synthesis approach, which aims to appraise and bring together results from multiple qualitative studies (Jensen & Allen, 1996; Murray & Stanley, 2015), we aimed to synthesize the numerous built environment determinants and operational definitions. The analysis involved three stages, closely linked to what has been described by Murray and Stanley (2015). Stage I and stage II involved extracting data, reducing data and generating categories of built environment measures. Following this, an aggregated analysis of the findings and categories that evolved in stage I and stage II was carried out in stage III (Fig. 2).

In the first stage, we wrote down all different built environment determinants from the fifth column of Appendix A on separate pieces of colored paper. Next, we identified and extracted the operational definitions of each determinant from the included articles. All operational definitions were written in a separate document, together with their associated built environment determinant.

In the second stage, we organized the determinants that captured the same characteristics within the built environment into main categories. After we created preliminary themes, we sorted the operational definitions under each main category. Then, we reduced the data on operational definitions. This was carried out by (1) identifying the studies that applied the same definitions and (2) merging operational definitions that were equal except for the unit of measurement (e.g., hectare, acre or km^2) or the feature measured (e.g., intersections and cul-de-sacs). Finally, we sorted the operational definitions within each main category into subcategories, where we iteratively compared and contrasted categories until the research group reached agreement. This resulted in seven main categories and 18 subcategories of built environment determinant measures (Tables 1–7).

The main and subcategories, which evolved in stage II, enabled us to conduct an aggregated analysis in stage III. In this stage, we identified categories of measures that were most commonly applied, and in which ways studies combined measures from different categories. We also analyzed whether any particular buffer distances were applied for the different subcategories of measures and whether some of the main categories of measures were studied in relation to specific outcomes.

3. Results

Of the 90 articles included, most involved children and adolescents aged older than 10 years (Appendix A). About one third (n = 33) of the studies included children younger than 10 years of age. The most frequently studied outcome was participation in activities, such as physical activity and active travel to destinations, whereas only six studies

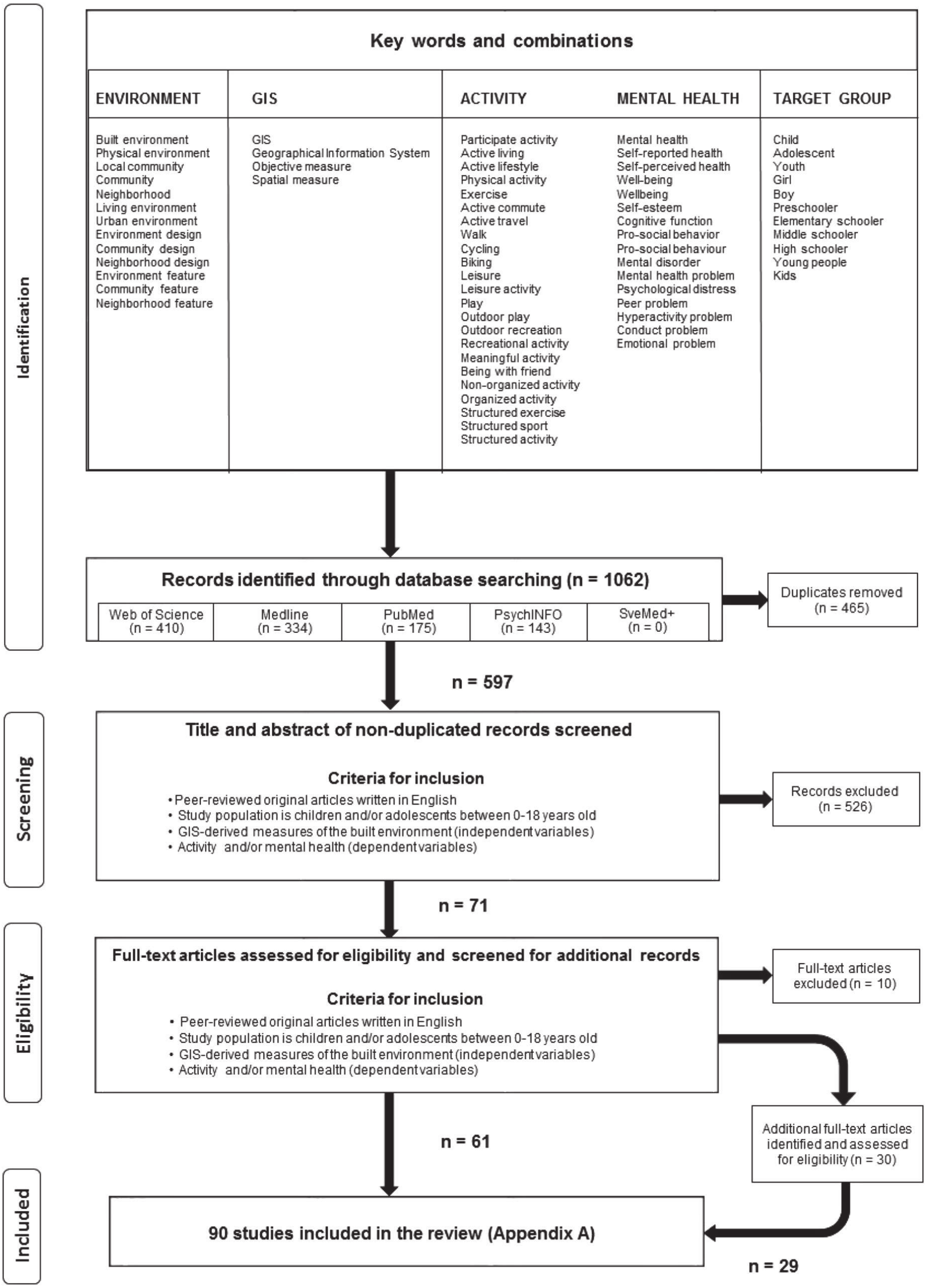

Fig. 1. Flow chart of the systematic review process.

examined mental health-related outcomes.

We identified seven main categories and 18 subcategories of measures. The main categories were population measures, built form measures, land-use measures, road/street environment measures, facility and amenity measures, neighborhood green and open space measures and composite measures. A multitude of operational definitions, with large variability in the unit and feature of measurement, was applied in the reviewed studies. Many operational definitions were not

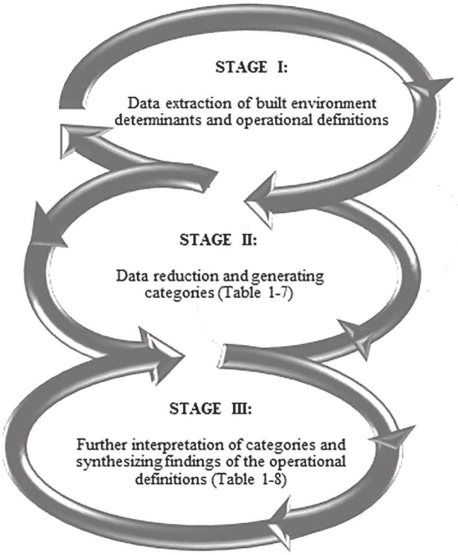

Fig. 2. A schematic representation of the content analysis process.

explicitly presented. All categories of built environment determinant measures and operational definitions are shown in Tables 1–7. Below, we present synthesized findings of the main categories.

3.1. Population measures

Population measures captured population density. These measures were the least frequently applied measures (n = 12). We identified five different operational definitions, which predominantly counted the number of residents or calculated the proportion of residents within defined areas. One operational definition targeted the proportion of children and adolescents within buffers around the home address[(46)].

3.2. Built form measures

Built form measures mainly captured the density of built features and encompassed operational definitions of residential density, total building density and the urban-rural status of the home address. In total, 25 studies used built form measures. Residential density measures were the most frequently applied (n = 19), and computing the number of residential units per unit of measurement within buffers was most common. This operational definition was applied in 14 out of 19 studies, but the unit of measurement (hectare, residential parcel, residential acre, km^2) varied among the studies.

3.3. Land-use measures

This category encompassed operational definitions of land-use or land-cover and land-use mix. Land-use measures were applied in 24 studies, of which 19 studies applied land-use mix measures. Studies operationalized land-use mix using the entropy index (n = 12), Herfindahl-Hirschman index (n = 5), or the dissimilarity index (n = 1), whereas one study lacked an operational definition[(48)]. The land-use types included in the indexes differed between the studies, and two studies did not report the land-use types included[(11, 55)].

3.4. Road/street environment measures

Road/street environment measures included operational definitions of road/street patterns and connectivity, traffic exposure and safety features and pedestrian infrastructure. This main category of measures consisted of numerous operational definitions and was among the most commonly applied (n = 48). Of the 44 studies that applied road/street patterns and connectivity measures, more than half (n = 24) computed the number of intersections divided by the unit or feature within buffer distances. The types of intersections included varied among the studies. Traffic exposure and safety-related measures captured the presence (yes/no) or length of specific road types, as well as the presence (yes/no) or number of safety-related features, such as speed bumps, slow points and traffic and/or pedestrian lights within buffers.

3.5. Facility and amenity measures

Operational definitions of facility and amenity measures captured the distance to, count or proportion of and topography connected to access to facilities and/or amenities. These measures were applied in 54 studies, and thus, were the most frequently used measures. Studies mainly applied operational definitions that measured the distance to (n = 34) and the number or proportion of facilities and/or amenities (n = 29). Operational definitions of distance were based on computing either a straight-line or street-, road- or pedestrian network distance, of which the network distance was the most frequently used measure

Table 1
Population measures with subcategories and operational definitions of the determinants.

	Subcategories with operational definitions	Unit, amount or feature	Buffer sizes
Population measures (n = 12)	**Population density**[5, 6, 7, 8, 9, 11, 32, 39, 46, 47, 56, 88]		
	(A) Number of residents within a square of 9 hectares around home[5, 6], within the buffer[7] or within the traffic analysis zone of the residence and school[56] (B) Number of residents ***per unit*** within the buffers[8, 11, 39, 88] or the school catchment area[9] (C) Number of residents at the postal code level divided by the postal code area[32] (D) Total area of residential land divided by the sum of residents within the buffers[47] (E) Proportion of 0- to 15-year-olds within the buffer[46]	(B) Square km[8, 9, 11] Square mile[39, 88]	100 m[6, 8] 200 m[5, 6] 400 m[39, 56] 500 m[6, 8, 46, 47] 800 m[32, 88] 1000 m[11] 1600 m[39, 47]

Table 2
Built form measures with subcategories and operational definitions of the determinants.

	Subcategories with operational definitions	Unit, amount or feature	Buffer sizes
Built form measures (n = 25)	**Residential density**[7, 8, 12, 13, 21, 29, 31, 42, 43, 45, 46, 47, 48†, 59, 61, 63, 77, 78, 79]		
	(A) Number of residences within the buffer[79] (B) Number of residential units[7, 8, 12, 13, 21, 29, 31, 42, 43, 45, 46, 61, 77, 78] or households[59] ***per unit*** within the buffers (C) Total area of residential land divided by the number of residential units within the buffer[47] or the number of residential units divided by the residential land area within the buffer[63]	(B) Hectare[7, 8, 46] Residential parcel[12, 13] Residential acre[29, 31, 42, 43, 45, 61, 77, 78] Unit land (excluding water)[21] Square km[59]	100 m[8] 200 m[48] 400 m[45, 48, 59] 500 m[8, 46, 47] 800 m[21, 29, 45, 48, 77, 78] 1000 m[12, 13, 31, 42, 43, 63] 1600 m[45, 47, 48, 61] 2000 m[79]
	Total building density[6, 7, 8, 12, 38, 45, 59, 61, 66]		
	(A) Number of buildings within a square of 25 hectare around the home[6] or within the buffer[7] (B) Summed building footprint area of the total buildings[38] or all buildings of a ***particular land-use***[38] within the buffer (C) Summed building footprint area of the total buildings[38] or all buildings of a ***particular land-use***[38] multiplied by the number of floor levels within the buffer (D) Gross floor area in all buildings divided by the buffer area[7, 8] (E) Total area of buildings divided by the buffer area[66] (F) Square footage of retail buildings divided by the square footage of retail land parcels within the buffers[12, 61] (G) Retail floor space divided by the retail lot size for each parcel of land[45] (H) Overall built area per built lots area within the buffer[59]	*Applies to definitions in* (B) *and* (C) Residential land-use[38] Commercial land-use[38] Institutional land-use[38] Mixed land-use[38] Under-construction land-use[38]	100 m[6, 8, 66] 150 m[38] 200 m[6] 400 m[45, 59,] 500 m[6, 8] 800 m[45, 66] 1000 m[12] 1600 m[45, 61]
	Urban-rural status of home address[65, 66, 67]		
	(A) Urban-rural classification of each home address based on the predominant settlement component of the census output area in which the home address is located, categorized as urban, town and fringe, and village, hamlet or isolated dwellings[65, 66, 67]		100 m[66, 67] 800 m[66, 67]

†Not defined or specified.

(n = 27). Which types of facilities/amenities were measured varied, but in general, the studies measured the distance to school and computed the number of physical activity/sport facilities within the buffers.

3.6. Neighborhood green and open space measures

Neighborhood green and open space measures included operational definitions that captured the distance to, count or proportion and type of green and open space, as well as structures surrounding parks. This main category of measures was the second most frequently applied (n = 49). Studies mainly used operational definitions of distance to (n = 14) and number or proportion of green and open spaces within the buffers (n = 42). A few studies measured the types of green and open spaces in detail[28, 37, 44, 47], whereas one study measured structures surrounding parks[28]. As for facility and amenity measures, the majority of the studies used the network distance when the distance to green and open spaces was computed (n = 9). Many different types of green and open spaces, such as parks, cemeteries, gardens and forests, were measured.

3.7. Composite measures

Composite measures combined measures and operational definitions from different categories to produce indexes. This category of measures was applied in 21 studies. We identified operational definitions as either walkability indexes (n = 16) or facility and amenity indexes (n = 8). Within both subcategories there were many operational definitions. Only four of 10 operational definitions within the walkability index category were applied in more than one study. All studies that applied facility and amenity index measures used different operational definitions.

Table 3
Land-use measures with subcategories and operational definitions of the determinants.

	Subcategories with operational definitions	Unit, amount or feature	Buffer sizes
Land-use measures (n = 24)	**Land-use or land-cover**[7, 8, 13, 29, 31, 41, 43, 48†, 77, 78]		
	(A) Presence of different *land-uses* within the buffers[31, 43] (B) Specific land-use[a] at different activity locations[41] (C) Number of retail and entertainment parcels[13] (D) *Amount* of specific *land-uses* within the buffers[31, 77, 78] (E) Proportion of *different land-uses/land-covers* within the buffers[7, 8] (F) Parcels of residential land divided by the number of parcels of land within the buffer[29]	(A) Commercial land-use[31, 43] Recreation/open space land-use[31, 43] (D) Acres of recreation/open space[31] Square feet of recreational area[77, 78] Square feet of residential land[78] (E) Single-family housing areas[7, 8] Semi-detached housing areas[7] Apartment building areas[7] Traffic areas[7] Public buildings[8]	100 m[8] 200 m[48] 400 m[48] 500 m[8] 800 m[29, 41, 48, 77, 78] 1000 m[13, 31, 43] 1600 m[48]
	Land-use mix[7, 8, 11, 12, 16, 20, 31, 42, 43, 45, 47, 48†, 55, 61, 64, 66, 67, 85, 88]		
	(A) Evenness distribution of the proportion of the estimated square footage/floor space of different *land-uses* within the buffers using the following formula, known as the entropy index[7, 8, 11, 12, 31, 42, 43, 45, 47, 55, 61, 85]: $[-\sum_u (p_u \times \ln p_u) \div \ln n]$, where *u* is the land-use classification, *p* is the proportion of land dedicated to a particular land-use, and *n* is the total number of land-use classifications. (B) Squared and summed proportion of different land-uses[b] within the buffer using the following formula, known as the Herfindahl-Hirschman index[16, 20, 66, 67, 88]: $\sum_{u=1}^{n} (p_u \times 100)^2$, where *u* is the land-use classification, *p* is the proportion of each type of land use within buffer or area, and *n* is the number of land-use types. (C) Dissimilarity index to measure the degree to which different land-uses exist[64]	(A) Residential, commercial, office and institutional land-use[7, 8, 31, 43] Residential, office, entertainment, retail and institutional land-use[42, 45, 61] Residential, agricultural, recreational, institutional, industrial and commercial land-use[47, 85] Residential, retail, food, entertainment and office land-use[12] Not specified[11, 55]	50 m[64] 100 m[8, 16, 66, 67] 200 m[48, 64] 400 m[45, 48, 64] 500 m[8, 47, 55] 800 m[16, 20, 29, 41, 45, 48, 55, 64, 66, 67, 77, 78, 88] 1000 m[11, 12, 31, 42, 43] 1600 m[45, 47, 48, 61, 64, 85] 2000 m[64]

†Not defined or specified.
aIncluding buildings, other built land-use, roads and pavements, gardens, parks, farmland, grassland, woodland and beaches.
bFarmland, woodland, grassland, uncultivated land, other urban, beach, marshland, sea, small settlement, private gardens, parks, residential, commercial, multiple-use buildings, other buildings, unclassified, buildings and roads.

3.8. Combination of measures and outcomes of the studies

The majority of the studies (n = 63) combined measures from two or several different main categories. None of the studies combined measures from all categories, but five studies measured determinants within six main categories(7, 8, 11, 45, 61). Nearly one third of the studies (n = 28) applied measures from one main category only. Population measures, built form measures, land-use measures and road/street environment measures were always combined with measures from one or several other categories.

An overview of the specific outcomes of the studies and the main categories of measures applied is presented in Table 8. All the main categories were studied in relation to active travel and physical activity. Studies with mental health-related outcomes applied population measures(46), built form measures(30, 46) and neighborhood green and open space measures(2, 30, 37, 44, 46, 50). Green and open space measures were applied to study the greatest number of outcomes in total.

3.9. The geographic areas of exposure

The majority of the studies (n = 72) used ego-centered boundaries as the sole way of defining the geographic areas of exposure. Other definitions, such as administrative areas, were applied in 13 studies, whereas five studies combined ego-centered and other definitions. In studies that applied ego-centered definitions, we identified the following geocoded locations as the centroids for the area of exposure: home address (n = 62), geographic center of the postal/ZIP codes for home or school (n = 5), school address (n = 14) or an individual's route/distance to school (n = 8).

The buffering techniques applied around these centroids varied. Out of 77 studies, 43 used circular buffer distances, 29 used network buffer distances and five studies used both buffer types. The network buffers were created along roads, streets or pedestrian zones. About one fourth of the studies (n = 22) defined the areas of exposure within two or more buffer distances, but using one specific distance was most common (n = 55). The distances ranged from 50 m to 8050 m. Descriptive statistics showed that the most frequent distance was 800 m, followed by 1600 m (Table 9). The mean buffer distance was 1156.1 m (SD = 1162.6). Larger distances (≥3000 m) were less typical. Distances ≥3000 m were used only in conjunction with circular buffers, in studies investigating built environment determinants of moderate-to-vigorous physical activity(3, 4, 54, 60) or emotional well-being(37).

The buffer distances applied for each subcategory of measures are shown in Tables 1–7. Structures surrounding parks were measured within a distance of 800 m only(28), whereas the urban-rural status of

Table 4
Road/street environment measures with subcategories and operational definitions of the determinants.

	Subcategories with operational definitions	Unit, amount or feature	Buffer sizes
Road/street environment measures (n = 48)	**Road/street patterns and connectivity measures**[4, 7, 8, 10, 11, 12, 13, 14, 15, 16, 20, 22, 29, 31, 32, 33, 36, 38, 39, 42, 43, 45, 47, 48†, 52, 54, 55, 56, 57, 59, 61, 63, 64, 66, 67, 69, 77, 78, 79, 80, 82, 84, 88, 90]		
	(A) Number of *road/street features* within the buffers[7, 14, 15, 22, 32, 38, 39, 56, 64, 79]	(A) Intersections[a 7, 14, 15, 22, 32, 38, 39, 56, 64, 79] Cul-de-sacs[22, 32] Street-blocks[56]	50 m[64] 100 m[8, 16, 66, 67] 150 m[38] 200 m[48, 64, 80] 250 m[57] 400 m[39, 45, 48, 56, 57, 59, 64] 500 m[8, 10, 47, 55] 750 m[10] 800 m[14, 15, 16, 20, 29, 32, 41, 45, 48, 55, 57, 64, 66, 67, 77, 78, 88, 90] 1000 m[4, 10, 11, 12, 13, 31, 42, 43, 57, 63] 1250 m[10] 1500 m[10] 1600 m[36, 39, 45, 47, 48, 52, 61, 64, 69, 85, 90] 2000 m[10, 22, 32, 64, 79, 84] 3000 m[4] 5000 m[4, 54] 8050 m[4]
	(B) Total length of access paths (over passes, access lanes and throughways between buildings)[22] or number of access points[36] within the buffers		
	(C) Overall street pattern (colony internal street, spontaneous or gridiron street pattern) within the defined buffer [38]		
	(D) Median block size within the buffer[52]		
	(E) Street width (excluding sidewalk width) within the buffer[78]		
	(F) Number of intersections[a] divided by the *unit/feature* within the buffers or block group[4, 8, 10, 11, 12, 13, 16, 29, 31, 42, 43, 45, 47, 54, 55, 59, 61, 63, 66, 67, 69, 77, 78, 80]	(F) Square km[4, 11, 12, 13, 31, 43, 47, 55, 59, 63] Acre[42, 45, 61] Land area[10, 54, 69] Buffer area[8, 16, 66, 67, 80] Length of street network in feet[29] Length of street network in mile[77, 78]	
	(G) Number of cul-de-sacs[12, 57, 80] or street-blocks[57] divided by the *unit/feature* within the buffers	(G) Square km[12, 57] Intersections[57] Total area[80]	
	(H) Number of ≥ 4-way intersections divided by all intersections within the buffers[8, 22, 57]		
	(I) Number of intersections divided by the total number of intersections and cul-de-sacs within the buffers denoted as the connected node ratio[16, 54, 66, 67]		
	(J) Mean intensity of intersections calculated with kernel intensity approaches using six different bandwidths within the buffers[10]		
	(K) Total road length divided by the *unit of measurement* denoted as road density[8, 16, 66, 67]	(K) Buffer area[8, 16, 66, 67] or route length[8]	
	(L) Pedestrian network area (e.g. 800 m street network buffer) divided by the maximum area within the Euclidean distance (e.g., 800 m circular buffer) denoted as an effective walkable area[16, 20, 33, 66, 67, 84]		
	(M) Street network route length divided by the straight-line distance[66, 67, 82] or the straight-line distance divided by the length of the street network route[80] denoted as the route directedness		
	(N) Number of street segments (links)[4] or the total length of street segments[54] divided by the number of intersections and cul-de-sacs (nodes) within the buffers denoted as the link:node ratio[4] or the block length[54]		
	(O) Combined scores of the intersection density, the average block length and the connected node ratio[54]		
	(P) The proportion of circuits or loops within a network relative to the maximum number of possible routes, given the number of intersections (α)[90] or the standardized and combined values of (α), (β) the ratio of intersections to street segments and (γ) the proportion of street segments relative to the maximum		

(*continued on next page*)

Table 4 (*continued*)

	possible given the number of intersections[88] (Q) Standardized and combined values of the average street length, the average area within a block and the average block perimeter denoted as the block size factor[88]		
	Traffic exposure and safety-related measures[5, 6, 8, 14, 15, 16, 20, 22, 27, 32, 33, 36, 48, 52, 57, 63, 64, 66, 67, 80, 82, 84]		
	(A) Residing on a road containing a cul-de-sac[14, 15, 20] (B) Presence of a major or minor road adjacent to the child's home[66] (C) Route[5, 8, 16, 27, 66, 67, 82] or buffer area[80] including or intersecting with a *road/street/track* (D) Number of *safety-related features* within the buffers[14, 15, 64] (E) Total length [5, 6, 14, 15, 22, 32, 64] or length per square km[8, 57] of *different roads/streets* within the buffer (F) Total length of *different road types* divided by the total road length within the buffers[8, 14, 15, 16, 66, 67] (G) Number of busy streets divided by the area (excluding water) within the buffer[52] (H) Total length of high-speed roads divided by the length of the low-speed roads within the buffer[63] (I) Total length of the *different road types* divided by the total length of the access roads within the buffer denoted as the vehicular traffic exposure[33] or the road traffic volume[84] (J) Number of streetlights divided by the road length[8, 66, 67] or the route[8, 16, 66, 67] within the buffers (K) Signalized intersections divided by the number of street intersections within the buffers[8, 57] (L) Proportion of busy streets[36] or low-speed-limit streets[48] within the buffers (M) Proportion of the route within an urban area[16, 66, 67]	(C) Motorway[5] Main street and/or side street[5] Major road[8, 27] Primary and/or secondary road[16, 66, 67] Freeway, highway or arterial road[82] Railroad track[8, 80] (D) Speed humps[14, 15] Gates/barriers on roads[14, 15] Slow-points, sections, narrowings[14, 15] Traffic and/or pedestrian lights[14, 15, 64] (E) Motorways[5] Main streets and/or side streets[5, 6] Small routes[6] Major roads[8, 57, 64] Local roads[14, 15, 22, 57] Busy roads[22, 32] (F) Primary roads[8, 16, 66, 67] Local roads[14, 15] (I) Primary-, district- and local distributors[33] All roads (excluding access roads)[84]	50 m[64] 100 m[6, 8, 16, 66, 67] 200 m[5, 6, 48, 64, 80] 250 m[57] 400 m[48, 57, 64] 500 m[6, 8] 800 m[14, 15, 16, 20, 32, 48, 57, 64, 66, 67] 1000 m[57, 63] 1600 m[36, 48, 52, 64] 2000 m[22, 33, 64, 84]
	Pedestrian infrastructure[8, 14, 15, 22, 32, 36, 47, 52, 55, 64, 66, 69, 70]		
	(A) Straight-line[36] or street network distance[52, 69] to the nearest bike/walking trail (B) Total length of walking/cycling tracks[14, 15, 22, 32] or sidewalks[47] within the buffers (C) Presence and width (m) of sidewalks and bicycle paths within the buffer[64] (D) Total square km of multi-use path space within the buffer[55] (E) Length of walk- or bikeways divided by the route length[8] (F) Area of pavement divided by the total road length within the buffer[66] (G) Land area of sidewalks and bicycle lanes divided by the total land area[70]		50 m[64] 100 m[8, 66] 200 m[64] 400 m[64] 500 m[8, 47, 55] 800 m[14, 15, 32, 55, 64, 66] 1500 m[70] 1600 m[36, 47, 52, 64, 69] 2000 m[22, 64]

[†]Not defined or specified.
[a](1) The number of all intersections[8, 10, 11, 12, 13, 14, 15, 16, 22, 29, 31, 32, 38, 39, 43, 54, 59, 61, 64, 66, 67, 69, 77, 78].
(2) The number of 3- and/or more-way intersections[4, 7, 42, 45, 63, 79].
(3) The number of 3- and 4-way intersections[47, 55, 80].
(4) The number of 3- and 4-way major road intersections and 4-way local road intersections[56].

home addresses were measured within 100 and 800 m distances[(66, 67)]. Otherwise, all remaining subcategories were measured within several buffer distances. Road/street patterns and connectivity measures, count or proportion of facilities and/or amenities and neighborhood green and open space, type of green and open space and facility and amenity indexes were measured within distances ≥3000 m.

4. Discussion

4.1. The measured determinants and their operational definitions

In this review, we identified seven main categories and 18 subcategories of measures that are used to assess the built environment.

Table 5
Facility and amenity measures with subcategories and operational definitions of the determinants.

	Subcategories with operational definitions	Unit, amount or feature	Buffer sizes
Facility and amenity measures (n = 54)	**Distance to facilities and/or amenities**[5, 7, 8, 12, 18, 20, 22, 27, 28, 33, 36, 45, 47, 48, 52, 53, 55, 56, 57, 58, 59, 62, 63, 65, 67, 69, 74, 80, 81, 82, 84, 87, 88, 90]		
	(A) Straight-line distance to *facilities/amenities* from home[5, 7, 8, 56, 81, 90] or from the traffic analysis zone of the residence and school[56] (B) Street, road or pedestrian network distance to *facilities/amenities* from home[12, 18, 20, 22, 27, 33, 36, 45, 47, 48, 52, 53, 55, 57, 59, 62, 63, 65, 67, 69, 74, 80, 82, 84, 87, 88] or from the park perimeter[28] (C) Shortest combined street network distance to the nearest public school, restaurant of any type, fast food restaurant, supermarket, and convenience store[58]	*Applies to definitions in (A) and (B)* School[5, 8, 12, 18, 20, 22, 33, 36, 47, 48, 52, 53, 55, 56, 57, 59, 62, 63, 65, 67, 69, 80, 82, 84, 88, 90] Public transportation stop[7] Store[59] or shop[87] Beach[27, 28, 45] Recreational facility[a] [7, 45, 48, 55] Recreation center[b] [36, 52, 69] Friends'/relatives' house[87] Gyms/fitness centers[36, 52, 69, 74] Sport venue[20] Tennis court[74] Indoor pool[74] Physical activity/sport facility[c] [81] Other visited places[d] [87] Central business district[56]	100 m[8, 67] 200 m[5, 48, 80] 250 m[57] 400 m[45, 48, 56, 57, 59] 500 m[8, 47, 55] 800 m[18, 20, 45, 48, 55, 57, 58, 67, 87, 88, 90] 1000 m[12, 42, 57, 63] 1600 m[36, 45, 47, 48, 52, 69, 81, 90] 2000 m[22, 33, 84, 87]
	Count or proportion of facilities and/or amenities[4, 7, 8, 10, 11, 22, 25, 32, 34, 35, 36, 39, 45, 51, 52, 61, 64, 68, 70, 71, 72, 73, 76, 79, 81, 85, 86, 87, 88]		
	(A) Number of *facilities/amenities* within the buffers[4, 7, 22, 25, 32, 35, 36, 39, 45, 61, 64, 68, 70, 71, 76, 79, 81, 85, 86, 87, 88] or within the block group[34] (B) Presence/absence of activity/sport facilities[c] and leisure facilities[e] within the buffers[51] (C) Number of *facilities/amenities* divided by the *unit of measurement* within the buffers[8, 10, 11, 36, 52, 72] or a ZIP code-defined neighborhood[73] (D) Standardized z-score of the number of playgrounds/km^2 within the buffer[11] (E) Density of police stations and neighborhood storefronts within the buffer[64] (F) Mean intensity of public transportation stops calculated with kernel intensity approaches using six different bandwidths within the buffers[10]	*Applies to definitions in (A) and (C)* Physical activity/sport facilities[c] [4, 22, 32, 34, 35, 51, 70, 71, 72, 73, 81, 86, 88] Public transportation stops[7, 8, 10, 11, 36, 39, 52] Playgrounds[11] Schools[f] [45, 61, 68, 87] Recreation centers[36, 76] Gyms/fitness centers[36] Gymnasiums[39] Private recreational facilities[45, 61, 76] Church[68] Church/synagogue/temple[87] Daily destinations[g] [79] Public recreational facilities[h] [85] Retail food outlets[52] Smaller food stores[i] [87] Supermarkets[87] Shopping centers[87] Fast food outlets[87] Retail shops[j] [87] Community service (library, post)[87] Commercial facilities[k] [25, 68] Recreation venues[l] [87] (C) Route length[8] Square km[11] Hectare[36] Area[8, 10, 73] Area (excluding water)[52]	50 m[64] 100 m[8, 67] 200 m[5, 48, 64, 80] 250 m[57] 400 m[39, 45, 48, 56, 57, 59, 64, 72] 500 m[8, 10, 47, 51, 55, 86] 750 m[10] 800 m[18, 20, 32, 35, 45, 48, 55, 57, 58, 64, 67, 72, 87, 88, 90] 1000 m[4, 10, 11, 12, 42, 51, 57, 63] 1200 m[68] 1250 m[10] 1500 m[10, 70] 1600 m[25, 36, 39, 45, 47, 48, 52, 61, 64, 69, 71, 73, 76, 81, 85, 90] 2000 m[10, 22, 64, 72, 79, 84, 87] 3000 m[4] 5000 m[4] 8050 m[4]
	Topography measures connected to accessibility of facilities and/or amenities[5, 82]		
	(A) Altitude difference between home and school in meters[5] (B) Presence of a steep incline (≥ 5.7 degrees, ≥ 10 % slope) along any segment of the route to school[82]		200 m[5]

(*continued on next page*)

Table 5 (*continued*)

[a](1) Recreational facility not specified[7, 48, 55].
(2) Private recreational facility not further specified[45].
(3) Recreational facilities including arenas, community centers, sports complexes/stadiums and swimming pools[60].
[b](1) Recreation center not specified[36, 52].
(2) Recreation center considered as either recreation center, community center or school[69].
[c](1) Physical activity/sport facilities not specified[4, 73].
(2) Physical activity/sport facilities defined as basketball, BMX riding, cricket, football, gymnastics, netball, swimming, skating, soccer, squash and tennis[22, 32].
(3) Physical activity/sport facilities defined as schools (elementary and secondary schools, colleges, universities), public facilities (public beach, pools, tennis courts, recreation centers), youth organizations (boy/girl scouts and youth centers), parks and recreation services, YMCA/YMWA, public fee facilities (physical fitness facilities, bicycle rental, public golf courses), instruction (dance studios, basketball instruction, marital arts), outdoor (sporting and recreational camps, swimming pools) and member (athletic club and gymnasiums, tennis clubs and basketball clubs)[34].
(4) Physical activity/sport facilities defined as paved off-road bicycle trails, gyms, parks (traditional open green space parks and skate parks), athletic fields (baseball diamonds and soccer fields) and the adolescents' school[35].
(5) Physical activity/sport facilities defined as swimming pools, sports complexes and stadiums[51]
(6) Physical activity/sport facilities defined as sport halls, skate parks, fitness centers, sporting grounds and swimming pools[70, 71].
(7) Physical activity/sport facilities defined as locations for basketball, tennis, cricket, football, soccer, netball, skateboarding and squash and locations of playing courts (indoor and outdoor), purpose-built BMX tracks, swimming pools, leisure centers, and gyms[72].
(8) Physical activity/sport facilities defined as basketball courts, golf course, martial art studio, playing field, running track, skating rink, swimming pool and dance/gymnastics clubs[81].
(9) Physical activity/sport facilities as sporting venues, recreational facilities and parks[86].
(10) Physical activity/sport facilities as basketball and golf courses, martial art studios, parks, tracks, swimming pool, walking/biking trails, dance studio[88].
[d] Other visited places defined as library, BMX skate park, bike track, recreation center, daycare, other schools, river, lake/creek, church, community hall, postbox, beach, clubhouse, youth group, graffiti alley, nursing home, caravan park, bush, bowling club, tennis court, golf course, cemetery or quarry[87].
[e] Leisure facilities defined as open air museums, open air theatres, recreation centers, amusement parks, safari parks, game reserves and zoos[51].
[f] (1) Public and private schools, charter and colleges included in the count of schools[68].
(2) Only government primary schools included in the count of schools[87].
[g] Daily destinations defined as retail, supermarkets, sports clubs, schools and educational institutions[79].
[h] Recreational facilities defined as soccer fields, baseball diamonds, basketball and tennis courts, community centers, arenas, pools, playgrounds and wading pools[87].
[i] Smaller food stores defined as bakery, ice cream store, candy store, delicatessen, mini mart and convenience store[87].
[j] Retail shops defined as CD/DVD/video/game, book shop, crafts/stationary, gift/novelties/souvenir, newsagents, pet shop, sport stores and toys/hobbies[87].
[k] (1) Commercial facilities defined as dance/gymnastics, martial arts, exercise/health clubs, swimming/diving, golf, youth organizations, bowling, stables, yoga and racquetball/tennis[25].
(2) Commercial facilities defined as individual-activity facilities (dance studios, diving, health clubs, martial arts, racquetball courts, rock climbing, sailing, SCUBA diving, self-defense instruction, skating rinks, sky-diving instruction, stables, tennis and yoga), team-activity facilities (atheletics organizations, baseball/softball clubs, basketball clubs, cheerleading, golf, gymnastics, hockey, paintball, soccer clubs and swimming pool), multipurpose-activity facilities (recreation centers, youth organizations and clubs)[68].
[l]Recreation venues defined as amusement centers, community halls/centers, recreation centers/indoor sports venues, dancing venues, martial arts venues, sports grounds, tennis courts, squash centers and tenpin bowling[87].

The range of categories reflects the many different aspects of the built environment needed when examining the impact of the built environment on the mental health of and activity participation by children and adolescents. This corresponds to findings from a previous review (Brownson et al., 2009). While Brownson et al. (2009) reviewed GIS-derived measures applied to study physical activity, and did not distinguish between studies conducted among children, adolescents and adults, the present review focused on measures applied to study mental health and activity participation in childhood and adolescence. Children often use the built environment within neighborhoods for activity purposes, such as free play, whereas the activities of adults are more utilitarian. Thus, children and adolescents have different needs, preferences and radius of movement than adults. The built environment determinants promoting health in adulthood do not necessarily promote mental health and participation in activities among children and adolescents. This undermines the importance of measuring the determinants that in significant ways accommodate health-promoting activities in childhood and adolescence (Oliver et al., 2016).

We identified that the most frequently applied measures were facility and amenity measures, neighborhood green and open spaces measures, and road/street environment measures. These main categories capture key built environment determinants that matter for mental health and activity participation in childhood (Christian et al., 2015). This suggests that these main categories of measures identified are relevant, and should continue to be applied in future studies. Nevertheless, the relationship between the built environment, mental health and activity participation is complex (Sallis et al., 2006), and the built environment, where children and adolescents spend their time, includes other potential determinants, such as built form and land-use (Ding et al., 2011). Although the remaining main categories of measures were applied less frequently, they are considered important for providing detailed findings that can improve planning of health-promoting childhood environments. The combined use of measures from several main categories could be important to assess the many-faceted impact of the built environment. The majority of the studies assessed in this review used measures from two or more main categories.

We identified a considerable inconsistency and a lack of clarity in the operational definitions. This is parallel to previous findings and discussions (Brownson et al., 2009; Forsyth et al., 2006). In many studies, definitions were not explicitly presented, and in one study,

Table 6
Neighborhood green and open space measures with subcategories and operational definitions of the determinants.

	Subcategories with operational definitions	Unit, amount or feature	Buffer sizes
Neighborhood green and open space measures (n = 49)	**Distance to green and open space**[2, 3, 20, 26, 27, 36, 45, 48, 50, 52, 59, 69, 83, 87]		
	(A) Non-specified distance to the nearest *green space/open space* from home[2, 3] (B) Straight-line distance to the nearest *green space/open space* from home[26, 36, 50] (C) Street, road or pedestrian network distance to the nearest *green space/open space* from home[20, 27, 45, 48, 52, 59, 69, 83, 87]	*Applies to definitions in (A), (B) and (C)* Park[2, 3, 26, 27, 45, 48, 52, 59, 69] Park/recreation space[36] Cemetary, garden, park or plant nursery[50] and forest[50] Green space/recreation site[20, 48] Public open space (excluding educational institutions and golf course)[83]	200 m[48] 300 m[2, 50] 400 m[45, 48, 59] 500 m[26, 50] 800 m[20, 45, 48, 83, 87] 1600 m[36, 45, 48, 52, 69] 2000 m[87] 3000 m[3]
	Count or proportion of green and open space[1, 2, 3, 6, 7, 8, 10, 11, 12, 20, 21, 22, 26, 28, 29, 30, 31, 32, 36, 37, 39, 40, 45, 46, 48, 50, 51, 55, 61, 64, 68, 70, 72, 73, 75, 77, 78, 79, 85, 87, 89, 90]		
	(A) Presence of *green space* within the buffers[50, 51] or at the activity location points[89] (B) Number of *green spaces/open spaces* within the buffers[22, 26, 31, 32, 39, 45, 48, 61, 68, 70, 72, 73, 75, 87, 90] (C) Number of *green spaces/open spaces* per km^2 within the buffers[11, 12, 55] (D) Size (m^2) of each park[28] (E) *Amount* of park area[26, 29, 45, 64, 77, 78] or green space[6] within the buffers[26, 29, 45, 64, 77, 78] or a square of 25 hectares around the home address[6] (F) Proportion of *green space/open space*[3, 7, 8, 20, 36, 37, 40, 46, 51] within the buffers (G) Number of *green spaces/open spaces* divided by the total land area within the buffer[10] or within a ZIP code-defined neighborhood[73] (H) Proportion of recreational area devoted to sports clubs and stadiums, parks, woodland, wetlands and churchyards within the buffer[79] (I) Total park area or park land within the buffers [30, 77, 78, 85] divided by the total land area[30, 85] or the total land of residential use[77, 78] (J) Total area of park and non-park recreation land (ft^2) divided by the total area of residential land use (ft^2) within the buffer[77, 78] (K) Protected and recreational open space in m^2/person within 800 m of the center of the grid cell[21] (L) Mean NDVI[d] within the defined buffer[2, 50, 51] or for different *features* within the buffer[1, 26, 28] (M) Mean intensity of *green space/open space* within the buffers calculated with kernel intensity approaches using six different bandwidths[10]	*Applies to definitions in (A), (B) and (C)* Parks[a 11, 12, 26, 39, 48, 55, 61, 68, 70, 72, 73, 75, 90] Freely accessible open space[22] Sport or recreation open space[22, 31, 32] Reserve/park open space[32] Parks and trails[45] Green space (excl. parks)[11] Green space (< 2 or > 2 acre)[87] Cemetary, garden, park, plant nursery (< 5000, ≥ 5000 m^2)[50] Forest[51] Parks and gardens[51] Not specified[89] (E) Hectare[6, 29] Acre[45] Square feet[77, 78] Square meter[64] (F) Recreational and undeveloped land[3] Park land and forests[7] Parks and recreation space[8, 36] Forests[8] Woodland or green space[20] Total natural space[b 37] Green space[c 37, 40] Fields, forests, parks, water[46] Tree cover (vegetation> 5 m)[51] *Applies to definitions in (G) and (M)*	50 m[64] 100 m[6, 8] 200 m[5, 6, 48, 64] 300 m[2, 50] 400 m[39, 45, 48, 64, 72] 500 m[1, 6, 8, 10, 26, 46, 50, 51, 55] 750 m[10] 800 m[20, 21, 29, 30, 32, 45, 48, 55, 64, 72, 77, 78, 87, 90] 1000 m[4, 10, 11, 12, 31, 40, 51] 1200 m[68] 1250 m[10] 1500 m[10, 70] 1600 m[36, 39, 45, 48, 61, 64, 73, 75, 76, 85, 90] 2000 m[10, 22, 64, 72, 79, 87] 3000 m[3] 5000 m[4, 37] 8050 m[4]

(*continued on next page*)

Table 6 (*continued*)

	Playgrounds, parks and green spaces[10] Parks[73] (L) All activity locations[1] All parks[26] Each park[28]	
Type of green and open space[28, 37, 44, 47]		
(A) Number of patches of trees/forests within the buffer[44] (B) Number of trees within 5 m of each road edge along the route to school[47] or within a park[28] (C) Total tree canopy area within a park[28] (D) Total tree canopy area divided by the park size[28] (E) Proportion of blue space (oceans, lakes, rivers and streams) within the buffer[37] (F) Summed area (m^2) of a patch type (trees/forests) divided by the total area (m^2) within the buffers[44] (G) Summed area (m^2) of a patch type (trees/forests) divided by the number of patches of trees/forests within the buffers denoted as the patch size[44] (H) Summed distances (m) from all patches of trees/forests to the nearest neighboring patch of trees/forests divided by the number of patches with trees/forests denoted as the nearest neighborhood distance[44] (I) [∑ (0.25 × perimeter of patch)/ √area in m^2 of same patch type] / total number of patches of the same land cover denoted as mean shape index[44] (J) [1 –∑perimeter of patches/∑(perimeter of patches × √area in m^2) of a patch]/[1- 1/√total landscape area in m^2]$^{-1}$ denoted as patch cohesion index [44]		400 m[44] 500 m[47] 800 m[44] 1600 m[47] 5000 m[37]
Structures surrounding park[28]		
(A) Park surrounded by a minor road[28] (B) Length of the park perimeter surveilled by facing residential lots per total perimeter of the park[28]		800m[28]

[a](1) Number of parks/km^2 was computed separately for parks without built recreational amenities, parks containing at least one sports field, parks containing at least one playground, and parks containing at least one sports field and playground[55].
(2) National parks, provincial and territorial parks, and municipal parks and sport fields[60].
[b]Total natural space defined as local parks and sport fields, provincial/territorial parks, national parks, other parks, wooded areas, campgrounds, picnic areas, golf courses, driving ranges, national wildlife and migratory areas, botanical gardens, and water bodies, such as oceans, lakes, rivers and streams[37].
[c](1) Green space defined as local parks and sport fields, provincial/territorial parks, national parks, other parks, wooded areas, campgrounds, picnic areas, and treed areas (a field vegetated primarily, > 50%, by trees and shrubs)[40].
(2) Green space defined as undeveloped and publicly accessible green space defined as meadows (a field vegetated primarily, > 50%, by grass and shrubs) golf courses, driving ranges, national wildlife and migratory areas and botanical gardens[37].
[d]The Normalized Difference Vegetation Index (NDVI) is calculated from the visible and near-infrared light (NIR) reflected by vegetation. Healthy vegetation absorbs most of the visible light (VIS) that hits it, and reflects a large proportion of the near infrared light. Unhealthy or sparse vegetation reflects more visible light and less near-infrared light. Written mathematically, the formula is NDVI = (NIR − VIS)/(NIR + VIS).

operational definitions were lacking[(48)]. Accordingly, several of the operational definitions presented in Tables 1–7 are inadequately described. The present findings elucidate that operational definitions need a larger degree of conformity, and that precise definitions of the determinants are still lacking in many studies, which have severe consequences in different fields of built environment research. First, interpreting the findings is difficult. Second, the possibilities for comparisons across studies are reduced. Last, opportunities to disseminate results to key individuals, such as planners, are potentially obstructed. As an example, the variation of components included in the operational definitions of walkability, as well as different weighting of the components, make findings from studies that assess the impact of walkability of such nature.

Despite the great diversity of measures identified, high-quality operational definitions are vital for accurate assessment of the determinants. Inaccurate and incomplete data represent threats to the GIS-derived measures and consistency in operational definitions. GIS data used within studies are processed from sources originally acquired for purposes such as assessing taxes, managing infrastructure investments and planning road maintenance, and not for assessing the impact of the built environment on health. Therefore, the data quality varies by country, region and even municipality, and this might explain why we identified numerous operational definitions (Brownson et al., 2009; Forsyth et al., 2006). Few studies have been conducted to validate the

Table 7
Composite measures with subcategories and operational definitions of the determinants.

	Subcategories with operational definitions	Unit, amount or feature	Buffer sizes
Composite measures (n = 21)	**Walkability indexes**[11, 13, 17, 23, 24, 33, 42, 45, 49, 52, 53, 61, 62, 69, 84, 87]		
	(A) ∑ [z(intersection density) + z(residential density) + z(land-use mix)] within the buffer[11]		400 m[45] 800 m[45, 87] 1000 m[11, 13, 42] 1600 m[45, 52, 61, 69] 2000 m[17, 33, 84, 87]
	(B) ∑ [2 × z(intersection density) + z(residential density) + z(land-use mix)] within buffers[23, 24]		
	(C) ∑ [z(intersection density) + z(residential density) + z(land-use mix) + z(public transit density)] within the buffer[11]		
	(D) ∑ [z(residential density) + z(intersection density) + z(employment density)] within the buffer[52, 69]		
	(E) ∑ [2 × z(intersection density) + z(residential density) + z(land-use mix) + z(retail floor area ratio)] within the buffer[13, 42, 45, 61] or neighborhood[t 62]		
	(F) ∑ [decile score(dwelling density) + decile score(street connectivity) + decile score(land use)] for each meshblock[49]		
	(G) ∑ [decile score(intersection density) + decile score(dwelling density) + decile score(land-use mix) + decile score(retail floor area ratio)] in a city[a 53]		
	(H) ∑ [z(effective walkable area) + z(vehicular traffic exposure) + z(residential density)][17]		
	(I) ∑ [decile score(effective walkable area) + decile score(vehicular traffic exposure)[32]/(road traffic volume)[84]] within the buffers[33, 84]		
	(J) ∑ [score†(effective walkable area) + score†(road volume exposure)] within the buffer[87]		
	Facility and amenity indexes[9, 11, 19, 49, 53, 60, 63, 79]		
	(A) Mean of the summed and weighted z-scores for street connectivity, destination density and level of urbanization within the school catchment area[9]		300 m[19] 800 m[19] 1000 m[11] 2000 m[79] 5000 m[63]
	(B) ∑ [z(number of playgrounds/km^2) + z(number of parks/km^2)] within the buffer[11]		
	(C) ∑ [z(number of playgrounds/km^2) + z(number of parks/km^2) + (number of green spaces/km^2)] within the buffer[11]		
	(D) ∑ [z(residential density) + z(recreational facilities) + z(daily destinations) + z(street connectivity)] within the buffer[79]		
	(E) ∑ [z(green areas) + z(road density) + (destination density)] within the buffers[19]		
	(F) Standardized and summed domain scores of different destinations within each meashblock[49]		
	(G) Combined ranked scores for the number of parks, educational, recreational and park trails, and recreational facilities within the buffer[60]		
	(H) Summed sub-domain scores of accessible green space (km^2), beaches (km^2) and number of sport facilities and within 800 m of the population weighted centroid denoted as the recreational amenity index derived from the recreational domain of the NDAI[53]		
	(I) Summed sub-domain scores for the presence of supermarkets, gas stations, bakeries, greengrocers, butchers, fishmongers, and convenience and fast food stores within 800 m of the population weighted centroid denoted as the food outlet index derived from the food retail domain of the NDAI[53]		
	(J) Weighted and summed intensity measures of 35 different destinations within nine domains within the buffer[63]		

[a]Walkability scores for each mesh-block were computed before the mean value of all mesh-block walkability scores within a neighborhood[62] or city[53].

data sources used to operationalize the built environment determinants (Matthews et al., 2009), and this issue will be important in the future.

Nearly all studies that measured distance to facilities/amenities or green and open spaces computed the distance along the street-, road-, or pedestrian network. Distances measured along roads, public transportation routes, pedestrian and/or cycling paths provide more precise measures of access compared to straight-line distances (Thornton et al., 2011). Therefore, network distances seem the most appropriate, and

Table 8
An overview of the outcomes of the studies and the main categories of measures applied.

Main categories	Outcomes of the studies
Population measures	Active travel[5, 7, 8, 9, 33, 46, 47, 56, 88] Physical activity[9, 11, 39] Play[6] Self-perceived health[46] Subjective health complaints[46]
Built form measures	Active travel[7, 8, 12, 13, 31, 42, 43, 46, 47, 59, 63, 65, 66, 67] Physical activity[21, 29, 45, 48, 61, 63, 77, 78, 79] Play[6] Outdoors activities[38] Self-perceived health[46] Subjective health complaints[46]
Land-use measures	Active travel[7, 8, 12, 13, 31, 42, 43, 47, 64, 66, 67, 88] Physical activity[11, 20, 29, 41, 45, 48, 55, 61, 64, 77, 78, 85] Independent mobility[16]
Road/street environment measures	Active travel[5, 7, 8, 12, 13, 14, 15, 31, 32, 33, 42, 43, 47, 56, 57, 59, 63, 64, 66, 67, 80, 82, 84, 88] Physical activity[4, 10, 11, 14, 15, 20, 22, 27, 29, 36, 39, 45, 48, 52, 54, 55, 61, 63, 64, 69, 70, 77, 78, 79, 90] Play[6] Outdoors activities[16] Independent mobility[38]
Facility and amenity measures	Active travel[5, 7, 8, 12, 32, 33, 47, 56, 57, 59, 62, 63, 64, 65, 67, 80, 82, 84, 88] Physical activity[4, 10, 11, 18, 20, 22, 25, 27, 34, 35, 36, 39, 45, 48, 51, 52, 53, 55, 58, 61, 63, 64, 68, 69, 70, 71, 72, 73, 74, 76, 79, 81, 85, 86, 90] Park use[28] Independent mobility[87]
Neighborhood green and open space measures	Active travel[7, 8, 12, 31, 32, 46, 47, 59, 64] Physical activity[1, 3, 10, 11, 20, 21, 22, 26, 27, 29, 36, 39, 40, 45, 48, 51, 52, 55, 61, 64, 68, 69, 70, 72, 73, 75, 77, 78, 79, 83, 85, 89, 90] Play[6] Park use[28] Independent mobility[87] Mental health problems[2] Health-related quality of life[44] Emotional well-being[37] Self-perceived health[46] Perceived stress[30] Behavioral problems[50] Subjective health complaints[46]
Composite measures	Active travel[9, 13, 17, 19, 33, 42, 62, 63, 84] Physical activity[9, 11, 19, 23, 24, 45, 49, 52, 53, 60, 61, 63, 69, 79] Independent mobility[87]

Table 9
Frequency of different buffer distances in studies with ego-centered definitions.

Buffer distances in meters	Frequency (n)
50	1
100	5
150	1
200	5
250	1
300	3
400	9
500	11
750	1
800	28
1000	12
1200	1
1250	1
1500	2
1600	17
2000	9
3000	2
5000	4
8050	1

accordingly, researchers and planners should endeavor to obtain network rather than straight-line distances when they map distances to specific destinations. However, network distances are more labor-intensive to compute and places greater demands on the data quality (Koppen, Sang, & Tveit, 2014). This implies that network distances may not be feasible if the GIS analyses are carried out for a large number of participants or for individuals spread across large geographical areas. Therefore, there is a need for high-performance computing (HPC) and better algorithms to reduce the computational burden of large datasets.

The types of facilities/amenities that were included in the operational definitions varied. Studies predominantly measured the distance to school or the number of physical activity/sport facilities. Only a few studies included other facilities/amenities, such as libraries and churches. This was expected as the outcomes of the studies mainly were active travel to school and physical activity. However, there has been a shift to addressing active living more broadly (Sallis et al., 2006), and the types of facilities/amenities that promote participation in other kinds of activities are more wide ranging than what we identified (Gallagher, Muldoon, & Pettigrew, 2015; Kyttä et al., 2012). If the operational definitions do not cover all facilities/amenities of interest, we are at risk of losing important information. Thus, consistency and agreement about which types of facilities/amenities to include in the operational definitions for assessing active living more broadly are needed. A recent report showed that the Norwegian authorities tend to fund facilities associated with organized physical activity and sports rather than unorganized activities (Thorén, Skjeggedal, & Vistad, 2016). Assessing a wider range of facilities/amenities, therefore, is important to provide policy makers with results that can secure informed priorities.

Although different types of green spaces, such as cemeteries and private gardens, were included in some operational definitions, the studies predominantly measured the distance to parks or the number of parks within buffers. Parallel to facility and amenity measures, there is a need to discuss and reach agreement about which types of green and open spaces should be included in the operational definitions. We identified few operational definitions that measured the qualities of green spaces. The exception was one study that examined whether the size of the parks and the total tree canopy area within the parks influenced park use for physical activity purposes(28). It is unlikely that the presence of green and open spaces in itself explains health benefits alone (Lee & Maheswaran, 2011). Among adults, access to and qualities of greenspaces are shown to influence use and levels of physical activity (Kaczynski et al., 2016; Owen, Humpel, Leslie, Bauman, & Sallis, 2004). Neighborhood parks are used for numerous purposes and the parks serve among other things as grounds for social and cultural interaction. In this regard, operational definitions measuring the qualities of green spaces could be important to use more extensively in studies among children and adolescents. The ParkIndex, developed by Kaczynski et al. (2016), has important elements of park quality that should be considered. These elements include park access amenities (i.e., adjacent sidewalk and public transit stop), count of park facilities (i.e., sports fields, trails and playgrounds), park amenities (i.e., lightening) and aesthetic features (i.e., meadow and water features). Other examples are park attractiveness, modeled as a function of the park size and the number of amenities within the park, and park accessibility for different modes of transportation (Dony, Delmelle, & Delmelle, 2015).

Operational definitions of walkability indexes and facility and amenity indexes, both representing composite measures, lacked consistency and were not explicitly presented. There is a need to refine and further develop several elements of these operational definitions for the index measures to be widely applicable and commensurable. First, there should be consistency in terms of which individual components are included (e.g., residential and intersection density) in the operational definitions. Furthermore, each individual component should be operationalized in the same manner. Regardless of these challenges, composite measures are useful. Built environment determinant measures correlate, and spatial multicollinearity can cause problems in statistical analysis. A way to avoid this problem is to use composite measures (Frank, Schmid, Sallis, Chapman, & Saelens, 2005).

Whether all the identified operational definitions are relevant for application in studies among children and adolescents remains to be studied and discussed. Initiatives to establish consensus about core measures, within the main and subcategories, to be applied in future studies, may be a pragmatic solution. The development of a standardized urban green space indicator for wide use for public health purposes among adults, as proposed by the World Health Organization, has been initiated by Annerstedt van den Bosch et al. (2016). Performing such work to refine measures and operational definitions applied among children and adolescents will be important in the future. In these processes, it is important to consider that the needs and preferences depend on the children's and adolescents' age. To ensure sufficiently specified and targeted measures, it could be relevant to develop and refine existing operational definitions separately for younger children and adolescents. This idea remains to be discussed.

Neighborhood green and open space measures were applied to study most outcomes. This is not surprising, considering the established explanatory mechanisms for how green space affects human health (Hartig et al., 2014; Lachowycz & Jones, 2013). Physical activity and active travel are widely studied, and all the main categories of measures were applied to study these outcomes. The opposite pertains to mental health-related outcomes. Therefore, we request more research that assesses the impact of a wider range of built environment determinants on mental health using GIS-derived measures. This is important to develop our understanding of the impact of built environment determinants on mental health in childhood and adolescence.

4.2. The geographic areas of exposure

We identified considerable variation in the buffering techniques applied to define the geographic areas of exposure. This is in accordance with a previous review (Brownson et al., 2009). However, we found some consistency in the definitions across the reviewed studies. Only a few studies used administrative areas or territorial definitions. It has been argued that such definitions are not suited to measure an individual's exposure to different built environment determinants (Chaix et al., 2009). Territorial definitions tend to represent the actual geographic areas used in an imprecise way. As an example, GIS-derived measures could produce biased estimates for study participants living at the edges of pre-defined spatial units (Oliver et al., 2007). We found that the majority of the studies used ego-centered definitions. Ego-centered definitions correspond better to the spatial areas used (Chaix et al., 2009). Thus, the use of buffering techniques around geocoded homes, schools or other individually defined centroids seems appropriate when investigating a child's exposure to different built environment determinants in his or her everyday life.

Regarding the buffer types used, we did not identify any consistency, but circular buffers were applied somewhat more frequently than network buffers. A discussion om whether to use circular or network buffers has been present in the literature (Chaix et al., 2009; Oliver et al., 2007). Due to the structure of the road or street network, all places within an area are not necessarily equally accessible (Chaix et al., 2009). Circular buffers are created independently of all built features, and may include areas with rivers, lakes, cliffs, large open spaces, buildings, railways and other barriers, which are not conducive for walking (Oliver et al., 2007). Network buffers, however, are typically created from roads, streets or pedestrian networks. This allows researchers to account for physical features and barriers, and a traversable area around the geographic centroid can be defined (Chaix et al., 2009; Oliver et al., 2007). Network buffers may be most relevant to apply when walking, and especially utilitarian walking (e.g., to and from school), and when other forms of active transportation are of interest. However, for outcomes such as physical activity, play and participation in other activities, this may not be the case. Areas considered less conducive for walking may provide several opportunities for activities. Potential areas for physical activity and play could include lakes, buildings and open spaces. In addition, constructing road network buffers is considerably more complex than circular buffers (Oliver et al., 2007). Accordingly, it may be more feasible to create circular buffers in many instances, as in studies where the computational burden of network buffers will be too high due to a large number of participants(3, 4, 37). It appears that both buffer types are applicable, but the choice should be considered in relation to the outcome of interest and with awareness of the limitations of the circular buffers.

There was substantial variation in the buffer distances applied across the reviewed studies. This corresponds to the lack of empirical findings for selecting appropriate buffer distances (Colabianchi et al., 2007). Nevertheless, we found distances of 800 and 1600 m were the most frequently used. Several arguments, underpinned by different theoretical assumptions, have been stated as reasons for selecting specific distances (Oliver et al., 2016), such as choosing distances that correspond to appropriate perceived walking distances (Colabianchi et al., 2007). There is a lack of evidence for perceived walking distances among children. However, Timperio, Crawford, Telford, and Salmon (2004) found that parental perceptions of appropriate walking distances for children were a round trip of 1500 m for 5- to 6-year-olds and 1600 m for 10- to 12-year-olds. This most likely explains why distances of 800 and 1600 m are most frequently applied.

About one fourth of the studies used two or more buffer distances, and some studies investigated the persistence of associations between the built environment determinants and physical activity for several buffer distances (Boone-Heinonen et al., 2010; van Loon et al., 2014). van Loon et al. (2014) found that built environment determinants measured within

1600 m buffer distances explained levels of physical activity better than smaller buffer distances. Boone-Heinonen et al. (2010) found the most consistent associations between physical activity and access to facilities within 3000 m distances, whereas intersection density yielded the strongest associations within 1000 m buffer distances.

Only a few of the reviewed studies used distances greater than or equal to 3000 m. Larger distances often represent driving distances (Colabianchi et al., 2007), and it is likely that this explains why few studies among children and adolescents applied distances greater than or equal to 3000 m. Interestingly, we identified that larger buffer distances were typically applied in studies that measured facilities/amenities, green spaces and road/street patterns and connectivity. Kyttä et al. (2012) found that children's meaningful places for activities during leisure time were clustered in the city center, whereas places for physical activity were located in the immediate surroundings of home. Moreover, western countries are car-oriented societies, which likely entails that children often are driven to places. This shows that facilities spread over larger geographic areas are relevant for participation in different activities rather than just facilities and features located in the immediate surroundings of home. This might also explain why larger buffer distances are applied in studies measuring facilities/amenities, green spaces and road/street patterns and connectivity.

Social-ecological theory also recognizes that societal, cultural and interpersonal factors influence children's and adolescents' behavior (Sallis et al., 2006), including their spatial behaviors. Negative parental perceptions of the neighborhood and restrictions on independent mobility influence children's range of movement within an area (Kyttä, 2004; Villanueva et al., 2012), and this could translate into smaller buffer distances. Parental activity behavior is another interpersonal factor of influence. As larger buffer distances probably cover the activity domains of parents, activities accomplished with parents or under parental supervision, could translate into larger buffer distances (van Loon et al., 2014). These factors, and our finding of inconsistency in buffering techniques applied across studies, clearly demonstrate the complexity of defining the geographic areas of exposure. Although, the selection of buffer distances is determined by the researcher, the advantage of GIS technology is that many plausible distances can be investigated at the same time (Thornton et al., 2011).

In the reviewed studies, the geographic areas of exposure were defined almost exclusively with buffers around residential locations or as pre-defined spatial units. However, children and adolescents engage in a multitude of activities that takes place outside these geographic areas (Villanueva et al., 2012). The concept of activity space is another way of defining the exposure areas. Assessing activity spaces requires other methods, such as personal diaries or a global positioning system, and the information obtained is incorporated into a GIS for further analysis. The geographic areas of exposure can be delineated based on where children and adolescents perform their daily activities. It has been stated that activity spaces reflect spatial behavior more precisely and may provide better estimates of exposure to the built environment determinants (Thornton et al., 2011). By assessing activity spaces we can capture the essential neighborhood areas that children and adolescents use (Loebach & Gilliland, 2014).

Although none of the reviewed studies determined the activity space of children and adolescents, a few studies measured actual use with GPS devices[(41, 89)]. These studies examined environmental characteristics of children's activity locations using GIS, and the studies demonstrated how different land-uses promoted physical activity. Spatial analyses of children's own perceptions, use and knowledge of the neighborhood, based on qualitative GIS approaches (Wridt, 2010) and SoftGIS methods (Kyttä et al., 2012), have revealed important information of how the built environment is used for activity purposes. Such approaches are important if we aim to study and create health-promoting environments for these target groups. In addition, we can use such knowledge to refine how we delineate the geographic areas of exposure so that they reflect the movement of children and adolescents in a study area.

4.3. Strengths and limitations

This review adds important knowledge through the systematization and evaluation of measures and operational definitions applied in previous studies. We aimed to conduct a comprehensive search in order to retrieve literature from different fields that apply GIS-derived measures considering the interdisciplinary nature of built environment research. However, we had limited access to databases, such as SCOPUS, and only studies written in English were included. In addition, the search strategy did not included MeSH terms, which could allow greater variety in specific keywords. Important keywords may also have been omitted. Although we selected keywords systematically, it is not inevitable that this process might be subject to personal bias. Nevertheless, based on the number of studies reviewed, we believe that we managed to identify a sufficient large share of existing studies, and thus, addressed the aims in thoroughly. Restricting the studies to children and adolescents only is considered a strength, due to the importance of developing specified and targeted measures that capture essential built environment determinants of health among these age groups. However, we did not distinguish between operational definitions applied in children and adolescents. This could be considered a weakness due to differences in use and needs across these age groups.

Although we ended up with seven main and 18 subcategories of measures, the categories identified are not mutually exclusive. Some operational definitions could have been classified into more than one category. It could be argued that operational definitions involving count or proportion of parks are measures of facilities/amenities. Moreover, we classified total road length, specifically denoted as road density, as road/street pattern and connectivity measures, whereas the total length of specific road types was classified as traffic exposure and safety-related measures. Both measures fit into the same categories. However, road function is used as a proxy for traffic volume (Giles-Corti et al., 2011), and therefore, we distinguished between the total road length and the length of different road types. Given the extensive formulas and GIS procedures for computing the built environment determinants, we had to set a limit on the level of detail in the operational definitions presented in Tables 1–7. Yet, we tried to provide sufficient information, so the overview can be used as an informative guide.

4.4. Implications for research and practice

This review elucidated that consistency in operational definitions is urgently needed. Although we showed several methodological issues and challenges remain, GIS is an important complementary and innovative methodological approach that can improve our understanding of the built environment determinants of health in childhood and adolescence, and lay the foundation for closer collaboration between researchers and planning practitioners. The presence of land-uses or access to facilities does not necessarily mirror actual use or entail a health impact. Thus, it is essential to combine GIS-derived measures with other types of data, such as actual use or health outcomes, to understand the impact of the built environment on health. This implies that close collaboration between researchers and planners is important for creating healthier environments for sustainable development. There are different conceptual and theoretical frameworks for thinking about child/adolescent health and development that may also relate to the understanding of the built environment. However, the scope of this review did not allow for discussion of conceptual or theoretical perspectives. To improve research in this area, we suggest that future investigations should address whether and how studies apply theoretical or conceptual frameworks to guide the choice of measures and operational definitions. This can provide essential knowledge for further conceptual work with categories and for refining and developing existing GIS measures of the built environment determinants. For improvements in studies and interpretation of findings, it is crucial that operational definitions are reported in reliable and transparent ways.

The selection of buffer types and distances needs to be based on the theoretical understanding and assumptions of the processes that link the built environment to health and well-being in childhood and adolescence.

5. Conclusion

This review contributes to ongoing methodological discussions of applying GIS-derived measures for investigating the impact of the built environment on health and well-being in childhood and adolescence, as well as using GIS as a tool in urban planning. We categorized and evaluated operational definitions of the built environment determinants and the geographic areas of exposure applied in previous studies among children and adolescents. Altogether, we identified seven main categories and 18 subcategories of measures, including numerous operational definitions of determinants, hypothesized to influence mental health and activity participation in childhood. The majority of the studies applied ego-centered definitions, and there was a considerable variation in the buffer types and buffer distances used to delimit the geographical areas of exposure. Findings from this review could be informative and helpful in research design and review processes, as well as in urban planning and community development processes. We suggest that the identified main categories of measures represent an initial step towards establishing consensus about which determinants are important to measure in built environment research and urban planning. This information could provide a basis for refining and further developing existing operational definitions, which eventually can ensure targeted use and consistency in measures applied across future studies and lead to joint operational definitions applied across research and practice.

Conflicts of interest

The authors declare that they have no conflicts of interest.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.landurbplan.2018.04.009.

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Appendix A. *Characteristics of the reviewed studies*

No.	Author (year)	Age group(s)	Health outcome(s)	Built environment determinants	Geographic areas of exposure: Ego-centered definitions – Distance	Ego-centered definitions – Type	Other definition
1	Almanza et al. (2012)	8-10 years 11-14 years	**Physical activity** *- Daily, total activity* *- Daily, moderate-to-vigorous*	• Neighborhood greenness	500 m	Circular *- Around home address*	
2	Balseviciene et al. (2014)	4-6 years	**Mental health problems**	• Proximity to city parks • Residential greenness	300 m	Circular *- Around home address*	
3	Boone-Heinonen et al. (2010a)	11-21 years[a]	**Physical activity** *- Weekly, moderate-to- vigorous* *- Wheel-based activity, active sport and exercise*	• Proportion of green space • Distance to neighborhood park (<200 ac) • Distance to major park ($\geq$ 200 ac)	3000 m	Circular *- Around home address*	
4	Boone-Heinonen et al. (2010b)	11-22 years[a]	**Physical activity** *- Weekly, moderate-to-vigorous* *- Wheel-based activity, active sport and exercise*	• Physical activity facilities • Intersection density • Link:node ratio	1000 m 3000 m 5000 m 8050 m	Circular *- Around home address*	
5	Bringolf-Isler et al. (2008)	6-7 years 9-10 years 13-14 years	**Active travel** *- To school* *- Walking, bicycling/kick scooter and inline skates*	• Distance to school • Intersecting motorway, main or side street on route • Length of street segments along route to school • Altitude difference between home and school • Population density	200 m	Circular *- Around straight-line distance to school*	
6	Bringolf-Isler et al. (2010)	6-7 years 9-10 years 13-14 years	**Play** *- Daily, vigorously, outdoor*	• Total length of main and side streets, and small routes • Population density • Building density • Proportion of green space	100 m 200 m 500 m	Circular *- Around home address*	
7	Broberg et al. (2013)	11 years 14 years	**Active travel** *- To meaningful places* *- Walking or bicycling*	• Land-use mix and other land use variables • Population size • Housing density • Building density and floor area ratio • Intersections • Distance to and number of transportation stops • Distance to recreational facilities			50 meter circular buffer around each reported meaningful place

8	Broberg and Sarjala (2015)	11 years 14 years	**Active travel** *- To school* *- Walking or bicycling*	• Distance to school • Streetlight density and signalized intersections • Road density and length of primary and major roads • Intersecting major roads or railroad on school journey • Building density, public buildings and land-use mix • 4-way intersections and intersection density • Density of public transport stops • Proportion of green spaces • Length of walk- or bikeways • Population density • Housing density • Proportion of single-family housing	100 m 500 m	Circular *- Around route to school* Circular *- Around home address*	
9	Buck et al. (2011)	6-10 years	**Active travel** *- To school* *- Walking and bicycling* **Physical activity** *- Daily, outdoor and leisure*	• Moveability index			School catchment area
10	Buck et al. (2015a)	2-9 years	**Physical activity** *- Daily, moderate-to-vigorous*	• Intensity of intersections • Intensity of public transportation stations • Intensity of public open spaces	500 m 750 m 1000 m 1250 m 1500 m 2000 m	Street network *- Around home address*	
11	Buck et al. (2015b)	2-9 years	**Physical activity** *- Daily, moderate-to-vigorous*	• Residential density[d] • Land-use mix • Intersection density • Public transportation station density • Density of playgrounds, parks and green spaces • Walkability index • Moveability index	1000 m	Street network *- Around home address*	
12	Carlson et al. (2014)	12-16 years	**Active travel** *- Weekly, to/from school* *- Walking, bicycling or skateboarding*	• Distance to school • Residential density • Street connectivity • Retail floor area ratio • Land-use mix • Cul-de-sac density • Number of parks	1000 m	Street network *- Around home address* *- Around school address*	
13	Carlson et al. (2015)	12-16 years	**Active travel** *- Daily* *- Walking and bicycling*	• Residential density • Intersection density • Number of retail parcels • Number of entertainment parcels • Walkability index	1000 m	Street network *- Around home address*	

14	Carver et al. (2008)	8-9 years 13-15 years	**Physical activity** *- Moderate-to-vigorous* *- Non-school hours on weekdays and weekend days* **Active travel** *- Weekly, to specific destinations* *- Walking and bicycling*	• Length of local roads • Local road index • Intersection density • Length of walking tracks • Speed bumps, gates/barriers and slow-points • Traffic and/or pedestrian lights • Residing on a cul-de-sac	800 m	Circular *- Around home address*
15	Carver et al. (2010)	8-9 years 13-15 years	**Physical activity** *- Two-year change* *- Daily, moderate-to-vigorous* **Active travel** *- Two-year change* *- Weekly, to specific destinations* *- Walking and bicycling*	• Length of local roads • Local road index • Intersection density • Length of walking tracks • Speed bumps, gates/barriers and slow-points • Traffic and/or pedestrian lights • Residing on a cul-de-sac	800 m	Circular *- Around home address*
16	Carver et al. (2014)	9-10 years	**Independent mobility** *- To school* *- Walking and bicycling*	• Neighborhood characteristics: road density, proportion of primary roads, effective walkable area, connected node ratio, junction density and land-use mix • Route characteristics: streetlight density, main road on route and proportion of route within an urban area	100 m 800 m	Pedestrian network *- Around route to school* Pedestrian network *- Around home address*
17	Christiansen et al. (2014)	11-13 years	**Active travel** *- To and from school* *- Walking, bicycling, roller-skates or skateboard*	• School walkability index	2000 m	Circular Pedestrian network *- Around school address*
18	Cohen et al. (2006)	11-12 years[b]	**Physical activity** *- Weekly, moderate-to-vigorous*	• Distance to school	800 m[f]	Circular *- Around home address*
19	Coombes et al. (2014)	10-11 years	**Physical activity** *- Change after transitioning from primary to secondary school* *- Weekdays* **Active travel** *- Change after transitioning from primary to secondary school* *- To school*	• Environmental supportiveness index	800 m 300 m 800 m	Road network *- Around home address* Road network *- Around school address* *- Around route to school*
20	Corder et al. (2013)	9-10 years	**Physical activity** *- One-year change* *- Daily, on weekdays and weekends, moderate-to-vigorous*	• Living in a cul-de-sac • Effective walkable area • Land-use mix • Proportion of woodland/green space • Distance to green space, sport venue and school	800 m	Road network *- Around home address*

21	Cradock et al. (2009)	13.7 years	**Physical activity** *- Weekend, moderate-to-vigorous*	• Housing density • Density of open space	800 m	Street network *- Around school address*	
22	Crawford et al. (2010)	10-12 years	**Physical activity** *- Daily, moderate-to-vigorous*	• Distance to school • Freely available public open space • Sport and recreation public open space • Sport facilities • Road connectivity • Length of busy and local roads	2000 m	Circular *- Around home address*	
23	De Meester et al. (2012)	13-15 years	**Physical activity** *- Daily, moderate-to-vigorous* *- Walking, bicycling and sports participation*	• Walkability index			1-5 contiguous statistical sectors
24	D'Haese et al. (2014)	9-12 years	**Physical activity** *- Daily, moderate-to-vigorous* *- Walking, cycling and sports participation*	• Walkability index			Statistical sectors
25	Dowda et al. (2007)	11.8 years	**Physical activity** *- 6-days accumulated* *- Moderate-to-vigorous* *- Non-school hours*	• Availability of commercial facilities	1600 m[f]	Circular *- Around home address*	
26	Dunton et al. (2014)	8-14 years	**Physical activity** *- Moderate-to-vigorous* *- Within park space*	• Distance to park • Park greenness • Total park area • Number of parks	500 m	Circular *- Around home address*	
27	Edwards et al. (2014)	12-15 years	**Physical activity** *- Organized and non-organized within parks and at beaches* *- Summer and winter*	• Proximity to park • Proximity to beach • Presence of a major road between residence and park • Presence of a major road between residence and beach			Street network distance between home and closest park and beach
28	Edwards et al. (2015)	12-15 years	**Park use** *- For physical activity*	• Number of trees and the tree canopy area • Park greenness • Road types surrounding the park • Perimeters surrounded by lots fronting the park • Park size • Proximity to the beach from the park			800 meter pedestrian network buffer around park and the park area in itself

29	Epstein et al. (2006)	8-15 years	**Physical activity** *- Activity counts* *- Daily, moderate-to-vigorous*	• Residential density • Percentage of residential parcel (land-use) • Street connectivity • Hectares of park area	800 m[f]	Street network *- Around home address*	
30	Feda et al. (2014)	13.5 years	**Perceived stress** *- Unpredictable, uncontrollable and overloaded*	• Proportion of park area	800 m	Street network *- Around home address*	
31	Frank et al. (2007)	5-20 years[a]	**Active travel** *- Walking* *- Over a two-day period*	• Residential density • Street connectivity • Land-use mix and • Presence and amount of specific land-uses • Number of recreation/open spaces	1000 m	Road network *- Around home address*	
32	Ghekiere et al. (2016)	10-12 years	**Active travel** *- Weekly, to local destinations*	• Population density • Number of cul-de-sacs, intersections and sport facilities • Length of busy roads and walking/cycling tracks • Density of reserve/park public open space • Density of sport/recreation public open space	800 m	Circular *- Around school address*	
33	Giles-Corti et al. (2011)	10-12 years	**Active travel** *- To school* *- Walking trips/week*	• Pedshed[e] • Vehicular traffic exposure • Distance to school • School walkability index	2000 m	Circular Pedestrian network *- Around home address*	
34	Gordon-Larsen et al. (2006)	12-18 years[b]	**Physical activity** *- Moderate-to-vigorous* *- Achievement of $\geq$ 5 bouts/week*	• Number of physical activity facilities			Census-block-groups falling into a 8050 m circular buffer
35	Graham et al. (2011)	14.8 years	**Physical activity** *- Daily, moderate-to-vigorous* *- School and out-of-school sports*	• Environmental resources for physical activity	800 m[f]	Circular *- Around home address*	
36	Graham et al. (2014)	14.4 years	**Physical activity** *- Weekly, moderate-to-vigorous*	• Distance to and proportion of green space • Distance to and density of recreation and sport centers • Distance to a bike or walking trail and the school • Density of transit stops, access points and busy streets	1600 m	Road network *- Around home address*	
37	Huynh et al. (2013)	11-16 years	**Emotional well-being**	• Proportion of natural space, green space and blue space	5000 m	Circular *- Around school address*	

38	Islam et al. (2016)	9-14 years	**Outdoors activities** *- Average time on weekdays*	• Street intersection density • Street pattern • Density characteristics • Land-use characteristics	150 m	Circular *- Around home address*	
39	Jago et al. (2006)	10-14 years	**Physical activity** *- Daily, sedentary, light and moderate-to-vigorous*	• Residential density[d] • Number of intersections, public transportation stops, parks and gymnasiums	400 m 1600 m[f]	Circular *- Around home address*	
40	Janssen and Rosu (2015)	11-13 years	**Physical activity** *- Frequency* *- In free-time outside of school*	• Proportion of undeveloped and publicly accessible green space	1000 m	Circular *- Around home from the geographic center of postal code*	
41	Jones et al. (2009)	9-10 years	**Physical activity** *- Bouts of moderate-to-vigorous* *- Minutes across four days*	• Land-use at activity locations	800 m	Pedestrian network *- Around home address*	
42	Kerr et al. (2006)	5-18 years	**Active travel** *- Weekly, to school* *- Walking and bicycling*	• Residential density • Intersection density • Land-use mix • Walkability index	1000 m	Street network *- Around home address*	Block group
43	Kerr et al. (2007)	5-18 years	**Active travel** *- Walking* *- Over a two-day period*	• Residential density • Intersection density • Land-use mix • Presence of specific land-uses	1000 m	Street network *- Around home address*	
44	Kim et al. (2016)	9-11 years	**Health-Related Quality of Life** *- Total score* *- Physical health score* *- Psychosocial health score*	• Landscape spatial patterns measures of urban forests and trees	400 m 800 m	Circular *- Around home address*	
45	Kligerman et al. (2007)	16.2 years	**Physical activity** *- Daily, moderate-to-vigorous*	• Residential density • Retail floor area ratio • Intersection density • Land-use mix • Walkability index • Number of schools, parks and private recreation • Acres of parks • Nearest park, private recreation facility and beach	400 m 800 m 1600 m	Street network *- Around home address*	

46	Kyttä et al. (2012)	10-12 years 13-15 years	**Active travel** *- To and from school* *- Walking and bicycling* **Self-perceived health** **Subjective health complaints** *- Headache, abdominal pain, backache, feeling low, irritability/bad mood, feeling nervous, sleeping difficulties and dizziness*	• Proportion of green structure • Residential density • Proportion of children	500 m	Circular *- Around home address*	
47	Larsen et al. (2009)	11-13 years	**Active travel** *- To and from school* *- Walking or bicycling*	• Residential density[d] • Dwelling density • Intersection density • Sidewalk length • Number of street trees • Land-use mix • Distance to school	500 m 1600 m	Circular *- Around home from the geographic center of postal code* Circular *- Around school address*	
48	van Loon et al. (2014)	8-11 years	**Physical activity** *- Daily, moderate-to-vigorous*	• Route to school measures: distance to school, intersection spacing, number of four way intersections • Home neighborhood measures: commercial density, residential density, land-use mix, intersection density, cul-de-sac density, proportion of low-speed-limit streets, number of parks, distance to the closest park and distance to the closest non-park recreation site	200 m 400 m 800 m 1600 m	Circular *- Around home address*	
49	Maddison et al. (2009)	12-17 years	**Physical activity** *- Daily, moderate-to-vigorous*	• Walkability index • Accessibility to facilities	4 km/hour (walking) < 5 min 6-10 min 11-20 min 21-30 min > 30 min	Road network *- Around home address*	Mesh blocks
50	Markevych et al. (2014)	10 years	**Behavioral problems** *- Emotional symptoms* *- Conduct problems* *- Hyperactivity/inattention* *- Peer relationship problems* *- Prosocial behavior*	• Neighborhood greenness • Distance to green space • Presence of green space • Size of green space	300 m 500 m	Circular *- Around home address*	
51	Markevych et al. (2016)	15 years	**Physical activity** *- Daily, sedentary, light and moderate-to-vigorous* *- In total and during leisure time*	• Neighborhood greenness • Percentage of tree cover • Presence of green spaces and forests • Sport and leisure facilities	500 m 1000 m	Circular *- Around home address*	

52	McDonald et al. (2012)	10-16 years	**Physical activity** *- Daily, moderate-to-vigorous*	• Transportation stop density • Block size • Busy street density • Distance to trail, recreation center, park, school, gym • Retail food outlet density • Walkability index	1600 m	Street network *- Around home address*	

53	McGrath et al. (2016)	9.3 years	**Physical activity**
			- Selected time periods: school commute, after school and weekend/holiday day
			- Minutes moderate-to-vigorous
			- Steps per hour
				• Distance to school
				• Neighborhood Destination Accessibility Index (NDAI)
				  - Food outlet index
				  - Recreational amenity index
				• Walkability index
							800 m road network buffer around neighborhood population-weighted centroid

54	Mecredy et al. (2011)	11-15 years	**Physical activity** *- Weekly, moderate-to-vigorous* *- Outside of school*	• Intersection density • Block length • Connected node ratio • Street connectivity scale	5000 m	Circular *- Around school address*	
55	Mitchell et al. (2016)	9-14 years	**Physical activity** *- Weekdays, non-school hours* *- Moderate-to-vigorous*	• Number of parks • Distance to school and recreational site • Land-use mix • Multi-use path space • Number of intersections	500 m 800 m	Circular *- Around home address*	
56	Mitra et al. (2010)	11-13 years	**Active travel** *- To and from school* *- Walking*	• Distance to school • Major and local road intersections • Number of street-blocks • Distance to central business district	400 m	Circular *- Around home address* *- Around school address*	
57	Mitra and Buliung (2012)	11-12 years	**Active travel** *- To school* *- Walking and bicycling*	• Distance to school • Street-block density • 4-way street intersections • Dead-ends/cul-de-sacs density • Proportion of signalized intersections • Length of local and major roads	250 m 400 m 800 m 1000 m	Circular *- Around home address*	Dissemination area (DA) and traffic analysis zone (TAZ)
58	Moore et al. (2013)	Middle school youth[c]	**Physical activity** *- Daily, moderate-to-vigorous*	• Combined distance to facilities	800 m[f]	Road network *- Around home address*	
59	Moran et al. (2016)	10-12 years	**Active travel** *- To school and neighborhood destinations* *- Walking and bicycling*	• Street connectivity • Residential density • Built coverage • Distance to school, nearest store and park	400 m	Circular *- Around home address*	

60	Nichol et al. (2010)	11-16 years[b]	**Physical activity** *- Weekly, moderate-to-vigorous* *- Out-of-school hours*	• Availability of recreational facilities	5000 m	Circular *- Around school address*	
61	Norman et al. (2006)	11-15 years	**Physical activity** *- Daily, moderate-to-vigorous*	• Number of recreation facilities, schools and parks • Residential density • Intersection density • Retail floor area ratio • Land-use mix • Walkability index	1600 m[f]	Street network *- Around home address*	
62	Oliver et al. (2014)	6-15 years	**Active travel** *- To school* *- Walking or bicycling*	• Distance to school • Walkability index			Five contiguous mesh blocks or more
63	Oliver et al. (2015)	9-13 years	**Physical activity** *- Daily, moderate-to-vigorous* *- Out-of-school time* **Active travel** *- Proportion of trips made by active travel*	• Street connectivity • Residential density • Distance to school • Neighborhood destination accessibility index (NDAI-C) • High-speed roads around schools	1000 m	Road network *- Around home address* *- Around school address*	
64	Oreskovic et al. (2014)	9.7 years	**Physical activity** *- Change after intervention* *- Daily, moderate-to-vigorous* **Active travel** *- Change after intervention* *- Weekly, to school*	• Presence of sidewalks and bicycle paths • Land-use mix • Street connectivity • Major road • Traffic signals • Police presence • Parks	400 m 800 m 1600 m 50 m 200 m 2000 m	Circular Street network *- Around school address* Circular *- Around route to school*	
65	Panter et al. (2010a)	9-10 years	**Active travel** *- Usual travel mode* *- Walking and bicycling*	• Distance to school • Urban-rural status of home address			Based on the specific home address
66	Panter et al. (2010b)	9-10 years	**Active travel** *- Usual travel mode* *- Walking and bicycling*	• Neighborhood characteristics: road outside child's home, road density, proportion of primary roads, building density, streetlight density, pavement density, effective walkable area, connected node ratio, junction density, land-use mix and urban-rural status • Route characteristics: streetlight density, main or secondary road en route, route directness, route within an urban area and land-use mix	100 m 800 m	Street network *- Around route to school* Street network *- Around home address*	

67	Panter et al. (2013)	10 years	**Active travel** *- Usual travel mode* *- Walking and bicycling*	• Neighborhood characteristics: road density, proportion of primary roads, streetlight density, effective walkable area, connected node ratio, junction density, land-use mix and urban-rural status • Route characteristics: distance between home and school, streetlight density, presence of main road, route directedness, land-use mix and route within urban area	100 m 800 m	Street network *- Around route to school* Street network *- Around home address*	
68	Pate et al. (2008)	≥ 18 years[a] < 18 years	**Physical activity** *- Daily 30-minute blocks* *- Moderate-to-vigorous*	• Number of schools, churches, commercial facilities and parks	1200 m[f]	Street network *- Around home address*	
69	Patnode et al. (2010)	10-17 years	**Physical activity** *- Daily, moderate-to-vigorous*	• Distance to park, gym/fitness facility, recreation center/ community center/school, bicycle/pedestrian trail and school attended • Walkability index	1600 m[f]	Street network *- Around home address*	
70	Prins et al. (2009)	14.1 years	**Physical activity** *- Weekly engagement in sports activities* *- Daily walking and cycling in leisure time*	• Number of parks • Number of sports facilities • Availability of sidewalks and bicycle lanes	1500 m	Circular *- Around home from centroid zip codes*	
71	Prins et al (2010)	15.2 years	**Physical activity** *- Weekly engagement in sports activities*	• Number of sports facilities	1600 m	Circular *- Around home from centroid of zip codes*	
72	Prins et al. (2011)	14.5 years	**Physical activity** *- Weekly, moderate-to-vigorous*	• Number of sports facilities • Number of parks	400 m 800 m 2000 m	Circular *- Around home address*	
73	Prins et al. (2012)	12-13 years	**Physical activity** *- Weekly engagement in sports activities*	• Number of sports facilities and parks • Density of sports facilities and parks	1600 m	Circular *- Around home address*	4-digit zip code area
74	Reimers et al. (2014)	11-17 years	**Physical activity** *- Leisure time sport participation*	• Distance to the gym • Distance to the tennis court • Distance to the indoor pool			Straight-line distance from home to facilities
75	Ries et al. (2009)	15.6 years	**Physical activity** *- Weekly, moderate-to-vigorous* *- Outside and within parks*	• Number of parks	1600 m[f]	Circular *- Around home address*	
76	Ries et al. (2011)	15.6 years	**Physical activity** *- Weekly, moderate-to-vigorous* *- Use of private and public facilities for physical activity*	• Number of public recreation centers • Number of private recreational facilities	1600 m[f]	Circular *- Around home address*	

77	Roemmich et al. (2006)	4-7 years	**Physical activity** *- Total minutes* *- Over a 4-day period*	• Housing density • Street connectivity • Amount of park and recreation area • Percentage of park and recreation area	800 m[f]	Circular *- Around home address*	
78	Roemmich et al. (2007)	8-12 years	**Physical activity** *- Daily, moderate-to-vigorous*	• Housing density • Street connectivity • Street width • Amount of residential land • Amount of park and recreation area • Percentage of park and recreation area	800 m[f]	Circular *- Around home address*	
79	Schipperijn et al. (2015)	15 years at baseline	**Physical activity** *- Daily, moderate-to-vigorous*	• Moveability index • Residential density • Recreational area • Number of daily destinations • Street connectivity	2000 m	Street network *- Around home address*	
80	Schlossberg et al. (2006)	12-14 years	**Active travel** *- To and from school* *- Walking and bicycling*	• Distance to school • Intersection density • Dead-end/cul-de-sac density • Route directness • Major road and railroad track on route to school	200 m[f]	Street network *- Around route to school*	
81	Scott et al. (2007)	11-12 years[b]	**Physical activity** *- Weekly, moderate-to-vigorous* *- Non-school hours*	• Distance to physical activity facilities	1600 m[f]	Circular *- Around home address*	
82	Timperio et al. (2006)	5-6 years 11-12 years	**Active travel** *- To and from school* *- Frequency of walking and/or bicycling*	• Distance to school • Busy road intersecting route and route along busy road • Pedestrian route directness • Steep incline en route to school			Shortest road network distance between home and school
83	Timperio et al. (2008)	8-9 years 13-15 years	**Physical activity** *- Moderate-to-vigorous* *- Average minutes on weekdays and weekends*	• Distance to public open space	800 m	Road network *- Around home address*	
84	Trapp et al. (2011)	10-12 years	**Active travel** *- To and from school* *- Trips/ week, bicycling*	• Distance to school • School walkability index • Road traffic volume • Pedshed[e]	2000 m	Circular Pedestrian network *- Around school address*	
85	Tucker et al. (2009)	11-13 years	**Physical activity** *- Daily, total, school-hour and after school*	• Proportion of park space • Recreational opportunities • Land-use mix	1600 m	Circular *- Around home and school from centroid of postal code*	

86	Uys et al. (2016)	9-11 years	**Physical activity** *- Daily, moderate-to-vigorous* *- Before and after school* *- Weekend*	• Number of physical activity facilities	500 m	Circular *- Around home address*	
87	Villanueva et al. (2012)	10-12 years	**Independent mobility** *- To local destinations* *- Walking or bicycling*	• School walkability index • Distance to green space, shops, friends'/relatives' houses and other visited places • Count of green space (<2 ac and ≥ 2 ac), smaller food stores, supermarkets, shopping centers, fast food outlets, churches/synagogues/temples, recreation venues, primary schools, community services and retail shops	800 m 2000 m	Circular *- Around home address* Circular Pedestrian network *- Around school address*	
88	Voorhees et al. (2010)	13-14 years[b]	**Active travel** *- To/from school* *- Weekday walking*	• Availability of physical activity destinations • Distance to school • Street connectivity index and block size factor • Land-use mix • Population density	800 m[f]	Street network *- Around home address*	
89	Wheeler et al. (2010)	10-11 years	**Physical activity** *- Moderate-to-vigorous*	• Presence of green space			Area of 400 km^2 across Bristol
90	Young et al. (2014)	12-16 years	**Physical activity** *- Daily, moderate-to-vigorous*	• Distance to school attended and any school • Number of parks • Street connectivity index	800 m[f] 1600 m[f]	Circular *- Around home address*	

[a] Age group ranging outside our predetermined age between 0-18 years; [b] Converted from grade to age; [c] Grade or age-group not specified in the article; [d] Operationalized as population density (see Table 1);
[e] Pedshed corresponds to effective walkable area (see Table 4); [f] Converted from miles to meters

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Paper II

Promoting activity participation and well-being among children and adolescents: A systematic review of neighborhood built environment determinants

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Abstract

Objective: The objective of this review was to identify, evaluate, and synthesize the findings on built environment determinants and their relation to participation in different domains of activities, including physical activity, recreational and social activities, and well-being in childhood and adolescence.

Introduction: Creating supportive environments for children and adolescents is a priority in society. To ensure informed decision-making and policy changes, initiatives need to rely on systematic development and the use of evidence-based knowledge. Thus, it is necessary to critically review the current evidence on the relations between features of the built environment and health in a more specific and detailed manner to better understand the health-promoting potential of neighborhood built environments.

Inclusion criteria: This review included studies on children and adolescents aged between five and 18 years, which examined relations between one or several neighborhood built environment determinants and participation in activities and/or well-being. The studies had to report test statistics for associations between built environment determinants and the outcomes, which means that descriptive cross-sectional studies were not eligible for inclusion.

Methods: A four-step search strategy was utilized to identify peer-reviewed studies within six databases. The search was limited to English articles published since January 2010. We developed a data extraction form and mined the descriptive details of each included study. The included studies were further assessed for methodological quality by three reviewer pairs independently, using the standard critical appraisal tools from the Joanna Briggs Institute. Due to the methodological heterogeneity of the included studies, a narrative summary of the quantitative findings was conducted.

Results: The 127 studies included in the review were mainly cross-sectional (87.4%). The built environment was most extensively studied in relation to the outcomes active travel (n=54) and unspecified physical activity (n=46). The evidence suggests that a composite determinant of facilities and amenities is related to more unspecified physical activity. Furthermore, less traffic exposure and more safety features, pedestrian infrastructure for walking and cycling, shorter distances to facilities and greater walkability supported active travel behavior. Fewer studies (n=11) examined the built environment determinants of organized sports and well-being, and limited, as well as contradictory, evidence existed for the relation between the built environment and well-being.

Conclusion: The determinants less traffic exposure and more safety features, pedestrian infrastructure for walking and cycling, shorter distances to facilities and greater walkability potentially support active travel behavior, whereas a high facility and amenity index might promote unspecified physical activity. Policies and planning processes should consider these determinants to strengthen children's and adolescents' health and well-being. However, there are remaining research gaps and important avenues for future research that need to be addressed before more specific and robust conclusions can be drawn.

Keywords: Health promotion; Physical environment; Physical activity; Active travel; Resilience.

Introduction

The neighborhoods in which children and their families live their daily lives are important settings for health-promoting actions and policy. As outlined in the Ottawa Charter for health promotion, one of the priorities is to create supportive environments for children and adolescents.[1] Both physical or built (e.g., residential areas, pedestrian infrastructure, and green spaces) and psychosocial (e.g., social cohesion and safety from crime) characteristics of neighborhoods can contribute to determining health and well-being in the younger population by either supporting or adversely influencing health.[2,3] This paper addresses neighborhood built environment determinants, such as buildings, land-use, green spaces and the provision of facilities, and their potential to support activity participation and strengthen well-being in childhood and adolescence.

Well-being fosters resilience and enables individuals to function well and thrive. Strengthening actions that can contribute to promoting well-being is therefore highly important.[4] Participation in meaningful activities, including organized activities, unstructured play, recreational activities or various forms of physical activity (PA) (e.g., walking, cycling and running), has several positive effects on both physical and mental health.[5-7] All these activities occur in different settings, such as the neighborhood, and supportive environments, which foster participation in activities and let children and adolescents expand their capabilities, can thus contribute to enhancing well-being.

A rapidly urbanizing world entails challenges, and there is a need to maintain, upgrade, and develop urban areas to promote public health.[8] To ensure informed decision-making and policy changes, initiatives need to rely on systematic development and the use of evidence-based knowledge and best practice.[9] A comprehensive understanding of neighborhood built environment determinants is therefore essential. The volume of literature that has examined the built environment as a modifiable determinant of health has expanded substantially over recent decades.[10-12] Given the great number of studies, as well as the myriad of methods applied, it has become increasingly difficult for researchers and stakeholders to have an overview of the evidence.[12] A recently published umbrella review provides important insights showing that neighborhoods with high street connectivity, mixed land-use and compact residential design were linked to higher levels of PA.[10] Bird *et al.*[10] also found that densely populated areas with good access to facilities increased PA and improved mental health in the general population. However, several gaps in the literature remain to be filled to better understand the health-promoting potential of neighborhood built environments.

Previous reviews of the built environment determinants of health in childhood and adolescence have mainly focused on and synthesized results by merging together different types of PA into one overall, unspecified PA outcome or considered total PA over the course of specific time periods.[13-16] A common finding of these reviews is that associations between the built environment and PA are inconsistent across studies. Alternatively, reviews that specifically address the determinants of active travel have consistently shown that neighborhoods with pedestrian infrastructure for walking/cycling, high walkability, less traffic exposure, and high safety as well as access to facilities support active travel behavior.[17-20] It is presumed that the relationship between the built environment and PA varies according to domains of activities, such as leisure-time PA, active travel to/from school and outdoor play.[3,12,14,21] This highlights the importance of being outcome-specific in the synthesis of results, which is a shortcoming of several existing reviews. Furthermore, less attention has been paid to the possible benefits of the built environment for the well-being of children and adolescents. Clark *et al.*[22] have shown that lack of access to green space and poor neighborhood quality, including derelict properties, graffiti, uneven pavements, speeding traffic, absence of public and private recreation space, and high crime levels, diminished children's mental health. New studies have added evidence since they published their review, but syntheses that are more recent are limited to assessing green and natural environments.[23-25] Reviews that have considered the broader built environment have mainly included people aged over 16 years.[26-29] One exception is Christian *et al.*[30] who found that the presence of neighborhood facilities was positively associated with children's physical health, well-being, and social competence. Nevertheless, this review considered only a small segment of the child population by exclusively focusing on those aged seven years or younger.

Specificity in the descriptions of how built environment determinants are measured and operationalized has also been a limitation of previous studies.[31,32] Only recently, Nordbø *et al.*[33] developed a framework for how to categorize built environment determinants, which can be useful in both future primary studies as well as review studies. Another important weakness of past syntheses of the literature is the lack of quality assessments of the individual studies. Bird *et al.*[10] highlighted that around 45% of existing reviews did not report any quality assessments. This lack of methodological quality assessment pertains to several published reviews of environmental determinants of activity participation and well-being of children and adolescents.[13,14,18,30] We therefore suppose it is necessary to comprehensively and critically review and synthesize the current evidence in a more specific and detailed manner to address the aforementioned gaps and shortcomings.

Review question/objective

The objective of this review was to identify, evaluate, and synthesize the findings on built environment determinants and their relation to participation in different domains of activities, including physical activity, recreational and social activities, and well-being among children and adolescents from a broader public health perspective. In particular, the objective was to identify which built environment determinants seem to promote participation in activities and well-being in childhood and adolescence.

Inclusion criteria

Participants

Based on a holistic, population-based public health approach in the young segment of the population, this review considered studies that included the general population of children and adolescents aged between five and 18 years. Studies that also included participants aged below/above this age were considered if stratified results were provided for age groups within our predetermined age range.

Exposure

Articles were eligible if they examined exposure to one or several built environment determinants. Built environment determinants here refer to all modifiable factors in the neighborhood context, such as residential density, land-use, buildings, roads and streets, traffic, pedestrian infrastructure, green space, safety, and aesthetic features, as well as proximity to and the presence of facilities, such as schools, shops, libraries, sports fields, and playgrounds. There were no restrictions on mode of measurement, and determinants could be assessed using, for example, geographic information systems (GIS), audits, or self-report. Articles were not considered if they validated specific methodologies for assessing the built environment. Additionally, considering the scope of this review and the notion that schools represent a separate setting for health promotion, with their own structural and organizational characteristics, articles were not eligible for inclusion if they focused on the school area or schoolyard only.

Outcomes

Articles with activity participation or well-being (or both) as the main outcome were considered for inclusion. Activity participation encompassed the everyday activities of children and adolescents potentially related to the built environment, including different domains of PA (e.g., outdoor play, active travel) and recreational and social activities (e.g., spending time with friends and peers).[3] Considering the scope of this review, studies examining sedentary behaviors (e.g., hours of screen time) were not eligible for inclusion. Well-being was broadly defined to encompass positive outcomes portraying individuals experience positive emotions and feelings, function well, and are able to realize their own abilities and thrive. The definition further included the contrasting outcomes characterized by negative emotions and feelings, as well as mental health and behavioral problems.[4] There were no restrictions on mode of measurement.

Types of studies

We considered quantitative studies involving natural experiments occurring in the neighborhood and analytical observational studies, including retrospective or prospective longitudinal research, case-control studies, and cross-sectional studies. The studies had to report test statistics (e.g., odds ratio, regression coefficient, and prevalence ratio) for associations between the built environment determinants and the outcomes, which means that descriptive cross-sectional studies were not eligible for inclusion.

Methods

The review protocol was prospectively registered in PROSPERO (CRD42018114413), and the PRISMA guidelines were followed throughout this review.[34]

Search strategy

A four-step search strategy was utilized to identify peer-reviewed studies within PubMed, Web of Science, Embase, MEDLINE, PsychINFO and CINAHL. The search was limited to English articles. Further, to avoid duplicating the results of previous reviews that have examined relations between the built environment and physical activity among children and adolescents, the search was also limited to identify articles published since January 2010.[13,14,18,19] To find relevant search terms, an initial limited search in Web of Science, PubMed, and Medline was undertaken, followed by an analysis of text words contained in the titles, abstracts, and keywords. In PubMed and MEDLINE, we also analyzed the MeSH index terms used to describe the articles. This preliminary search informed the development of a full search strategy, which was tailored for each database. Next, a full search was performed in PubMed and MEDLINE using both keywords and MeSH index terms. Thirdly, a full search was undertaken across Web of Science, Embase, PsychINFO and CINAHL using the identified keywords only. The full search strategies for each database are detailed in Appendix I. Lastly, based on the large number of studies, as well as the limited resources and time at our disposal, the reference lists of 50% of the included articles were screened for additional studies.

Study selection

All identified records were uploaded into EndNote X8.2 2018 (Clarivate Analytics, PA, USA) where duplicates were removed. The first author (ECAN) screened the titles and abstracts of the records. Uncertainty about inclusion or exclusion was resolved by seeking a second opinion from one of the co-authors (three instances during the screening process) or by obtaining confirmatory information from the full-text article. All papers selected for full-text retrieval were assessed for eligibility based on congruence with the inclusion criteria by the first author. Eligibility assessment was duplicated for 43 full-text articles by a co-author (HN 11, RKR 16 and GA 16). Disagreements about inclusion or exclusion of four of the articles emerged during the eligibility assessment. In these four instances, all co-authors assessed the articles independently and disagreements were reconciled though group discussions.

Assessment of methodological quality

Three independent reviewer pairs critically appraised the methodological quality of 90 out of 127 studies selected for inclusion (ECAN and HN 30; ECAN and RKR 30; ECAN and GA 30). Inter-rater agreement was 87.0% (disagreed on 32 items), 90.4% (disagreed on 24 items), and 90.4% (disagreed on 23 items) for each pair, respectively. Disagreements were solved through discussions in pairs. The methodological quality of the remaining 37 studies was assessed by ECAN only. We used standard critical appraisal tools tailored for the different study designs from the Joanna Briggs Institute, University of Adelaide, Australia.[35,36] The items were weighted equally (yes=1 vs. unclear/no/not applicable=0). A document clarifying what constituted acceptable levels of information for a study to receive a positive, negative, or unclear response was developed by two of the authors. This document was forwarded to all co-authors prior to the quality assessment. We decided to include all studies irrespective of quality. Each article received a total score, and based on this score, we rated the articles to be of either *"good", "fair",* or *"poor"* quality. Since cut-offs for the quality weighting of the evidence are not available for the critical appraisal tools, the weighting is based on the authors predetermined cut-offs detailed in Table 1. These cut-offs were based on the following criteria: (1) poor quality if 50% or fewer of the items were not satisfactory, (2) fair quality if 51-85% of the items were satisfactory, and (3) good quality if more than 85% of the items were satisfactory.

Data extraction

We developed a data extraction form and systematically recorded the following information from each paper: reference, country, age of the participants, total sample size, gender distribution, study design, built environment determinants, health outcomes, mode of measurement for both determinants and outcomes, and key findings. Regarding the age of the participants, we extracted the mean age if this was the only information reported. Further, 11 studies (five from USA and six from Canada) reported grades instead of age. For consistency, we converted the grades into age for these studies. These conversions were based on information written in government documents provided by Departments and Ministries of Education in USA and Canada. In the column for key findings, we report significant associations, presented either as effect measures with 90% or 95% CI or as effect measures with SE and p-values, from adjusted multivariate analyses. ECAN extracted the data for all the papers. Data extraction was duplicated for 30 articles by a co-author (HN 6, RKR 13 and GA 11).

Table 1: Predetermined cut-offs for the total quality score displayed for the different study designs.

Study design	Poor	Fair	Good
Cross-sectional	≤ 4	5-6	≥ 7
Case-control	≤ 5	6-8	≥ 9
Longitudinal/cohort	≤ 5	6-9	≥ 10
Quasi-experimental	≤ 4	5-7	≥ 8

Data synthesis

Statistical pooling was not possible due to the heterogeneity between the included studies in assessment of exposures and outcomes. Accordingly, the findings are presented in a narrative form with tables and figures to aid the presentation of data. The narrative synthesis involved two steps. First, we categorized the studies based on their general study characteristics to facilitate the interpretation of results. Then, the relations between the built environment determinants and the established categories of outcomes were synthesized using vote counting. These two steps are detailed below.

Categorizing the studies based on general study characteristics

Following the same logic as Ding *et al.*[14] we grouped the studies into categories based on their general study characteristics, such as year of publication, geographic origin, sample age, total sample size, study design, methods for assessing the built environment, and outcome measurement methods. The number of studies within each category was reported. We also grouped the outcomes into different categories to assist the interpretation of results. These categories were developed in the review process and were governed by both the content of the material as well as our aim of being domain-specific in the synthesis of activity outcomes. We established the following six mutually exclusive categories:

1) *Unspecified PA:* outcomes capturing different intensities of PA, such as moderate to vigorous PA and activity counts. For outcomes in this category, the context and domain of PA was not possible to specify into any of the categories below due to lack of information or that the outcome of the study was total PA during a specific time period.
2) *Leisure-time PA:* outcomes eliciting different intensities of PA or activity counts where it was evident that the activity occurred during leisure time (e.g., running for fitness) but the context was not possible to specify.
3) *Active travel:* outcomes capturing walking and/or cycling to/from school or other destinations within the neighborhood.
4) *Outdoor play/activity:* outcomes specifying that the activity/play occurred outside or at specific outdoor locations in the neighborhood, such as the street, park, beach or playground.
5) *Organized sports:* outcomes capturing participation in different sport activities, mainly organized sports such as handball, soccer, volleyball, football, dancing, karate and gymnastics.
6) *Well-being:* outcomes measuring aspects of well-being or positive mental health as well as negative mental health. This included perceived stress, self-esteem, quality of life, life satisfaction, happiness, well-being, behavioral problems, and emotional symptoms.

Coding and synthesizing relationships between the built environment and health outcomes

We synthesized the findings using the predetermined categories of built environment determinants developed by Nordbø *et al.*[33] (Figure 1). We added *aesthetics* to the list of categories to facilitate the interpretation of the findings. Each determinant from the separate studies was assigned into one of the 19 categories presented in the figure.

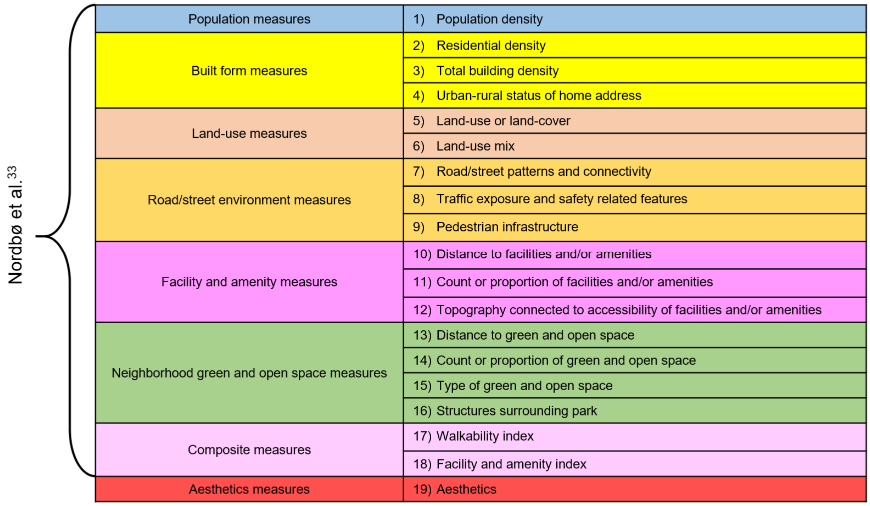

Figure 1: An overview of built environment determinant categories used to synthesize results.

We considered mainly results from adjusted multivariate analyses for the review. The exceptions were two studies with adjusted bivariate analyses and three studies with unadjusted estimates.[42,80] In one longitudinal study, we considered only cross-sectional (baseline) results, because the age at the six-year follow-up was 21 years and thus outside our target group.[144] The direction of each association was coded as "+" indicating a positive significant association, "0" representing a non-significant association, and "-" signifying a negative significant association between a built environment determinant and a particular health outcome. We counted the number of association codes for each study. For several studies, multiple entries were reported based on sub-group analyses or because several determinants and outcomes were studied. We synthesized the results separately for the six outcome categories. After all results had been extracted, we calculated the total number and the percentages of positive, negative, and non-significant associations for each investigated built environment determinant category.

Results

Study inclusion

Figure 2 presents the flowchart for the evidence acquisition and study selection process. The searches identified 2030 unique records. The screening process resulted in 162 full-text articles, of which 43 articles were excluded after eligibility assessment (Appendix II). An additional eight articles were identified through the screening of reference lists. In total, 127 articles met the inclusion criteria for this systematic review (Appendix III).

Methodological quality

The quality assessment rating for each study is presented in Appendix III, and the results from the critical appraisal are outlined in Appendix IV. Our assessment revealed that the quality of the included studies was quite good. The majority of the studies was rated as fair (57.4%), and 27.6% of the studies were of good quality (Table 2). In cross-sectional studies of fair quality, the item most frequently rated as not satisfactory was the *identification of confounders*. Several studies also had weaknesses in their *strategies to deal with confounding issues*. The reason for not evaluating these items as satisfactory was that vital confounders, such as individual-level income or education, were not measured in the studies or were omitted from the statistical analyses. Additional issues of selection bias due to lack of representativeness in the recruitment of participants were a main problem in cross-sectional studies of both fair and poor quality. The longitudinal studies were all of fair quality (n=14). The leading reasons for reduced quality scores in longitudinal studies of fair quality were the omission of important confounders and/or incomplete follow-up and lack of strategies to address study drop out.

Characteristics of included studies

Of the 127 studies included in this review, 59.8% had been published since January 2014 (Table 2). The majority of the studies (78.7%) were from North America and Europe. There were more studies on children than adolescents, and the study designs were mainly cross-sectional (87.4%). The sample sizes ranged from 39 to 64076. Active travel was the most studied outcome (n=54), followed by unspecified physical activity (n=46), whereas 11 studies examined the built environment determinants of organized sports and well-being. Studies assessed unspecified and leisure-time physical activity, active travel, and outdoor play/activity using either accelerometers or questionnaires, whereas organized sports and well-being outcomes were self-/parental-reported. GIS-derived measures were most commonly applied to assess the built environment, either as the only method of measurement (n=48) or combined with direct observation/audits (n=10), self-reported measures (n=28), or GPS (n=5).

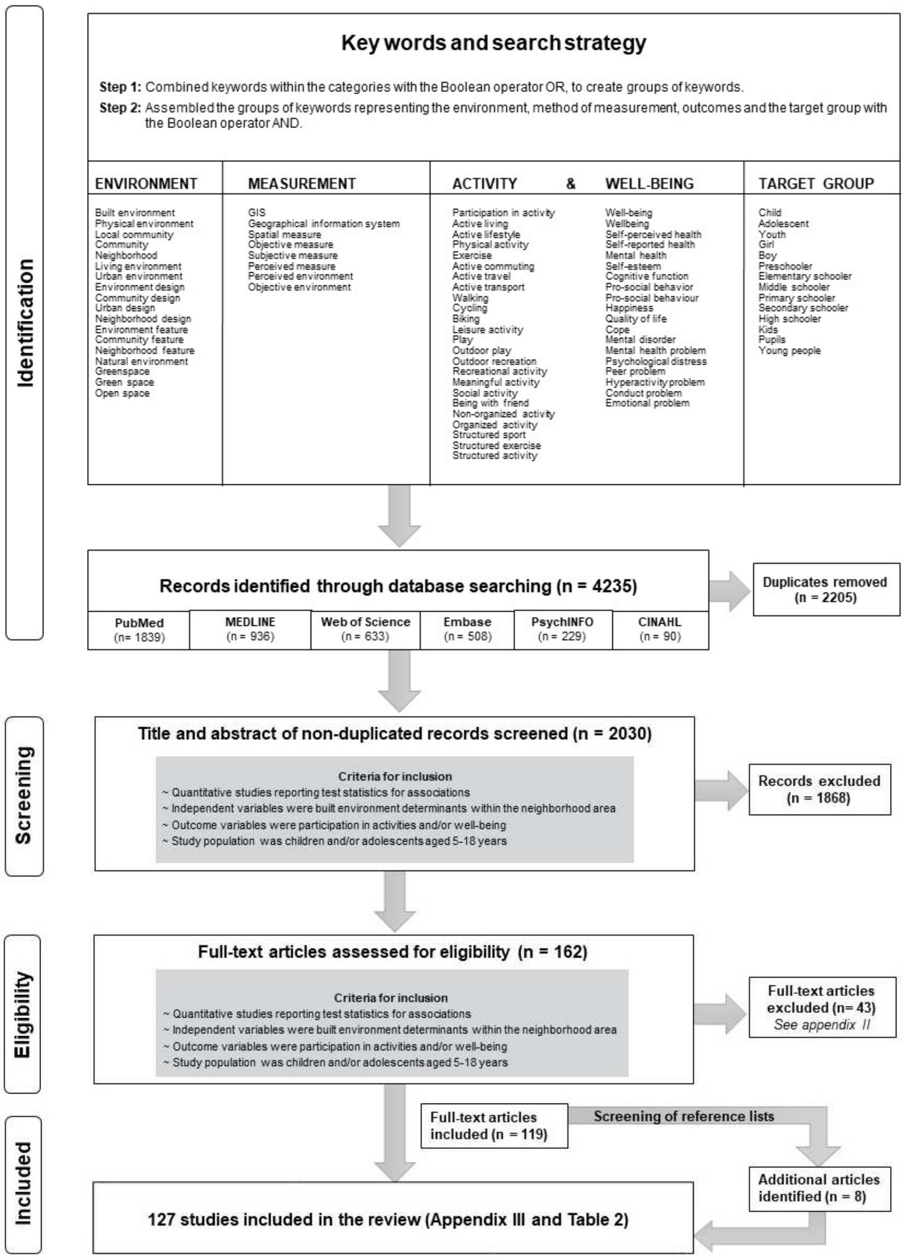

Figure 2: A modified PRISMA flow chart of the systematic review process.[34]

Table 2: Summary of general study characteristics of the papers reviewed.[37-163]

Characteristics	Count of studies	Reference
Year of publication		
2010-2013	51	37-38,43-44,46,49,53,57-59,61-65,69-70,72,79,82,84,88-90,99-100,103-104,109,113,117,122,129, 131-135,137,140-141,145-146,148-149,152-153,156-157,160,162
2014-June 2018	76	39-42,45,47-48,50-52,54-56,60,66-68,71,73-78,80-81,83,85-87,91-98,101-102,105-108,110-112, 114- 116,118-121,123-128,130,136,138-139,142-144,147,150-151,154-155,158-159,161,163
Geographic origin		
North America	54	38,40-41,48-52,59,61,71-72,75,77,79,82-85,88-89,92-95,98,100-103,108,113-114,117-118,121-123, 128-130,135,140-142,145-146,154,157-158,161-163
South America	2	60,78
Australia/New Zealand	20	53,58,73-74,76,81,87,104,109,111,126-127,136-137,143,147-149,156,159
Middle East and Asia	4	91,119-120,150
Africa	1	151
Europe	46	37,39,42-47,54-57,62-70,80,86,96-97,99,105-107,110,112,115-116,124-125,131-134,138-139,144, 152-153,155,160
Sample age		
Children (≤12 years)	56	37,39,41,46-47,54-55,57-59,61,64-68,72,76-78,81,85-86,94-95,102-103,106,109-112,115,119-120, 124,128-134,139,143,146-148,150-151,154-157,160,162
Adolescents (13-18 years)	28	42,56,60,62-63,70,82-83,87-89,97,100,105,107-108,116,123,125,136-137,140-142,144,152-153,158
Both age groups	43	38,40,43-45,48-53,69,71,73-75,79-80,84,90-93,96,98-99,101,104,113-114,117-118,121-122,126-127, 135,138,145,149,159,161,163
Total sample size		
<100	5	75,86,95,112,159
100-499	45	38,41,45,47,51,53,58-59,64,66-67,70-72,79,82,91,93,96,110-111,114-117,121,124,126-127,129-130, 135-137,140-141,144,150-151,153-156,161-162
500-999	33	44,46,52,55-57,62-63,65,68-69,77,81,85,87,100-102,105,109,118-120,123,125,128,134,139,142, 146-147,157-158
1000-1999	19	42-43,48,50,54,73-74,78,80,99,103,106-107,131,138,148-149,152,160
2000-4999	14	37,39-40,60-61,76,83-84,98,104,132-133,143,163
≥5000	11	49,88-90,92,94,97,108,113,120,145
Study design		
Cross-sectional	111	37-52,56,59-66,68-75,78-102,104,106-119,120*,121-122,124-133,135-140,142,145-146,148-163
Longitudinal	14	53-55,57-58,67,76-77,105,134,141,143-144,147
Case-control	1	103
Quasi-experimental	1	123
Method of measurement (determinants)		
GIS-derived	48	38-39,44-47,52-53,55-56,60,62,64,73,75,81-82,86,88-92,93,98-102,105-108,110,113-116,119,123, 126,130,137-138,142,144,147,154,161
Self-/parental perceived	28	40,49,61,63,67-70,72,78,80,97,103-104,109,118,120,124-125,128-129,136,145,150,153,155-156,162
Direct observation/audits	5	37,50,64,93,139
Combination of methods	45	41-43,48,51,54,57-59,65,71,74,76-77,79,83-85,87,91,94,96,111-112,117,121-122,127,131-135, 140-141,146,148-149,151-152,157-160,163
Other or unspecified	1	143
Health outcome categories		
Unspecified PA	46	41,47,57-58,60-62,66-68,70-72,77,79-80,82-83,87-89,93,96-98,107,109,116-118,123,125,129-130, 135-137,140,142-144,148,150,154,162-163
Leisure-time PA	22	50,53,56-57,60,78,92,105,107-108,111,113-114,116,122,127,138,143,146-147,151,160
Active travel	54	44-46,48,50-55,59-60,62-67,69,71-72,80-81,84-86,94,99-104,115-116,126-128,130-134,142,148-149, 152-153,155,157-158,161
Outdoor play/activity	21	37-38,40,42-43,46,50,68,73-74,79,91,112,120-121,131,141-142,146,156,159
Organized sports	11	46,62,66-67,79-80,82,116,131,138,142
Well-being	11	39,49,75-76,90,95,99,106,110,145,159
Method of measurement (outcomes)		
Accelerometer/Pedometer/GPS	37	38,47,52,55-58,77,86-87,93,96,98,109,111-112,114,117-118,121,125,127,129,135-137,139-141,144, 147,151,154,160-163
Self-/parental reported	72	37,39-46,48-49,51,54,59,61,63-65,68-70,73-76,78,81,83-85,88-92,94-95,97,99-106,108,110,113,115, 119-120,122-124,126,128,131-134,138,143,145,148-150,152-153,156-158
Combination of methods	18	50,53,60,62,66-67,71-72,79-80,82,107,116,130,142,146,155,159
Quality assessment rating		
Poor	19	44-45,48,70,73-74,85,91,93-94,101,110-112,118-120,124,129
Fair	73	40-41,43,46,49-51,53-58,59-60,62-65,67,69,71-72,75-78,83-84,86,88-89,92,96,99-100,102-105,114, 116-117,123,125,127-128,130-134,136-137,139-147,150,152,154-157,159-161,163
Good	35	37-39,42,47,52,61,66,68,79-81,87,90,95,97-98,106-109,113,115,121-122,126,135,138,148-149, 151,153,158,162

*The study utilized a mixed method design with a cross-sectional survey. The quantitative cross-sectional part of the study were considered.

Review findings

The findings on built environment determinants and their relation to participation in activities and well-being among children and adolescents are presented according to the established six categories of outcomes identified (i.e., unspecified PA, leisure-time PA, active travel, outdoor play/activity, organized sports and well-being).

The built environment and unspecified PA

Figure 3A shows the associations between built environment determinants and unspecified PA. The count/proportion of facilities/amenities was the most studied determinant (n=18). Total building density, urban-rural status, and land-use or land-cover have not been examined in relation to this outcome. We extracted 356 results from the 46 studies with unspecified PA as an outcome (Table 3). We found few favorable associations between residential density, type of green/open space, aesthetics, and unspecified PA. More than half of the studies (eight out of 13) that addressed road/street pattern and connectivity reported positive associations. Of these, there were three studies of good quality and five studies of fair quality. The proportion of positive associations was greatest for the composite determinant denoted as the facility and amenity index (77.8%). This determinant was investigated in relation to unspecified PA in 12 studies, of which half were rated as being of good quality. All the good quality studies consistently reported positive associations (Table 3).

Table 3: Summary of the relations between the built environment and unspecified PA based on results derived from 46 studies.

Built environment determinant (number of studies)	Results from adjusted analyses[a] +	0	-	Method of measurement (built environment)
Population density (5)				
Good quality				
Buck *et al.*[47]	1			GIS-derived
Kowaleski-Jones *et al.*[98]	2(A)	1(A)	3(C)	GIS-derived
Fair quality				
Da Silva *et al.*[60]		2		GIS-derived
Graham *et al.*[83]		1(G), 1(B)		GIS-derived
Young *et al.*[163]		3(A), 1(C)		GIS-derived
Total number of associations (%)	***3 (20.0)***	***9 (60.0)***	***3 (20.0)***	
Residential density (5)				
Good quality				
D'Haese *et al.*[68]		1		Self-/parental perceived
Hinckson *et al.*[87]		4		GIS-derived and perceived
Fair quality				
D'Haese *et al.*[67]		1(G)		Self-/parental perceived
Durand *et al.*[72]		1		Self-/parental perceived
Schipperijn *et al.*[144]		1(all), 1(G), 1(B)		GIS-derived
Total number of associations (%)	***0 (0.0)***	***10 (100.0)***	***0 (0.0)***	
Land-use mix (10)				
Good quality				
Buck *et al.*[47]		1		GIS-derived
D'Haese *et al.*[68]		2		Self-/parental perceived
Hinckson *et al.*[87]	1	5		GIS-derived and perceived
Fair quality				
Corder *et al.*[57]	1			GIS-derived
D'Haese *et al.*[67]		1(G), 1(B)		Self-/parental perceived
Durand *et al.*[72]		2		Self-/parental perceived
Hobin *et al.*[88]			1	GIS-derived
Hobin *et al.*[89]			1(G)	GIS-derived
Oreskovic *et al.*[130]	1			GIS-derived
Tung *et al.*[150]	1			Self-/parental perceived
Total number of associations (%)	***4 (22.2)***	***12 (66.7)***	***2 (11.1)***	

Road/street pattern and connectivity (13)				
Good quality				
Buck *et al.*[47]	1			GIS-derived
Hinckson *et al.*[87]	1	8		GIS-derived and perceived
Kowaleski-Jones *et al.*[98]	2(A)	1(A), 3(C)		GIS-derived
Fair quality				
Crawford *et al.*[58]	1 (B)			GIS-derived
Da Silva *et al.*[60]		1		GIS-derived
D'Haese *et al.*[67]	1(B)	1(G)		Self-/parental perceived
Durand *et al.*[72]		2		Self-/parental perceived
Graham *et al.*[83]		1(G), 1(B)		GIS-derived
Hobin *et al.*[89]		1(B)		GIS-derived
Oreskovic *et al.*[130]	1			GIS-derived
Schipperijn *et al.*[144]	1(all), 1(G)	1(B)		GIS-derived
Van Loon *et al.*[154]	1(G)			GIS-derived
Young *et al.*[163]		3(A), 1(C)		GIS-derived
Total number of associations (%)	***10 (30.3)***	***23 (69.9)***	***0 (0.0)***	
Traffic exposure and safety features (15)				
Good quality				
Davidson *et al.*[61]		1		Self-/parental perceived
D'Haese *et al.*[68]		1		Self-/parental perceived
Hinckson *et al.*[87]		1		Self-/parental perceived
Fair quality				
Crawford *et al.*[58]			1 (B)	Self-/parental perceived
Da Silva *et al.*[60]	1			GIS-derived
Duncan *et al.*[71]		1		Self-/parental perceived
Durand *et al.*[72]	1	2		Self-/parental perceived
Graham *et al.*[83]		2(G), 2(B)		GIS-derived and perceived
Moore *et al.*[117]	1(rural)	1(rural), 2(urban)		Self-/parental perceived
Oliveira *et al.*[125]		1		Self-/parental perceived
Oreskovic *et al.*[130]		2	1	GIS-derived
Van Loon *et al.*[154]	1(G)			GIS-derived
Young *et al.*[163]	2(A)	3(A), 2(C)	1(A)	Self-/parental perceived
Poor quality				
Moore *et al.*[118]		2		Self-/parental perceived
Olvera *et al.*[129]		3	1	Self-/parental perceived
Total number of associations (%)	***6 (16.7)***	***26 (72.2)***	***4 (11.1)***	
Pedestrian infrastructure (8)				
Good quality				
D'Haese *et al.*[68]		1		Self-/parental perceived
Hinckson *et al.*[87]		3		Self-/parental perceived
Fair quality				
Da Silva *et al.*[60]		3	1	GIS-derived
Durand *et al.*[72]	1	1		Self-/parental perceived
Graham *et al.*[83]	1(G)	1(B)		GIS-derived
Oliveira *et al.*[125]	1			Self-/parental perceived
Oreskovic *et al.*[130]		2		GIS-derived
Poor quality				
Moore *et al.*[118]		4		Self-/parental perceived
Total number of associations (%)	***3 (15.8)***	***15 (78.9)***	***1 (5.3)***	
Distance to facilities/amenities (12)				
Good quality				
D'Haese *et al.*[68]		1		Self-/parental perceived
McCormack *et al.*[109]		1(G)	1(B)	Self-/parental perceived
Patnode *et al.*[135]		1 (G)	1(G)	GIS-derived
Fair quality				
Corder *et al.*[57]			1	GIS-derived
Da Silva *et al.*[60]		1		GIS-derived
D'Haese *et al.*[67]		1(B)		Self-/parental perceived
Duncan *et al.*[71]	1	2		GIS-derived and perceived
Graham *et al.*[83]		3(G), 3(B)		GIS-derived
Moore *et al.*[117]		1(urban)	1(rural)	GIS-derived
Tappe *et al.*[146]	2			Self-/parental perceived
Van Loon *et al.*[154]		1(G)		GIS-derived
Young *et al.*[163]	1(A)	5(A), 1(C)	1(C)	GIS-derived
Total number of associations (%)	***4 (13.3)***	***21 (70.0)***	***5 (16.7)***	
Count/proportion of facilities/amenities (18)				
Good quality				
Buck *et al.*[47]	2			GIS-derived
Davidson *et al.*[61]	1			Self-/parental perceived
Galvez *et al.*[79]		4		Observation and GIS
Graham et al.[82]		2		GIS-derived
Hinckson *et al.*[87]		4		GIS-derived
Markevych *et al.*[107]	1	3		GIS-derived
Fair quality				
Crawford *et al.*[58]		2 (B)		Self-/parental perceived
Da Silva *et al.*[60]		8		GIS-derived
Graham *et al.*[83]		3(G), 3(B)		GIS-derived
Klinker *et al.*[96]	6			GIS-derived and GPS
Moore *et al.*[117]		1(rural), 1 (urban)		Self-/parental perceived
Nicosia and Datar[123]	1			GIS-derived
Oliveira *et al.*[125]		1		Self-/parental perceived
Prins *et al.*[137]		3[b]		GIS-derived
Ries *et al.*[140]		4		GIS-derived and perceived
Schipperijn *et al.*[144]		2(all), 2(G), 2(B)		GIS-derived
Young *et al.*[163]	1(C)	6(A), 1(C)		Self-/parental perceived

Poor quality				
Katapally and Muhajarine[93]		1		Direct observation/audit
Total number of associations (%)	***12 (18.5)***	***53 (81.5)***	***0 (0.0)***	
Distance to green/open space (3)				
Good quality				
Kowaleski-Jones *et al.*[98]		1(A)	2(A), 3(C)	GIS-derived
Fair quality				
Bird *et al.*[41]	7[c]	9[c]		Observation and GIS
Graham *et al.*[83]		1(G) 1(B)		GIS-derived
Total number of associations (%)	***7 (29.2)***	***12 (50.0)***	***5 (20.8)***	
Count/proportion of green/open space (11)				
Good quality				
Buck *et al.*[47]	1	3		GIS-derived
Galvez *et al.*[79]		2		Observation and GIS
Hinckson *et al.*[87]	1	3		GIS-derived
Markevych *et al.*[107]		8		GIS-derived
Fair quality				
Durand *et al.*[72]		1		Self-/parental perceived
Graham *et al.*[82]		1(G), 1(B)		GIS-derived
Klinker *et al.*[96]	1			GIS-derived and GPS
Oreskovic *et al.*[130]		1		GIS-derived
Prins *et al.*[137]		3[b]		GIS-derived
Sanders *et al.*[143]	2(B)	4(G), (2B)		Other
Young *et al.*[163]	1(A)	2(A), 1(C)		GIS-derived
Total number of associations (%)	***6 (15.8)***	***32 (84.2)***	***0 (0.0)***	
Type of green/open space (2)				
Good quality				
Markevych et a*l.*[107]		4		GIS-derived
Fair quality				
Da Silva *et al.*[60]		1		GIS-derived
Total number of associations (%)	***0 (0.0)***	***5 (100.0)***	***0 (0.0)***	
Walkability (11)				
Good quality				
Buck *et al.*[47]		2		GIS-derived
D'Haese *et al.*[66]		4		GIS-derived
Patnode *et al.*[135]		1(G)		GIS-derived
Fair quality				
De Meester *et al.*[62]	2(low SES)	2(high SES)		GIS-derived
Duncan *et al.*[71]		1		GIS-derived
Hobin *et al.*[88]			1	GIS-derived
Hobin *et al.*[89]			1(G), 1(B)	GIS-derived
Molina-Garcia *et al.*[116]		1		GIS-derived
Sallis *et al.*[142]	2	1		GIS-derived
Van Loon *et al.*[154]	1(B)			GIS-derived
Poor quality				
Katapally and Muhajarine[93]		1	1	Unspecified
Total number of associations (%)	***5 (23.8)***	***13 (61.9)***	***3 (14.3)***	
Facility and amenity index (12)				
Good quality				
Buck *et al.*[47]	3			GIS-derived
Davidson *et al.*[61]	1			Self-/parental perceived
Garcia-Cervantes *et al.*[80]	6[d]			GIS-derived and perceived
Hinckson *et al.*[87]	2			Self-/parental perceived
Kopcakova *et al.*[97]	1			Self-/parental perceived
Wilson *et al.*[162]	1			Self-/parental perceived
Fair quality				
Forthofer *et al.*[77]	1(all), 1(B)	1(G)		GIS-derived
Plotnikoff *et al.*[136]		2		Self-/parental perceived
Ries *et al.*[140]		2		GIS-derived and perceived
Schipperijn *et al.*[144]	1(all), 1(G)	1(B)		GIS-derived
Poor quality				
Duncan *et al.*[70]	1			Self-/parental perceived
Moore *et al.*[118]	1[e], 1(B)			Self-/parental perceived
Total number of associations (%)	***21 (77.8)***	***6 (22.2)***	***0 (0.0)***	
Aesthetics (5)				
Good quality				
D'Haese *et al.*[68]		11		Self-/parental perceived
Hinckson *et al.*[87]	1			Self-/parental perceived
Fair quality				
D'Haese *et al.*[67]		1(G)		Self-/parental perceived
Durand *et al.*[72]		1		Self-/parental perceived
Oliveira *et al.*[125]		1		Self-/parental perceived
Total number of associations (%)	***1 (6.7)***	***14 (93.3)***	***0 (0.0)***	

Abbreviations: G, girls; B, boys; A, adolescents; C, children; SES, neighborhood socio-economic status.
[a]+, number of positive significant associations; 0, number of non-significant associations; -, number of negative significant associations.
[b] Results from unadjusted analyses.
[c] Results from multivariate adjusted analyses with 90% CI.
[d] Results from bivariate adjusted analyses.
[e] The relationship was completely moderated by sex.

The built environment and leisure-time PA

Figure 3B shows that 15 environmental determinants have been investigated in relation to leisure-time PA. The determinant entailing traffic exposure and safety features was the most studied (n=10), followed by count/proportion of facilities/amenities (n=7). We extracted 442 results from the 22 studies examining determinants of leisure-time PA (Table 4). Few significant associations were identified for population density, residential density, building density, land-use mix, road/street pattern and connectivity, pedestrian infrastructure, and distance to green/open space as well as type of green/open space in terms of supporting leisure-time PA. However, only a few studies examined several of these determinants. The facility and amenity index showed the largest proportion of positive associations (38.8%) with leisure-time PA as well, but none of these studies were rated as being of good quality.

Table 4: Summary of the relations between the built environment and leisure-time PA based on results derived from 22 studies.

Built environment determinant (number of studies)	Results from adjusted analyses[a] +	0	-	Method of measurement (built environment)
Population density (1)				
Fair quality				
Da Silva *et al.*[60]		4		GIS-derived
Total number of associations (%)	***0 (0.0)***	***4 (100.0)***	***0 (0.0)***	
Residential density (2)				
Fair quality				
Cain *et al.*[50]		1(A), 1(C)		Direct observation/audit
Oliver *et al.*[127]	1	2		GIS-derived
Total number of associations (%)	***1 (20.0)***	***4 (80.0)***	***0 (0.0)***	
Total building density (1)				
Fair quality				
Cain *et al.*[50]	1(C)	2(A), 1(C)		Direct observation/audit
Total number of associations (%)	***1 (25.0)***	***3(75.0)***	***0 (0.0)***	
Land-use mix (1)				
Fair quality				
Mitchell *et al.*[114]		2(all), 2(G), 2(B)		GIS-derived
Total number of associations (%)	***0 (0.0)***	***6 (100.0)***	***0 (0.0)***	
Road/street pattern and connectivity (5)				
Good quality				
Mecredy *et al.*[113]			1	GIS-derived
Fair quality				
Cain *et al.*[50]		5(A), 4(C)	1(C)	Direct observation/audit
Mitchell *et al.*[114]		2(all), 2(G), 2(B)		GIS-derived
Oliver *et al.*[127]		2		GIS-derived
Young *et al.*[163]		3(A), 1(C)		GIS-derived
Total number of associations (%)	***0 (0.0)***	***21 (91.3)***	***2 (8.7)***	
Traffic exposure and safety features (10)				
Good quality				
Mecredy *et al.*[113]	1			Self-/parental perceived
Nichol *et al.*[122]	8[b]			Self-/parental perceived
Uys *et al.*[151]		6		Self-/parental perceived
Fair quality				
Cain *et al.*[50]	1(A), 1(C)	4(A), 3(C)	1(C)	Direct observation/audit
Carver *et al.*[53]	1(G)	6(G)	2(G)	GIS-derived
Da Silva *et al.*[60]		2		GIS-derived
Fueyo *et al.*[78]		2		Self-parental perceived
Oliver *et al.*[127]		1(weekend)	1(weekdays)	GIS-derived
Tappe *et al.*[146]		1		Self-/parental perceived
Poor quality				
McGrath *et al.*[111]		2[c]	6[c]	Direct observation/audit
Total number of associations (%)	***12 (24.5)***	***27 (55.1)***	***10 (20.4)***	
Pedestrian infrastructure (4)				
Fair quality				
Cain *et al.*[50]		11(A), 11(C)		Direct observation/audit
Da Silva *et al.*[60]		4		GIS-derived
Mitchell *et al.*[114]	2(all)	2(G), 2(B)		GIS-derived
Oliver *et al.*[127]	1(weekdays)	1(weekend)		Direct observation/audit
Total number of associations (%)	***3 (8.1)***	***34 (91.9)***	***0 (0.0)***	
Distance to facilities/amenities (6)				

Fair quality				
Da Silva *et al.*[50]		2		GIS-derived
Magalhães *et al.*[105]		3(G), 3(B)		GIS-derived
Mitchell *et al.*[114]		4(all), 4(G), 4(B)		GIS-derived
Oliver *et al.*[127]		2		GIS-derived
Tappe *et al.*[146]	1			Self-/parental perceived
Poor quality				
McGrath et al.[111]	2[c]	1[c]	1[c]	GIS-derived
Total number of associations (%)	***3 (11.1)***	***23 (85.1)***	***1 (3.7)***	
Count/proportion of facilities/amenities (7)				
Good quality				
Markevych *et al.*[107]	1	3		GIS-derived
Nichol *et al.*[122]		8[d]		GIS-derived
Uys *et al.*[151]	1	5		GIS-derived and perceived
Fair quality				
Cain *et al.*[50]	1(C)	10(A), 10(C)	1(A)	Direct observation/audit
Da Silva *et al.*[60]	1	10		GIS-derived
Fueyo *et al.*[78]		2		Self-/parental perceived
Poor quality				
McGrath *et al.*[111]		4[c]	4[c]	Observation and GIS
Total number of associations (%)	***4 (6.6)***	***52 (85.2)***	***5 (8.2)***	
Distance to green/open space (2)				
Fair quality				
Fueyo *et al.*[78]		4		Self-/parental perceived
Magalhães *et al.*[105]		3(G), 3(B)		GIS-derived
Total number of associations (%)	***0 (0.0)***	***10 (100.0)***	***0 (0.0)***	
Count/proportion of green/open space (6)				
Good quality				
Markevych *et al.*[107]		8		GIS-derived
Massougbodji *et al.*[108]	1(G)	1(B)		GIS-derived
Fair quality				
Janssen and Rosu[92]	1	1		GIS-derived
Mitchell *et al.*[114]	2(all), 1(G), 1(B)	6(all), 7(G), 4(B)	2(B)	GIS-derived
Sanders *et al.*[143]	2(B)	4(G), (2(B)		Other
Wheeler *et al.*[160]	1(G), 1(B)			GIS-derived
Total number of associations (%)	***11 (23.9)***	***33 (71.7)***	***2 (4.4)***	
Type of green/open space (3)				
Good quality				
Markevych *et al.*[107]		4		GIS-derived
Fair quality				
Cain *et al.*[50]		1(A), 1(C)		Direct observation/audit
Da Silva *et al.*[60]		2		GIS-derived
Total number of associations (%)	***0 (0.0)***	***8 (100.0)***	***0 (0.0)***	
Walkability (4)				
Good quality				
Uys *et al.*[151]		3		Self-/parental perceived
Fair quality				
Cain *et al.*[50]		3(A), 3(C)	1	Unspecified
Molina-Garcia *et al.*[116]		1		GIS-derived
Poor quality				
McGrath *et al.*[111]	3[c]	1[c]		GIS-derived
Total number of associations (%)	***3 (20.0)***	***11 (73.3)***	***1 (6.7)***	
Facility and amenity index (6)				
Fair quality				
Coombes *et al.*[56]	8(all), 3(G), 3(B)	1 (all)		GIS-derived
Oliver *et al.*[127]		1 (weekdays)	1(weekend)	GIS-derived
Remmers *et al.*[139]	35[e]	49[e]	4[e]	Direct observation/audit
Tappe *et al.*[146]		1		Direct observation and GIS
Timperio *et al.*[147]		22	1	GIS-derived
Poor quality				
McGrath *et al.*[111]	2[c]	2[c]		GIS-derived
Total number of associations (%)	***52 (38.8)***	***76 (56.7)***	***6 (4.5)***	
Aesthetics (3)				
Good quality				
Mecredy *et al.*[113]	1			Self-/parental perceived
Fair quality				
Cain *et al.*[50]		4(A), 4(C)		Direct observation/audit
Poor quality				
McGrath *et al.*[111]	3[c]	1[c]		Direct observation/audit
Total number of associations (%)	***4 (30.8)***	***9 (69.2)***	***0 (0.0)***	

Abbreviations: G, girls; B, boys; A, adolescents; C, children; SES, neighborhood socio-economic status.
[a]+, number of positive significant associations; 0, number of non-significant associations; -, number of negative significant associations.
[b] Positive associations for boys and girls, all grades (elementary, junior, high school) and by geographic location.
[c] Results from multivariate adjusted analyses with 90% CI
[d] Non-significant associations for boys and girls, all grades (elementary, junior, high school) and by geographic location.
[e] Stratified by time, straight-line and network distance from home to school.

The built environment and active travel behavior

The determinants associated with active travel are presented in Figure 3C. Traffic exposure and safety features (n=37), road/street pattern and connectivity (n=25), distance to facilities/amenities (n=25) and pedestrian infrastructure (n=24) were most frequently studied. We extracted 623 results from the 54 studies investigating determinants of active travel. Less traffic and higher safety were associated with increased active travel in all the 17 studies that reported positive associations, of which one study was rated as good, 14 were rated as fair, and two studies were of poor quality. Increased traffic exposure and safety concerns reduced the likelihood of active travel in 13 out of 15 studies that reported negative associations. The studies with deviating results found that the number of *slow points*, which are considered to encourage slower driving, was associated with less active travel in adolescent girls[53] and that more *traffic lights* were related to less walking for transport.[64] We also found consistency in associations for pedestrian infrastructure, walkability and distance to facilities/amenities. The total proportion of significant associations for walkability was 62.7% (58.8% positive and 3.9% negative). Of the 12 studies that reported any significant influence, the majority of studies were of either good or fair quality (n=11). Higher walkability was associated with more active travel in 11 studies, whereas one study found that active travel behavior was more frequent in areas of lower walkability.[116] Distance to facilities/amenities was associated with active travel in 20 out of 25 studies, of which five studies were rated as poor. The total proportion of significant associations was 78.2% (21.8% positive and 56.4% negative). All the significant associations consistently reflected that shorter distances increased whereas longer distances reduced active travel behavior.

Table 5: Summary of relations between the built environment and active travel based on results derived from 54 studies.

Built environment determinant (number of studies)	Results from adjusted analyses[a] +	0	-	Method of measurement (built environment)
Population density (5)				
Good quality				
Ghekiere *et al.*[81]	1			GIS-derived
Fair quality				
Da Silva *et al.*[50]		6		GIS-derived
Kyttä et al.[99]			1	GIS-derived
Voorhees *et al.*[157]		1		GIS-derived
Poor quality				
Larsen *et al.*[101]		1	1	GIS-derived
Total number of associations (%)	***1 (9.1)***	***8 (72.7)***	***3 (18.2)***	
Residential density (12)				
Good quality				
Carlson *et al.*[52]	2	1		GIS-derived
Van Dyck *et al.*[153]		1		Self-/parental perceived
Fair quality				
Cain *et al.*[50]	1(A)	1(C)		Direct observation/audit
Carlson *et al.*[51]		2		GIS-derived
De Meester *et al.*[63]		1		Self-/parental perceived
D'Haese *et al.*[67]		1(G)		Self-/parental perceived
Durand *et al.*[72]		1		Self-/parental perceived
Kyttä *et al.*[99]	1			GIS-derived
Oliver *et al.*[127]		2		GIS-derived
Vanwolleghem *et al.*[155]	1(week)	3(week), 4(weekend)		Self-/parental perceived
Poor quality				
Broberg *et al.*[44]			1	GIS-derived
Moran *et al.*[119]			2	GIS-derived
Total number of associations (%)	***5 (20.0)***	***17 (68.0)***	***3 (12.0)***	
Total building density (3)				
Fair quality				
Cain *et al.*[50]	1(A), 1(C)	1(A), 1(C)		Direct observation/audit
Poor quality				
Broberg and Sarjala[45]			2	GIS-derived
Moran *et al.*[119]	2			GIS-derived
Total number of associations (%)	***4 (50.0)***	***2 (25.0)***	***2 (25.0)***	
Urban-rural status of home address (2)				
Fair quality				

Panter *et al.*[133]	3	9		GIS-derived
Panter *et al.*[134]	2			GIS-derived
Total number of associations (%)	***5 (35.7)***	***9 (64.3)***	***0 (0.0)***	
Land-use or land-cover (3)				
Good quality				
Carlson *et al.*[52]		5	1	GIS-derived
Fair quality				
Larsen *et al.*[100]			1	GIS-derived
Poor quality				
Broberg *et al.*[44]	1			GIS-derived
Total number of associations (%)	***1 (12.5)***	***5 (62.5)***	***2 (25.5)***	
Land-use mix (12)				
Good quality				
Van Dyck *et al.*[153]		2		Self-/parental perceived
Fair quality				
Carver *et al.*[54]	1(G)			GIS-derived
De Meester *et al.*[63]			1	Self-/parental perceived
D'Haese *et al.*[67]		2(G), 5(B)		Self-/parental perceived
Durand et al.[72]		1	1	Self-/parental perceived
Larsen *et al.*[100]			1	GIS-derived
Larsen *et al.*[102]	2	2		GIS-derived
Oreskovic *et al.*[130]	1			GIS-derived
Vanwolleghem *et al.*[155]	2(week)	2(week), 4(weekend)		Self-/parental perceived
Voorhees *et al.*[157]		1		GIS-derived
Poor quality				
Buliung *et al.*[48]		2		GIS-derived
Noonan *et al.*[124]		1		Self-/parental perceived
Total number of associations (%)	***6 (19.4)***	***22 (71.0)***	***3 (9.6)***	
Road/street patterns and connectivity (25)				
Good quality				
Carlson *et al.*[52]	3			GIS-derived
Ghekiere *et al.*[81]	1	1		GIS-derived
Trapp *et al.*[148]		1(B)		GIS-derived
Trapp *et al.*[149]		1(B)		GIS-derived
Fair quality				
Cain *et al.*[50]	1(A), 3(C)	4(A),1 (C)	1(C)	Direct observation/audit
Carlson *et al.*[51]	1	2	1	GIS-derived and perceived
Carver *et al.*[53]	1(B)			GIS-derived
Carver *et al.*[54]		1(G), 1(B)	1(B)	GIS-derived
Da Silva *et al.*[60]		3		GIS-derived
De Meester *et al.*[61]			1	Self-/parental perceived
Durand *et al.*[72]	1	2		Self-/parental perceived
Gropp *et al.*[84]	1			GIS-derived
Helbich *et al.*[86]		3		GIS-derived
Larsen *et al.*[100]		1		GIS-derived
Oliver *et al.*[127]	2			GIS-derived
Oreskovic *et al.*[130]		1		GIS-derived
Panter *et al.*[132]		1	3	GIS-derived
Panter *et al.*[134]		2	1	GIS-derived
Vanwolleghem *et al.*[155]		4(week), 4(weekend)		Self-/parental perceived
Voorhees *et al.*[157]		1	1	GIS-derived
Williams *et al.*[161]	1			GIS-derived
Poor quality				
Broberg and Sarjala[45]		2		GIS-derived
Guliani *et al.*[85]		1(B)	1(all), 1 (G)	GIS-derived
Larsen *et al.*[101]		1	1	GIS-derived
Noonan *et al.*[124]	1			Self-parental perceived
Total number of associations (%)	***16 (24.2)***	***38 (57.6)***	***12 (18.2)***	
Traffic exposure and safety features (37)				
Good quality				
Ghekiere *et al.*[81]		1		GIS-derived
Trapp *et al.*[148]	1(B)	2(G), 1(B)	1(G)	GIS-derived and perceived
Trapp *et al.*[149]		2(G), 1(B)	2(B)	GIS-derived and perceived
Van Dyck *et al.*[153]		1		Self-/parental perceived
Fair quality				
Cain *et al.*[50]	2(A), 2(C)	2(A), 2(C)	1(A), 1(C)	Direct observation/audit
Carlson *et al.*[51]	1	1		Self-/parental perceived
Carver *et al.*[53]		2(C)	1(A)	GIS-derived
Carver *et al.*[54]	1(G), 1 (B)	2(G), 1(B)	3(G), 2(B)	GIS-derived and perceived
Curriero *et al.*[59]	1			GIS-derived
Da Silva *et al.*[60]	1(intermediate SES)	2		Self-/parental perceived
De Meester *et al.*[63]	1			Self-/parental perceived
De Vries *et al.*[64]	5	3	1	Direct observation/audit
D'Haese *et al.*[65]		2		Self-/parental perceived
Ducheyne *et al.*[69]	1	2		Self-/parental perceived
Duncan *et al.*[71]		1		Self-/parental perceived
Durand *et al.*[72]		3	2	Self-/parental perceived
Gropp *et al.*[84]		1		GIS-derived
Helbich *et al.*[86]		1		GIS-derived
Larsen *et al.*[100]			3	GIS-derived
Larsen *et al.*[102]	1	4	3	GIS-derived
Lee *et al.*[103]			1	Self-/parental perceived
Oliver *et al.*[127]		2		GIS-derived
Oluyomi *et al.*[128]	6			Self-/parental perceived
Oreskovic *et al.*[130]		3		GIS-derived
Page *et al.*[131]		2		Self-/parental perceived

Panter *et al.*[132]			2	GIS-derived
Panter *et al.*[133]	2	3	3	Self-/parental perceived
Panter *et al.*[134]	1	4		GIS-derived and perceived
Van Dyck *et al.*[152]		1		Self-/parental perceived
Vanwolleghem *et al.*[153]		4(week), 4(weekend)		Self-/parental perceived
Voorhees *et al.*[157]	1	2		Self-/parental perceived
Williams *et al.*[161]	1			GIS-derived
Poor quality				
Broberg *et al.*[44]			1	GIS-derived
Broberg and Sarjala[45]		1	1	GIS-derived
Buliung *et al.*[48]	2	16	3	GIS-derived and perceived
Guliani *et al.*[85]	2(all), 1(G), 3(B)	1(all), 2(G)		GIS-derived and perceived
Larsen *et al.*[101]		1		GIS-derived
Total number of associations (%)	***36 (24.0)***	***83 (55.3)***	***31 (20.7)***	
Pedestrian infrastructure (24)				
Good quality				
Ghekiere *et al.*[81]		1		GIS-derived
Van Dyck *et al.*[153]		1		Self-/parental perceived
Fair quality				
Buck *et al.*[46]		2		GIS-derived
Cain *et al.*[50]	1(A), 6(C)	10(A), 2(C)	3(C)	Direct observation/audit
Carver *et al.*[52]	1(A)	1(C)		GIS-derived
Da Silva *et al.*[60]	1(intermediate SES)	9	2(high SES)	GIS-derived
De Meester *et al.*[63]			1	Self-/parental perceived
De Vries *et al.*[64]	2	2		Direct observation/audit
D'Haese *et al.*[65]		2		Self-/parental perceived
D'Haese *et al.*[67]	1(G)	2(B)	1(B)	Self-/parental perceived
Ducheyne *et al.*[69]			1	Self-/parental perceived
Durand *et al.*[72]	1	2	1	Self-/parental perceived
Gropp *et al.*[84]		1		GIS-derived
Helbich *et al.*[86]	1			GIS-derived
Larsen *et al.*[102]		1	3	GIS-derived
Lee *et al.*[103]			1	Self-/parental perceived
Oliver *et al.*[127]		2		Self-/parental perceived
Oluyomi *et al.*[128]	7			Self-/parental perceived
Oreskovic et a*l.*[130]		2		GIS-derived
Van Dyck *et al.*[152]		2		Self-/parental perceived
Vanwolleghem *et al.*[155]		2(week), 4(weekend)	2(week)	Self-/parental perceived
Voorhees *et al.*[157]		2		Self-/parental perceived
Poor quality				
Buliung *et al.*[48]		1		GIS-derived
Guliani *et al.*[85]	1(all), 1(B)	1(all), 2(G)	1(B)	GIS-derived and perceived
Total number of associations (%)	***23 (24.7)***	***54 (58.1)***	***16 (17.2)***	
Distance to facilities and/or amenities (25)				
Good quality				
Oliver *et al.*[126]			1	GIS-derived
Trapp *et al.*[148]			1(B)	GIS-derived
Trapp *et al.*[149]			1(G), 1(B)	GIS-derived
Fair quality				
Carlson *et al.*[51]			2	GIS-derived
Currerio *et al.*[59]			1	GIS-derived
De Meester *et al.*[63]	1			Self-/parental perceived
D'Haese *et al.*[65]	1			Online route planner
D'Haese *et al.*[67]		1(G), (2(B)		Self-/parental perceived
Duncan *et al.*[71]	1	1	1	GIS-derived and perceived
Helbich *et al.*[86]		2		GIS-derived
Larsen *et al.*[100]			2	GIS-derived
Larsen *et al.*[102]			4	GIS-derived
Lee *et al.*[103]	2			Self-/parental perceived
Oliver *et al.*[127]			2	GIS-derived
Page *et al.*[131]	2(B)	2(G)	2	GIS-derived and perceived
Panter *et al.*[132]			2	GIS-derived
Panter *et al.*[134]	4			GIS-derived
Voorhees *et al.*[157]			1	GIS-derived
Poor quality				
Broberg *et al.*[44]		1		GIS-derived
Broberg and Sarjala[45]			4	GIS-derived
Buliung *et al.*[48]		1	1	GIS-derived
Guliani *et al.*[85]			1(all), 1(G), 1(B)	GIS-derived
Kim and Lee[94]	1			GIS-derived
Larsen *et al.*[101]			1	GIS-derived
Moran *et al.*[119]		2	1	GIS-derived
Total number of associations (%)	***12 (21.8)***	***12 (21.8)***	***31 (56.4)***	
Count/proportion of facilities/amenities (13)				
Good quality				
Ghekiere *et al.*[81]	1			GIS-derived
Fair quality				
Cain *et al.*[50]	4(A), 5(C)	8(A), 6(C)		Direct observation/audit
Da Silva *et al.*[60]		2		GIS-derived
De Vries *et al.*[64]	2			Direct observation/audit
D'Haese *et al.*[65]	1	1		Self-/parental perceived
Durand *et al.*[72]			1	Self-/parental perceived
Lee *et al.*[103]		1		Self-/parental perceived
Oluyomi *et al.*[128]	1			Self-/parental perceived
Page et al.[131]		2		Self-/parental perceived
Voorhees *et al.*[157]	2	1		GIS-derived and perceived
Poor quality				

Broberg and Sarjala[45]			2	GIS-derived
Guliani *et al.*[85]		1(all), 1(G), 1(B)		GIS-derived
Larsen *et al.*[101]		1		GIS-derived
Total number of associations (%)	***16 (36.4)***	***25 (56.8)***	***3 (6.8)***	
Distance to green and open space (1)				
Poor quality				
Moran *et al.*[120]		1		GIS-derived
Total number of associations (%)	***0 (0.0)***	***1 (100.0)***	***0 (0.0)***	
Count/proportion of green/open space (7)				
Good quality				
Ghekiere *et al.*[81]	1	1		GIS-derived
Wang *et al.*[158]	1			GIS-derived
Fair quality				
Da Silva *et al.*[60]		3		GIS-derived
De Vries *et al.*[64]		1	1	Direct observation/audit
Kyttä *et al.*[99]			1	GIS-derived
Lee *et al.*[103]	1			Self-/parental perceived
Oreskovic *et al.*[130]		1		GIS-derived
Total number of associations (%)	***3 (27.3)***	***6 (54.5)***	***2 (18.2)***	
Type of green and open space (6)				
Fair quality				
Cain *et al.*[50]		1(A), 1(C)		Direct observation/audit
Da Silva *et al.*[60]		3		GIS-derived
Larsen *et al.*[100]	1			GIS-derived
Larsen *et al.*[102]	1	1		GIS-derived
Oluyomi *et al.*[128]	1			Self-/parental perceived
Poor quality				
Buliung *et al.*[48]		1		GIS-derived
Total number of associations (%)	***3 (30.0)***	***7 (70.0)***	***0 (0.0)***	
Walkability (17)				
Good quality				
Carlson *et al.*[52]	3			GIS-derived
D'Haese *et al.*[66]	1[b], 1(low SES)	4, 1(high SES)		GIS-derived
Molina-Garcia and Queralt[115]	1	1		GIS-derived
Van Dyck *et al.*[153]		1		Self-/parental perceived
Wang *et al.*[158]	1			GIS-derived
Fair quality				
Cain *et al.*[50]	2(A), 2(C)	1(A)	1(C)	Direct observation/audit
Carver *et al.*[54]		1(G), 1(B)		Self-/parental perceived
De Meester *et al.*[62]		4		GIS-derived
D'Haese *et al.*[65]		2		Self-/parental perceived
Duncan *et al.*[71]	1			GIS-derived
Molina-Garcia *et al.*[116]			1	GIS-derived
Panter *et al.*[133]	4	2		Self-/parental perceived
Panter *et al.*[134]		1		Self-/parental perceived
Sallis *et al.*[142]	1			GIS-derived
Van Dyck *et al.*[152]	1			Self-/parental perceived
Williams *et al.*[161]	11[c]			GIS-derived
Poor quality				
Kim and Lee[94]	1			Self-/parental perceived
Total number of associations (%)	***30 (58.8)***	***19 (37.3)***	***2 (3.9)***	
Facility and amenity index (6)				
Good quality				
Garcia-Cervantes *et al.*[80]	1[d]			Self-/parental perceived
Wang *et al.*[158]	1			Direct observation/audit
Fair quality				
Coombes *et al.*[55]		8		GIS-derived
Oliver *et al.*[127]	1(weekdays)	1(weekends)		GIS-derived
Williams *et al.*[161]	1			GIS-derived
Poor quality				
Broberg *et al.*[44]			1	GIS-derived
Total number of associations (%)	***4 (28.6)***	***9 (64.3)***	***1 (7.1)***	
Aesthetics (10)				
Fair quality				
Cain *et al.*[50]		3(A), 4(C)	1(A)	Direct observation/audit
D'Haese *et al.*[65]		2		Self-/parental perceived
D'Haese *et al.*[67]	1(B)			Self-/parental perceived
Durand *et al.*[72]	1	1		Self-/parental perceived
Gropp *et al.*[84]	1	1		Self-/parental perceived
Oluyomi *et al.*[128]	1		2	Self-/parental perceived
Page *et al.*[131]		2		Self-/parental perceived
Vanwolleghem *et al.*[155]	1(week)	3(week), 4(weekend)		Self-/parental perceived
Voorhees *et al.*[157]		1		Self-/parental perceived
Poor quality				
Noonan *et al.*[124]			1	Self-/parental perceived
Total number of associations (%)	***5 (16.7)***	***21 (70.0)***	***4 (13.3)***	

Abbreviations: G, girls; B, boys; A, adolescents; C, children; SES, neighborhood socio-economic status.
[a] +, number of positive significant associations; 0, non-significant associations; -, negative significant associations
[b] In the relation between walkability and walking for transport a moderating effect of neighborhood SES was found.
[c] Results stratified by gender, age groups and season.
[d] Results from bivariate adjusted analyses.

The built environment and participation in outdoor play/activity

Figure 4A shows that 17 different determinants have been investigated in relation to outdoor play/activity among children and youth. Several of these determinants had few studies (nine with two studies or fewer). We extracted 247 results from 21 studies for outdoor play/activity (Table 6). Traffic exposure and safety features (n=10) and count/proportion of facilities/amenities (n=9) were the most studied determinants. All six studies that reported positive associations for traffic and safety features found that less traffic and/or higher safety increased outdoor play/activity, but two of the studies were of poor quality. Of the studies that reported negative associations, two found that more traffic and safety concerns were associated with less outdoor play/activity,[43,73] whereas three presented results that conflicted with this.[37,50,121] In these studies, less traffic and/or higher safety were associated with less outdoor play/activity. The contradictory findings were mainly observed for adolescents and boys. Increased count/proportion of facilities/amenities was associated with more outdoor play/activity in six out of nine studies, but three of these studies also reported associations in the opposite direction.[37,50,74]

Table 6: Summary of the relations between the built environment and outdoor play/activity based on results derived from 21 studies.

Built environment determinant (number of studies)	**Results from adjusted analyses[a]** +	0	-	**Method of measurement (built environment)**
Population density (2)				
Fair quality				
Bringolf-Isler *et al.*[43]		4		GIS-derived
Rodriguez *et al.*[141]	2			GIS-derived
Total number of associations (%)	***2 (33.3)***	***4 (66.7)***	***0 (0.0)***	
Residential density (2)				
Good quality				
D'Haese *et al.*[68]		1		Self-/parental perceived
Fair quality				
Cain *et al.*[50]		1(A)	1(C)	Direct observation/audit
Total number of associations (%)	***0 (0.0)***	***2 (66.7)***	***1 (33.3)***	
Total building density (2)				
Fair quality				
Cain *et al.*[50]		2(A), 2(C)		Direct observation/audit
Poor quality				
Islam *et al.*[91]			2	GIS-derived
Total number of associations (%)	***0 (0.0)***	***4 (66.7)***	***2 (33.3)***	
Urban-rural status of home address (1)				
Fair quality				
Babey *et al.*[40]		2		Self-/parental perceived
Total number of associations (%)	***0 (0.0)***	***2 (100.0)***	***0 (0.0)***	
Land-use or land-cover (1)				
Poor quality				
McMinn *et al.*[112]	1	2	1	GIS-derived and GPS
Total number of associations (%)	***1 (25.0)***	***2 (50.0)***	***1 (25.0)***	
Land-use mix (1)				
Good quality				
D'Haese *et al.*[68]	1	1		Self-/parental reported
Total number of associations (%)	***1 (50.0)***	***1 (50.0)***	***0 (0.0)***	
Road/street patterns and connectivity (5)				
Good quality				
Aarts *et al.*[37]			1(G), 2(B)	Direct observation/audit
D'Haese *et al.*[68]			1	Self-/parental perceived
Fair quality				
Cain *et al.*[50]		3(A), 5(C)	2(A)	Direct observation/audit
Rodriguez *et al.*[141]			2	GIS-derived
Tappe *et al.*[146]			1	Self-/parental perceived
Total number of associations (%)	***0 (0.0)***	***8 (47.1)***	***9 (52.9)***	
Traffic exposure and safety features (10)				
Good quality				
Aarts *et al.*[37]	2(G), 3(B)		1(G), 4(B)	Direct observation/audit
D'Haese *et al.*[68]		1		Self-/parental perceived
Nguyen *et al.*[121]		3	1	GIS-derived and perceived

Fair quality				
Bringolf-Isler *et al.*[43]		1(A)	1(C)	Self-/parental perceived
Cain *et al.*[50]	1(A), 1(C)	3(A), (4C)	1(A)	Direct observation/audit
Page *et al.*[131]	1(G)	1(B)		Self-/parental perceived
Veitch *et al.*[156]	2	1		Self-/parental perceived
Poor quality				
Edwards *et al.*[73]			4	GIS-derived
Edwards *et al.*[74]	1			Direct observation/audit
Islam *et al.*[91]	2			Direct observation/audit
Total number of associations (%)	***13 (33.3)***	***14 (35.9)***	***12 (30.8)***	
Pedestrian infrastructure (6)				
Good quality				
Aarts *et al.*[37]			1(G)	Direct observation/audit
D'Haese *et al.*[68]		1		Self-/parental perceived
Nguyen *et al.*[121]		4		GIS-derived and perceived
Fair quality				
Cain *et al.*[50]	2(C)	10(A), 5(C)	1(A), 4(C)	Direct observation/audit
Tappe *et al.*[146]	1			Self-/parental perceived
Poor quality				
Edwards *et al.*[74]	1			Direct observation/audit
Total number of associations (%)	***4 (13.3)***	***20 (66.7)***	***6 (20.0)***	
Distance to facilities and/or amenities (5)				
Good quality				
D'Haese *et al.*[68]	1			Self-/parental perceived
Fair quality				
Babey *et al.*[40]	1	1		Self-/parental perceived
Page et al.[131]		6		GIS-derived and perceived
Tappe *et al.*[146]	1			Self-/parental perceived
Poor quality				
Edwards *et al.*[73]		5	3	GIS-derived
Total number of associations (%)	***3 (16.7)***	***12 (66.6)***	***3 (16.7)***	
Count/proportion of facilities/amenities (9)				
Good quality				
Aarts *et al.*[37]		3	1(G)	Direct observation/audit
Galvez *et al.*[79]	3	4		Direct observation and GIS
Fair quality				
Buck *et al.*[46]	1			GIS-derived
Cain *et al.*[50]	2(C)	11(A), 4(C)	5(C)	Direct observation/audit
Page *et al.*[131]		2		Self-/parental perceived
Rodrigues *et al.*[141]	2	4	2	GIS-derived
Tappe *et al.*[146]			2	Self-/parental perceived
Poor quality				
Edwards *et al.*[74]	4	1	1	Direct observation/audit
Islam *et al.*[91]	1			Direct observation/audit
Total number of associations (%)	***13 (24.5)***	***29 (54.7)***	***11 (20.8)***	
Distance to green and open space (1)				
Poor quality				
Edwards *et al.*[73]		2		GIS-derived
Total number of associations (%)	***0 (0.0)***	***2 (100.0)***	***0 (0.0)***	
Count or proportion of green/open space (7)				
Good quality				
Almanza *et al.*[38]	3	1		GIS-derived
Bloemsma *et al.*[42]	3	17[b]	2	GIS-derived and perceived
Galvez *et al.*[79]		2		Direct observation and GIS
Fair quality				
Bringolf-Isler *et al.*[43]		4		Self-/parental perceived
Rodrigues *et al.*[141]	1	1		GIS-derived
Ward *et al.*[159]	1			GIS-derived
Poor quality				
Edwards *et al.*[74]		1		GIS-derived
Total number of associations (%)	***8 (22.2)***	***26 (72.2)***	***2 (5.6)***	
Type of green and open space (2)				
Fair quality				
Cain *et al.*[50]		1(A), 1(C)		Direct observation/audit
Poor quality				
Edwards *et al.*[74]	1			GIS-derived
Total number of associations (%)	***1 (33.3)***	***2 (66.7)***	***0 (0.0)***	
Walkability (2)				
Fair quality				
Cain *et al.*[50]		1(A), 2(C)	2(A), 1(C)	Direct observation/audit
Sallis *et al.*[142]		1		GIS-derived
Total number of associations (%)	***0 (0.0)***	***4 (57.1)***	***3 (42.9)***	
Facility and amenity index (3)				
Fair quality				
Buck *et al.*[46]	1			GIS-derived
Tappe *et al.*[146]		2		Direct observation and GIS
Poor quality				
Moran *et al.*[120]	3[c]			Self-/parental perceived
Total number of associations (%)	***4 (66.7)***	***2 (33.3)***	***0 (0.0)***	
Aesthetics (4)				
Good quality				
Aarts *et al.*[37]			1(B)	Direct observation/audit
Fair quality				
Cain *et al.*[50]	2(C)	4(A), 1(C)	1(C)	Direct observation/audit
Page *et al.*[131]		2		Self-/parental perceived
Tappe *et al.*[146]	2			Self-/parental perceived

Total number of associations (%)	***4 (30.8)***	***7 (53.8)***	***2 (15.4)***	

Abbreviations: A, adolescents; C, children; G, girls; B, boys.
[a]+, number of positive significant associations; 0, non-significant associations; -, negative significant associations
[b] Results from bivariate analyses stratified by type of activity conducted at green spaces.
[c] Stratified by outdoor location.

The built environment and participation in organized sports

We found that eight out of 19 built environment categories had been examined as determinants of participation in organized sports (Figure 4B). In total, 37 results from 11 studies were extracted for this outcome (Table 7). All the studies were of either good or fair quality. Walkability was the most investigated determinant (n=4), followed by distance to facilities/amenities, count/proportion of facilities/amenities, and the facility/amenity index, which were investigated in three studies each. The majority of the results for neighborhood walkability were non-significant (71.4%). The five significant associations reported for distance to facilities/amenities were contradictory. Longer distance was associated with more participation in organized sports in one study,[67] but reduced the likelihood of participating in sports activities in another study.[138] In a third study, the authors reported that greater access to facilities increased participation in organized sports among 10- to 11-year olds.[131]

Table 7: Summary of the relations between the built environment and organized sports based on results derived from 11 studies.

Built environment determinant (number of studies)	**Results from adjusted analyses[a]** +	0	-	**Method of measurement (built environment)**
Land-use mix (1)				
Fair quality				
D'Haese *et al.*[67]		1(G)		Self-/parental perceived
Total number of associations (%)	***0 (0.0)***	***1 (100.0)***	***0 (0.0)***	
Traffic exposure and safety features (1)				
Fair quality				
Page *et al.*[131]		2		Self-/parental perceived
Total number of associations (%)	***0 (0.0)***	***2 (100.0)***	***0 (0.0)***	
Distance to facilities and/or amenities (3)				
Good quality				
Reimers *et al.*[138]		1(B)	1(G)	GIS-derived
Fair quality				
D'Haese *et al.*[67]	1(G)[b]	1(G)[b]		Self-/parental perceived
Page *et al.*[131]	2(G), 1(B)	3		GIS-derived and perceived
Total number of associations (%)	***4 (40.0)***	***5 (50.0)***	***1 (10.0)***	
Count/proportion of facilities/amenities (3)				
Good quality				
Galvez *et al.*[79]		4		Direct observation and GIS
Fair quality				
Buck *et al.*[46]		1		GIS-derived
Page *et al.*[131]	1(G)	1(B)		Self-/parental perceived
Total number of associations (%)	***1 (14.3)***	***6 (85.7)***	***0 (0.0)***	
Count or proportion of green/open space (1)				
Good quality				
Galvez *et al.*[79]		2		Direct observation and GIS
Total number of associations (%)	***0 (0.0)***	***2 (100.0)***	***0 (0.0)***	
Walkability (4)				
Good quality				
D'Haese *et al.*[66]	1[c]	1(high SES)	1(low SES)	GIS-derived
Fair quality				
De Meester *et al.*[62]		2		GIS-derived
Molina-Garcia *et al.*[116]		1		GIS-derived
Sallis *et al.*[142]		1		GIS-derived
Total number of associations (%)	***1 (14.3)***	***5 (71.4)***	***1 (14.3)***	
Facility and amenity index (3)				
Good quality				
Garcia-Cervantes *et al.*[80]	1[d]			GIS-derived and perceived

Graham *et al.*[82]		2		GIS-derived
Fair quality				
Buck *et al.*[46]		1		GIS-derived
Total number of associations (%)	***1 (25.0)***	***3 (75.0)***	***0 (0.0)***	
Aesthetics (2)				
Fair quality				
D'Haese *et al.*[67]		2		Self-/parental perceived
Page *et al.*[131]		2		Self-/parental perceived
Total number of associations (%)	***0 (0.0)***	***4 (100.0)***	***0 (0.0)***	

Abbreviations: G, girls; B, boys, SES, neighborhood socio-economic status.
[a] +, number of positive significant associations; 0, non-significant associations; -, negative significant associations.
[b] Change in child's perception was positively associated, whereas change in parental was non-significantly associated with sport participation.
[c] In the relation between walkability and sport participation a moderating effect of neighborhood SES was found.
[d] Results from bivariate adjusted analyses.

The built environment and well-being

Figure 4C shows that only six different determinant categories were considered in the studies examining relationships between the built environment and well-being, of which three were neighborhood green/open space factors. The count/proportion of green/open space was the most frequently studied determinant (n=7). The other determinants had been investigated in two studies or fewer. We extracted 123 results for the well-being outcomes (Table 8). Increased count/proportion of green/open space was associated with fewer behavioral problems,[39] less perceived stress,[75] greater well-being,[76,90] and better self-perceived health[99] but unrelated to quality of life.[110] All the studies that reported any significant associations between count/proportion of green/open space and well-being were of either good or fair quality. Two studies of good quality examined distance to green/open space as a determinant of well-being. One of the studies reported that longer distance to green space was associated with increased risk of hyperactivity/inattention and peer relationship problems,[106] whereas the other study did not find any favorable associations.[39] The studies considering neighborhood aesthetics found that less favorable aesthetic conditions were associated with more behavioral and mental health problems,[49,145] which accounted for 58.3% of the associations extracted.

Table 8: Summary of the relations between the built environment and well-being based on results derived from 11 studies.

Built environment determinant		**Results from adjusted analyses[a]**		**Method of measurement**
(number of studies)	+	0	-	**(built environment)**
Traffic exposure and safety features (2)				
Fair quality				
Butler *et al.*[49]		4		Self-/parental perceived
Singh and Ghandour[145]		1	1	Self-/parental perceived
Total number of associations (%)	***0 (0.0)***	***5 (83.3)***	***1 (16.7)***	
Count or proportion of facilities/amenities (1)				
Fair quality				
Butler *et al.*[49]	2	6		Self-/parental perceived
Total number of associations (%)	***2 (25.0)***	***6 (75.0)***	***0 (0.0)***	
Distance to green and open space (2)				
Good quality				
Amoly *et al.*[39]		9		GIS-derived
Markevych *et al.*[106]		4	2	GIS-derived
Total number of associations (%)	***0 (0.0)***	***13 (86.7)***	***2 (13.3)***	
Count or proportion of green/open space (7)				
Good quality				
Amoly *et al.*[39]		18	9	GIS-derived
Huynh et *al.*[90]	4	9		GIS-derived
Fair quality				

Feda *et al.*[75]	1			GIS-derived
Feng and Astell-Burt[76]	3	7	8	Other and perceived
Kyttä et *al.*[99]	1			GIS-derived
Ward *et al.*[159]	6			GIS-derived
Poor quality				
McCracken *et al.*[110]		4		GIS-derived
Total number of associations (%)	***15 (21.4)***	***38 (54.3)***	***17 (24.3)***	
Type of green and open space (1)				
Good quality				
Kim *et al.*[95]	5	7		GIS-derived
Total number of associations (%)	***5 (41.7)***	***7 (58.3)***	***0 (0.0)***	
Aesthetics (2)				
Fair quality				
Butler *et al.*[49]	2	4		Self-/parental perceived
Singh and Ghandour[145]		1	5	Self-/parental perceived
Total number of associations (%)	***2 (16.6)***	***5 (41.7)***	***5 (41.7)***	

[a]*+, number of positive significant associations; 0, non-significant associations; -, negative significant associations.*

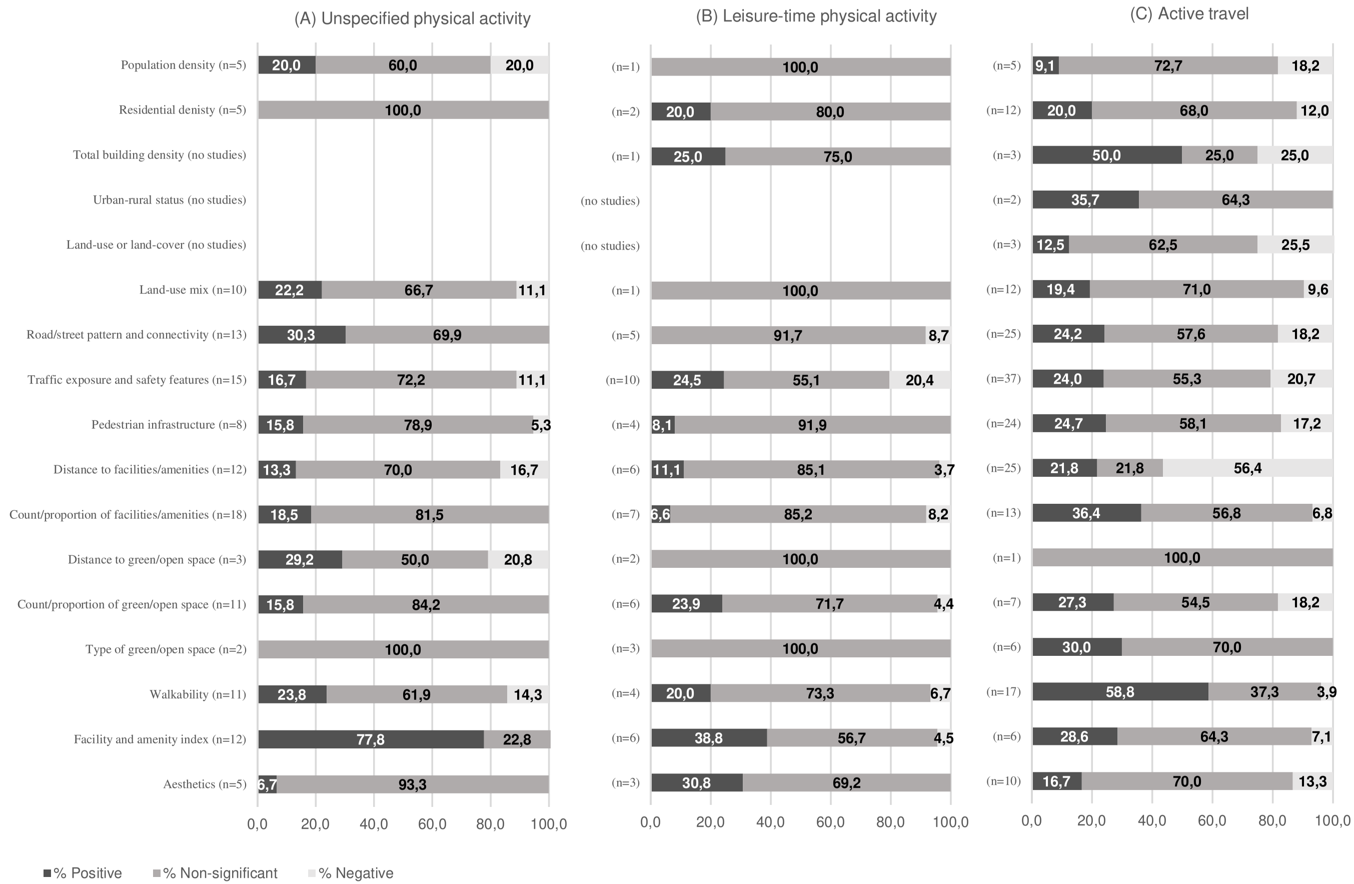

Figure 3. Synthesized overview of the findings for each determinant and (A) unspecified PA, (B) leisure-time PA, and (C) active travel.

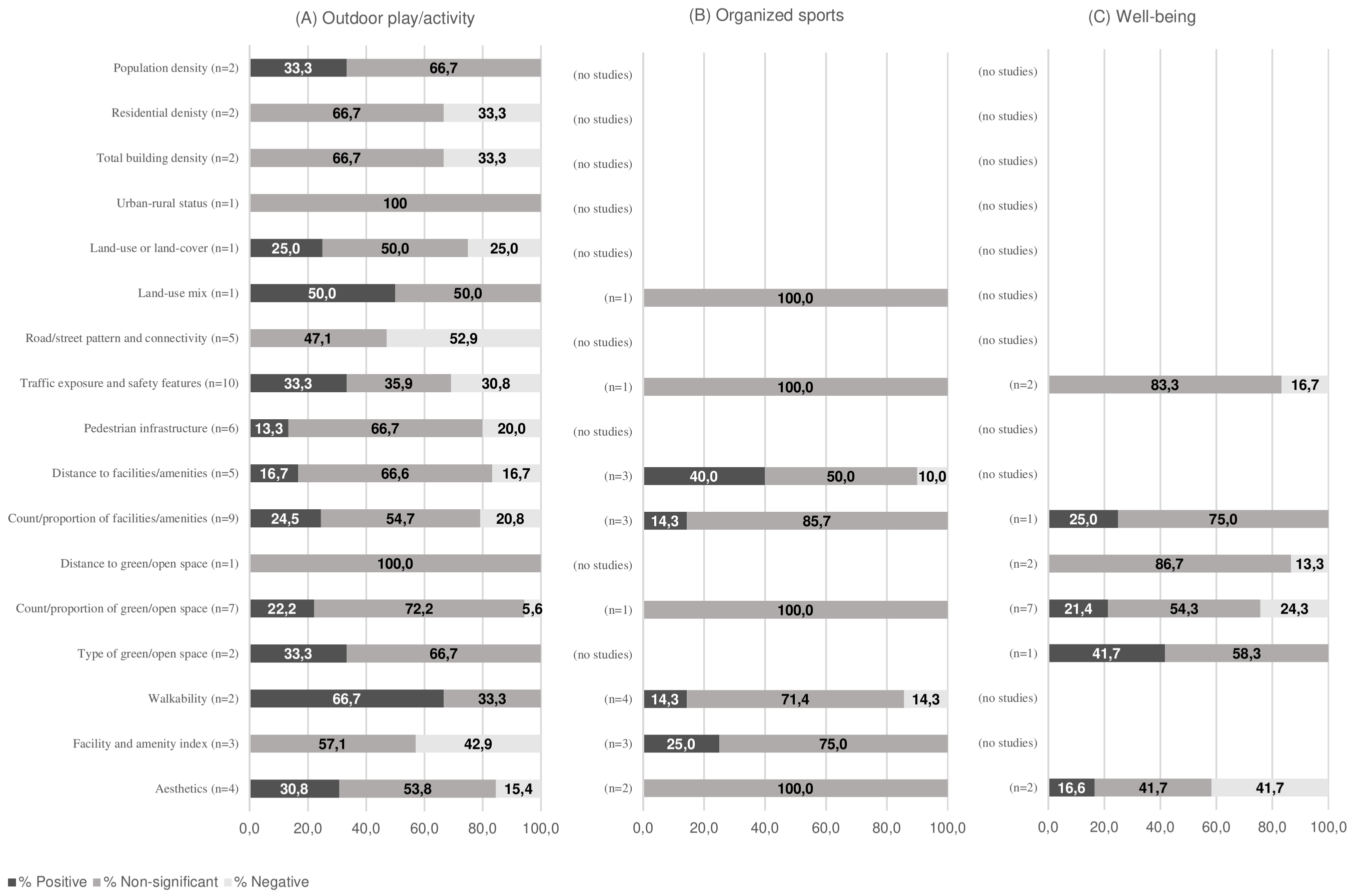

Figure 4. Synthesized overview of the findings for each determinant and (A) outdoor play/activity, (B) organized sports, and (C) well-being.

Discussion

This systematic review has comprehensively evaluated and summarized evidence from 127 studies investigating the built environment determinants of activity participation and well-being among children and adolescents. We found that a broad range of environmental features were considered, which underscores the complexity of determinants. The built environment was most extensively studied in relation to active travel and unspecified PA, and the evidence suggests associations between some of the determinants and the two outcomes. Limited evidence existed for the relationship between the built environment and well-being among children and adolescents.

A novel finding in this review was that the facility and amenity index was most consistently related to unspecified PA and to some extent leisure-time PA. The majority of the studies supporting such a beneficial association were of good quality. The facility and amenity index is a combined measure or score of several determinants, such as facilities, green space, traffic safety, and pedestrian infrastructure.[33] Composite measures include synergy between different determinants, and a higher facility and amenity index score represents neighborhoods that, for example, have both mixed residential and commercial land-use, connected streets with direct access for pedestrians, and a variety of facilities. The determinants likely influence health through complex interactions, and assessing relationships through a composite measure may result in a cumulative impact.[164] However, it is not straightforward to use composite determinants. Conceptual, as well as empirical, knowledge of the interrelationships among the determinants, along with knowledge about their relationships with specific outcomes, is required to reasonably assemble them into indexes.[165] Additionally, composite measures are often inconsistently defined and inadequately reported in studies.[33] These inconsistencies lead to difficulties in interpreting the findings, which in turn complicates the use of results for planning purposes.

Another key finding was a lack of consistency across studies for the rest of the built environment determinants in relation to unspecified PA and leisure-time PA. There could be two main explanations for this inconsistency. First, the included studies were highly methodologically heterogeneous. The outcomes, neighborhood areas and built environment determinants were measured and operationalized in multiple ways across studies. Different measurement approaches can provide distinct and inconsistent results between studies and in turn mask consistencies in the syntheses of evidence.[166,167] Second, this systematic review considered subjects aged between five and 18 years. According to the socio-ecological model of health, there are dynamic relations between the environment and individuals. The same built environment determinants might influence people's health and well-being differently depending on factors such as age, which also could explain our inconsistent finding.[168,169] Nevertheless, the inconsistent results in associations between the built environment and PA is in line with a previously published literature review in which no built environment determinants were unambiguously associated with PA.[14] Contrary to the review findings of Ding *et al.*[14] who reported that higher residential density was related to increased PA in children, we found no favorable associations for residential density. The relationship between density and the ability to participate in activities appears to be complex. Kyttä *et al.*[170] have suggested that the association between density and PA is mediated by accessibility. A dense area without arenas for PA, or where such arenas have blocked access because of heavy traffic, will not enhance participation.

Compared to unspecified PA and leisure-time PA, we found more consistency in associations between several of the determinants and active travel. Neighborhoods with low traffic and/or high safety, pedestrian infrastructure for walking/biking, shorter distances to facilities, and greater walkability could be beneficial in terms of facilitating active travel behavior. Our findings corresponds with the results from several previous reviews of the determinants of active travel.[17-19] Although the vast majority of our results derived from cross-sectional studies of fair quality, our findings provide additional confirmatory evidence that these determinants are promising in terms of promoting active travel between different destinations in the neighborhood among children and adolescents.

The activity behaviors of children and adolescents are influenced by the different contexts in which the activities are undertaken.[3] Active travel between destinations only occurs within the built environment, whereas unspecified and leisure-time PA can be carried out in other contexts (e.g., indoors). The active travel behavior of children and adolescents thus depends more likely on the different facilitators and barriers in the built environment than the other two physical activity outcomes, which is reflected in our findings. Furthermore, the unspecified and leisure-time PA outcomes mainly considered children's and adolescents' total activity independent of context. Assessing PA independent of context can result in low specificity of PA measures, which can explain both the absence of associations and the inconsistent results identified for the determinants of these two outcomes. A solution to increase the specificity of measures is to monitor the activity levels of the target group and locations simultaneously, using both accelerometers and GPS.[171] A few studies included in this review measured activity outcomes in this manner,[39,96,112,141,160,161] among which one found that the highest physical activity intensities occurred in green space compared to other outdoor and indoor areas.[160]

Many built environment determinants of outdoor play/activity have been investigated, but only a few studies examined several of these determinants. These few studies provided limited evidence. Nevertheless, in studies of good or fair quality, we found some consistent associations between less traffic and/or higher safety and more outdoor play/activity, particularly among children, whereas contradictory results were observed for adolescents. These findings can be explained by the fact that children generally have more parental constraints than adolescents and that traffic danger and safety concerns are often important reasons for parental restrictions.[172,173] Consequently, children and adolescents use their neighborhood surroundings differently, which can provide mixed results in these age groups. Nearby streets may offer opportunities for outdoor play/activity for children, and it has been pointed out that cul-de-sacs could be a key determinant in that regard.[174] The disparities found between age groups highlight the importance of stratified analyses to detect such variations. The results also show that ensuring low traffic exposure or more safety features could potentially be relevant to support outdoor play/activity among children. Similar findings have been reported for children below the age of seven.[30] However, more research is needed to clarify the potential of traffic- and safety-related determinants to support outdoor play/activity.

We identified a limited number of studies addressing relationships between the built environment and participation in organized sports. Although these studies were of good or fair quality, the 37 extracted results did not provide any clear evidence from which to draw conclusions, especially considering that several of these results were contradictory. In regard to well-being, a few studies provided some insight showing that more neighborhood green/open space was linked to fewer behavioral problems, less perceived stress, greater well-being, and better self-perceived health. Similar findings have been reported elsewhere, both among children and adolescents[23,24] and in the general population.[25] As reported in previous reviews, we also identified that poorer neighborhood aesthetic conditions were associated with more mental health and behavioral problems.[22,27] However, only a small number of studies examined well-being outcomes, and there were more non-significant than positive findings. Thus, this review continue to support the inconclusive nature of associations reported in previous syntheses.[22-25,27]

Although investigations of the built environment determinants of health have increased rapidly over the last two decades, this field of research is still quite young and under development.[11] We have identified that there remains a substantial gap in understanding the relations between built environment determinants and well-being as well as other activity outcomes, such as organized and social activities. Further, study quality issues and methodological challenges, such as inconsistent use of operational definitions and measures of the environmental determinants, remain to be resolved.[33] Thus, it might be too early to dismiss the potential of all non-significantly or inconsistently associated determinants to support participation in activities and well-being in childhood and adolescence.

Strengths and limitations of this review

A major strength of this review is its inclusivity. We were able to consider a broad range of built environment determinants and health outcomes from recently published studies. We grouped the outcomes and synthesized the results separately for each outcome category. This enabled an outcome-specific synthesis of associations, which addressed an important shortcoming in the existing reviews. Our findings are based on adjusted associations, with a few exceptions. Due to prominent confounding issues in associations between the built environment and health, this is considered a strength.[11] We also assessed if confounders were adequately considered in each study, and the limited adjustment or omission of important confounders was accounted for by the quality assessment weighting.

We acknowledge the importance of measuring the built environment using different methods to provide evidence in this field. Therefore, studies using a variety of measurement approaches were included in this review, resulting in high heterogeneity across studies. This can be viewed as both a strength and a limitation. Mode of measurement is shown to greatly influence the consistency of associations between the built environment and PA.[14] Since the focus of this review was to provide an outcome-specific synthesis, we did not synthesize the results based on different measurement modes. Furthermore, we assigned similar built environment constructs to predetermined categories to facilitate the interpretation of the results. The determinants were measured differently across studies and some determinants may have been grouped incorrectly. Nevertheless, we argue it is important to consider the total evidence in this outcome-specific synthesis, but future reviews could provide results specific to different modes of measurement.

Although a large number of studies was reviewed, it is possible that we missed articles in the retrieval process. Only papers written in English were included, and we had limited access to databases. Furthermore, the exclusion of unpublished/gray literature could have been a weakening factor as studies showing statistically significant, positive results may are more likely to be published than those that do not.[175] Consequently, this present systematic review is vulnerable to publication bias, and the findings are likely to be biased toward positive results. Nevertheless, we tried to minimize the likelihood of publication bias in the analysis and synthesis of the review findings by counting all positive, negative and non-significant results from the articles. We were not able to use two independent reviewers throughout the entire review process due to time and resource constraints. However, we tried to reduce the risk of bias at all stages, and we particularly focused on providing a rigorous quality assessment.

Conclusion

This evidence synthesis follows up on previous reviews of the built environment determinants of health in childhood and adolescence and includes an assessment of the most recently published literature on health-promoting environments for children and adolescents. We found that the facility and amenity index was consistently associated with unspecified PA and to some extent leisure-time PA. The small number of studies examining participation in organized sports and well-being provided limited evidence, which impedes us from drawing specific conclusions regarding relationships between the built environment and these outcomes. We found most consistent associations for active travel and the determinants less traffic exposure and/or higher safety, pedestrian infrastructure for walking/biking, shorter distances to facilities, and higher walkability. Policies and planning processes should consider these determinants to strengthen children’s and adolescents’ health and well-being. However, there are remaining research gaps and important avenues for future research that need to be addressed before more specific and robust conclusions can be drawn.

Recommendations for practice

The evidence from this review suggest that the determinants less traffic exposure and/or higher safety, pedestrian infrastructure for walking/biking, shorter distances to facilities, and higher walkability may be essential in supporting children and adolescents to travel actively to and from their daily destinations. This finding ought to be used for improvement and specification of relevant public health and planning policies as well as spatial planning practice. It must be emphasized that this recommendation is largely based on results from cross-sectional studies, which is problematic as associations do not equal causation. However, the associations observed were largely desirable and appear to outweigh unfavorable levels of physical inactivity.

Recommendations for research

One key area for further research is to investigate a greater variety of activity outcomes in more depth. Increased focus on a broader range of activities could contribute to expand our knowledge on how the built environment can provide opportunities for activity participation. There is also an urgent need for studies examining the built environment determinants of positive mental health and well-being. Neighborhood green space seems to have gained the focus in studies addressing relationships between the built environment and well-being up to date. In this respect, we suggest that more attention be directed toward a broader spectrum of built environment determinants. Some determinants may not be directly associated with activity participation or well-being, and potential mediators and effect modifications need more exploration. Furthermore, subgroup analyses and increased specificity in outcome and built environment measures, as well as clear definitions of the geographical units and built environment determinants of interest, are important to strengthen the study results. As identified by the quality assessment, there is a need for improved study quality. Particularly, the consideration of confounders has to be more rigorous, and in studies with longitudinal assessment, there should be strategies to minimize loss to follow-up. The vast majority of the reviewed studies relied on cross-sectional designs, and we request more research adopting longitudinal designs and natural experiments to strengthen any causal associations.

In this current systematic review, the focus was on the entire segment of the younger population and to providing an outcome- and determinant-specific synthesis. The complexity of built environment determinants and their links to activity participation and well-being in childhood and adolescence revealed herein raise additional issues that warrant detailed exploration in future evidence syntheses. To improve the review findings and to give a clearer picture of the evidence base, focusing on a narrower age-range could add additional insight. Further, it seems necessary to synthesize results based on objective and perceived environmental measures separately due to the heterogeneity in measurement approaches.

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Conflicts of interest

There is no conflict of interest in this project.

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Appendix I: An overview of the full search strategies for each database.

PubMed

Search	Query
#1	"Built environment" [Title/Abstract] OR "Physical environment" [Title/Abstract] OR "Local community" [Title/Abstract] OR Community [Title/Abstract] OR Neighborhood [MeSH] OR "Living environment" [Title/Abstract] OR "Urban environment" [Title/Abstract] OR Environment design [MeSH] OR "Community design" [Title/Abstract] OR "Urban design" [Title/Abstract] OR "Neighborhood design" [Title/Abstract] OR "Environment* feature*" [Title/Abstract] OR "Community feature*" [Title/Abstract] OR "Natural environment" [Title/Abstract] OR Greenspace [Title/Abstract] OR "Green space" [Title/Abstract] OR "Open space" [Title/Abstract]
#2	GIS [Title/Abstract] OR Geographic information systems [MeSH] OR "Spatial measure*" [Title/Abstract] OR Objective measure* [MeSH] OR Perceived measure* [MeSH] OR Perceived environment [MeSH] OR Objective environment [MeSH]
#3	Participation in activity [MeSH] OR Active living [MeSH] OR Active lifestyle [MeSH] OR Physical activity [MeSH] OR Active transport [MeSH] OR "Active travel" [Title/Abstract] OR "Active commuting" [Title/Abstract] OR Walking [Title/Abstract] OR Biking [Title/Abstract] OR Cycling [Title/Abstract] OR Leisure activity [MeSH] OR Play [Title/Abstract] OR "Outdoor play" [Title/Abstract] OR "Outdoor recreation" [Title/Abstract] OR Recreational activity [MeSH] OR "Meaningful activity" [Title/Abstract] OR Social activity [MeSH] OR Being with friend [MeSH] OR Organized activity [MeSH] OR "Structured sport*" [Title/Abstract] OR "Structured exercise" [Title/Abstract] OR "Structured activity" [Title/Abstract] OR Well-being [MeSH] OR Mental health [MeSH] OR Self-reported health [MeSH] OR "Self-perceived health" [Title/Abstract] OR Self-esteem [MeSH] OR Cognitive function [MeSH] OR Pro-social behavior [MeSH] OR Happiness [Title/Abstract] OR Quality of life [MeSH] OR Cope [MeSH] OR Mental disorder [MeSH] OR "Mental health problem*" [Title/Abstract] OR "Psychological distress" [Title/Abstract] OR "Peer problem*" [Title/Abstract] OR "Conduct problem*" [Title/Abstract] OR "Emotional problem*" [Title/Abstract]
#4	Child [MeSH] OR Child* [Title/Abstract] OR Adolescent [MeSH] OR Girl* [Title/Abstract] OR Boy* [Title/Abstract] OR "Elementary schooler*" [Title/Abstract] OR "Middle schooler*" [Title/Abstract] OR "Primary schooler*" [Title/Abstract] OR "Secondary schooler*" [Title/Abstract] OR "High schooler*" [Title/Abstract] OR Kids [Title/Abstract] OR Pupils [Title/Abstract] OR "Young people" [Title/Abstract]
#5	#1 AND #2 AND #3 AND #4 Limited to 2010, published and English language
Results from original search conducted on April 11th 2017: 1679 records	
Results from updated search conducted on June 10th 2018: 160 records	

MEDLINE

Search	Query
#1	"Built environment" [kw] OR "Physical environment" [kw] OR "Local community" [kw] OR Community [kw] OR Neighborhood [kw] OR "Living environment" [kw] OR "Urban environment" [kw] OR Environment design [MH] OR "Community design" [kw] OR "Urban design" [kw] OR "Neighborhood design" [kw] OR "Environment* feature*" [kw] OR "Community feature*" [kw] OR "Natural environment" [kw] OR Environment [MH] OR "Green space" [kw] OR "Open space" [kw]
#2	GIS [kw] OR Geographic information systems [MH] OR "Spatial measure*" [kw] OR "Objective measure*" [kw] OR "Perceived measure*" [kw] OR Perception [MH] OR Objective environment [MH]
#3	"Participation in activity" [kw] OR "Active living" [kw] OR "Active lifestyle" [kw] OR Exercise [MH] OR "Active transport" [kw] OR "Active travel" [kw] OR "Active commuting" [kw] OR Walking [MH] OR Biking [kw] OR Cycling [MH] OR Leisure activity [MH] OR Play and playthings [MH] OR "Outdoor play" [kw] OR Recreation [MH] OR "Recreational activity" [kw] OR "Meaningful activity" [kw] OR "Social activity" [kw] OR Interpersonal relations [MH] OR "Organized activity" [kw] OR Sports [MH] OR "Structured activity" [kw] OR Well-being [kw] OR Mental health [MH] OR Health status [MH] OR "Self-perceived health" [kw] OR Self-concept [MH] OR "Cognitive function" [kw] OR Social behavior [MH] OR Happiness [MH] OR Quality of life [MH] OR Adaption, psychological [MH] OR Mental disorders [MH] OR "Mental health problem*" [kw] OR Stress, psychological [MH] OR Child behavior disorder [MH]
#4	Child [MH] OR Child* [kw] OR Adolescent [MH] OR Girl* [kw] OR Boy* [kw] OR "Elementary schooler*" [kw] OR "Middle schooler*" [kw] OR "Primary schooler*" [kw] OR "Secondary schooler*" [kw] OR "High schooler*" [kw] OR Kids [kw] OR Pupils [kw] OR "Young people" [kw]
#5	#1 AND #2 AND #3 AND #4 Limited to 2010, published and English language
Results from original search conducted on April 11th 2017: 839 records	
Results from updated search conducted on June 10th 2018: 97 records	

Web of Science

Search	Query
#1	"Built environment" OR "Physical environment" OR "Local community" OR Community OR Neighborhood OR Neighbourhood OR "Living environment" OR "Urban environment" OR "Environment design" OR "Community design" OR "Urban design" OR "Neighborhood design" OR "Neighbourhood design" OR "Environment* feature*" OR "Community feature*" OR "Natural environment*" OR Greenspace OR "Green space" OR "Open space"
#2	GIS OR "Geographic information systems" OR "Spatial measure*" OR "Objective measure*" OR "Perceived measure*" OR "Perceived environment" OR "Objective environment"
#3	"Participation in activity" OR "Active living" OR "Active lifestyle" OR Exercise* OR "Active transport" OR "Active travel" OR "Active commute*" OR Walking OR Biking OR Cycling OR "Leisure activity*" OR Play* OR "Outdoor play*" OR "Outdoor recreation*" OR "Recreational activity" OR "Meaningful activity" OR "Social activity" OR "Being with friend*" OR "Non-organized activity" OR "Organized activity" OR "Structured activity" OR "Structured exercise*" OR "Structured sport*" OR Well-being OR Wellbeing" OR "Mental* health*" OR "Self-reported health" OR "Self-perceived health" OR Self-esteem OR "Cognitive function*" OR "Pro-social behavior" OR "Pro-social behaviour" OR Happiness OR "Quality of life*" OR Cope* OR "Mental disorder*" OR "Mental health problem*" OR "Psychological distress" OR "Peer problem*" OR "Hyperactivity problem*" OR "Conduct problem*" OR "Emotional problem*"
#4	Child* OR Adolescent* OR Girl* OR Boy* OR "Elementary schooler*" OR "Middle schooler*" OR "Primary schooler*" OR "Secondary schooler*" OR "High schooler*" OR Kids OR Pupils OR "Young people"
#5	#1 AND #2 AND #3 AND #4 Limited to 2010, published and English language
Results from original search conducted on April 11th 2017: 518 records	
Results from updated search conducted on June 10th 2018: 115 records	

Embase

Search	Query
#1	“Built environment” OR “Physical environment” OR “Local community” OR Community OR Neighborhood OR Neighbourhood OR “Living environment” OR “Urban environment” OR “Environment design” OR “Community design” OR “Urban design” OR “Neighborhood design” OR “Neighbourhood design” OR “Environment* feature*” OR “Community feature*” OR “Natural environment*” OR Greenspace OR “Green space” OR “Open space””
#2	GIS OR “Geographic information systems” OR “Spatial measure*” OR “Objective measure*” OR “Perceived measure*” OR “Perceived environment” OR “Objective environment”
#3	“Participation in activity” OR “Active living” OR “Active lifestyle” OR Exercise* OR “Active transport” OR “Active travel” OR “Active commute*” OR Walking OR Biking OR Cycling OR “Leisure activity*” OR Play* OR “Outdoor play*” OR “Outdoor recreation*” OR “Recreational activity” OR “Meaningful activity” OR “Social activity” OR “Being with friend*” OR “Non-organized activity” OR “Organized activity” OR “Structured activity” OR “Structured exercise*” OR ”Structured sport*” OR Well-being OR Wellbeing” OR “Mental* health*” OR “Self-reported health” OR “Self-perceived health” OR Self-esteem OR “Cognitive function*” OR ”Pro-social behavior” OR “Pro-social behaviour” OR Happiness OR “Quality of life*” OR Cope* OR “Mental disorder*“ OR “Mental health problem*” OR “Psychological distress” OR “Peer problem*” OR “Hyperactivity problem*” OR “Conduct problem*” OR “Emotional problem*”
#4	Child* OR Adolescent* OR Girl* OR Boy* OR “Elementary schooler*” OR “Middle schooler*” OR “Primary schooler*” OR “Secondary schooler*” OR “High schooler*” OR Kids OR Pupils OR “Young people”
#5	#1 AND #2 AND #3 AND #4 Limited to 2010, published and English language
Results from original search conducted on April 11th 2017: 431 records	
Results from updated search conducted on June 10th 2018: 77 records	

PsychINFO

Search	Query
#1	(“Built environment” OR “Physical environment” OR “Local community” OR Community OR Neighborhood OR Neighbourhood OR “Living environment” OR “Urban environment” OR “Environment design” OR “Community design” OR “Urban design” OR “Neighborhood design” OR “Neighbourhood design” OR “Environment* feature*” OR “Community feature*” OR “Natural environment*” OR Greenspace OR “Green space” OR “Open space””) [title, abstract, key concept]
#2	(GIS OR “Geographic information systems” OR “Spatial measure*” OR “Objective measure*” OR “Perceived measure*” OR “Perceived environment” OR “Objective environment”) [title, abstract, key concept]
#3	(“Participation in activity” OR “Active living” OR “Active lifestyle” OR Exercise* OR “Active transport” OR “Active travel” OR “Active commute*” OR Walking OR Biking OR Cycling OR “Leisure activity*” OR Play* OR “Outdoor play*” OR “Outdoor recreation*” OR “Recreational activity” OR “Meaningful activity” OR “Social activity” OR “Being with friend*” OR “Non-organized activity” OR “Organized activity” OR “Structured activity” OR “Structured exercise*” OR ”Structured sport*” OR Well-being OR Wellbeing” OR “Mental* health*” OR “Self-reported health” OR “Self-perceived health” OR Self-esteem OR “Cognitive function*” OR ”Pro-social behavior” OR “Pro-social behaviour” OR Happiness OR “Quality of life*” OR Cope* OR “Mental disorder*“ OR “Mental health problem*” OR “Psychological distress” OR “Peer problem*” OR “Hyperactivity problem*” OR “Conduct problem*” OR “Emotional problem*”) [title, abstract, key concept]
#4	(Child* OR Adolescent* OR Girl* OR Boy* OR “Elementary schooler*” OR “Middle schooler*” OR “Primary schooler*” OR “Secondary schooler*” OR “High schooler*” OR Kids OR Pupils OR “Young people”) [title, abstract, key concept]
#5	#1 AND #2 AND #3 AND #4 Limited to 2010, published and English language
Results from original search conducted on April 11th 2017: 189 records	
Results from updated search conducted on June 11th 2018: 40 records	

CINAHL

Search	Query
#1	"Built environment" [kw] OR "Physical environment" [kw] OR "Local community" [kw] OR Community [kw] OR Neighborhood [kw] OR Neighbourhood [kw] OR "Living environment" [kw] OR "Urban environment" [kw] OR "Environment design" [kw] OR "Community design" [kw] OR "Urban design" [kw] OR "Neighborhood design" [kw] OR "Neighbourhood design" [kw] OR "Environment* feature*" [kw] OR "Community feature*" [kw] OR "Natural environment*"[kw] OR Greenspace [kw] OR "Green space" [kw] OR "Open space"" [kw]
#2	GIS [kw] OR "Geographic information systems" [kw] OR "Spatial measure*" [kw] OR "Objective measure*" [kw] OR "Perceived measure*" [kw] OR "Perceived environment" [kw] OR "Objective environment" [kw]
#3	"Participation in activity" [kw] OR "Active living" [kw] "Active lifestyle" [kw] OR Exercise* [kw] OR "Active transport" [kw] OR "Active travel" [kw] OR "Active commute*" [kw] OR Walking [kw] OR Biking [kw] OR Cycling [kw] OR "Leisure activity*" [kw] OR Play* [kw] OR "Outdoor play*" [kw] OR "Outdoor recreation*" [kw] OR "Recreational activity" [kw] OR "Meaningful activity" [kw] OR "Social activity" [kw] OR "Being with friend*"[kw] OR "Non-organized activity" [kw] OR "Organized activity" [kw] OR "Structured activity" [kw] OR "Structured exercise*" [kw] OR "Structured sport*" [kw] OR Well-being [kw] OR Wellbeing" [kw] OR "Mental* health*" [kw] OR "Self-reported health" [kw] OR "Self-perceived health" [kw] OR Self-esteem [kw] OR "Cognitive function*" [kw] OR "Pro-social behavior" [kw] OR "Pro-social behaviour" [kw] OR Happiness [kw] OR "Quality of life*" [kw] OR Cope* [kw] OR "Mental disorder*" [kw] OR "Mental health problem*" [kw] OR "Psychological distress" [kw] OR "Peer problem*" [kw] OR "Hyperactivity problem*" [kw] OR "Conduct problem*" [kw] OR "Emotional problem*" [kw]
#4	Child* [kw] OR Adolescent* [kw] OR Girl* [kw] OR Boy* [kw] OR "Elementary schooler*" [kw] OR "Middle schooler*" [kw] OR "Primary schooler*" [kw] OR "Secondary schooler*" [kw] OR "High schooler*" [kw] OR Kids [kw] OR Pupils [kw] OR "Young people" [kw]
#5	#1 AND #2 AND #3 AND #4 Limited to 2010, published and English language
Results from original search conducted on April 11th 2017: 71 records	
Results from updated search conducted on June 11th 2018: 19 records	

Appendix II: Excluded studies and the reasons for their exclusion.

Reference	Reason for exclusion
Alberico, C.O., Schipperijn, J., & Reis, R.S. (2017). Use of global positioning system for physical activity research in youth: ESPACOS Adolescentes, Brazil. *Preventive Medicine.,* 27.	Only descriptive results presented.
Baran, P.K., Smith, W.R., Moore, R.C., Floyd, M.F., Bocarro, J.N., Cosco, N.G., et al. (2014). Park Use Among Youth and Adults: Examination of Individual, Social, and Urban Form Factors. *Environment and Behavior,* 46, 768-800.	The outcome was the total number of youth in the park zone, and the unit of analysis was the park activity zone.
Bejleri, I., Steiner, R.L., Fischman, A., & Schmucker, J.M. (2011). Using GIS to analyze the role of barriers and facilitators to walking in children's travel to school. *Urban Design International,* 16, 51-62.	Evaluated GIS-methodologies to analyze the role of barriers and facilitators that influence path and accessibility to school.
Boone-Heinonen, J., Casanova, K., Richardson, A.S., Gordon-Larsen, P., Boone-Heinonen, J., Casanova, K., et al. (2010). Where can they play? Outdoor spaces and physical activity among adolescents in U.S. urbanized areas. *Preventive Medicine,* 51, 295-298.	The study included 11-21 year-old, and no stratified analyses were conducted.
Broberg, A., Kytta, M., & Fagerholm, N. (2013). Child-friendly urban structures: Bullerby revisited. *Journal of Environmental Psychology,* 35, 110-120.	Tested an assessment model of environmental child-friendliness (independent mobility and opportunities to actualize affordances).
Buck, C., Kneib, T., Tkaczick, T., Konstabel, K., & Pigeot, I. (2015). Assessing opportunities for physical activity in the built environment of children: interrelation between kernel density and neighborhood scale. *International Journal of Health Geographics,* 14.	Studied the influence of varying spatial scales and addressed suitable methods for assess point characteristics of the built environment.
Carver, A., Veitch, J., Sahlqvist, S., Crawford, D., & Hume, C. (2014). Journal of Transport & Health. *Journal of Transport & Health,* 1, 267-273.	Outcome was territorial range.
Cerin, E., Baranowski, T., Barnett, A., Butte, N., Hughes, S., Lee, R.E., et al. (2016). Places where preschoolers are (in)active: an observational study on Latino preschoolers and their parents using objective measures. *International Journal of Behavioral Nutrition and Physical Activity,* 13.	The study included preschoolers only (3-5 years).
Christian, H., Knuiman, M., Divitini, M., Foster, S., Hooper, P., Boruff, B., et al. (2017). A Longitudinal Analysis of the Influence of the Neighborhood Environment on Recreational Walking within the Neighborhood: Results from RESIDE. *Environ Health Perspect,* 125.	The study included adults only.
Christian, H., Zubrick, S.R., Knuiman, M., Nathan, A., Foster, S., Villanueva, K., et al. (2017b). Nowhere to Go and Nothing to Do but Sit? Youth Screen Time and the Association With Access to Neighborhood Destinations. *Environment and Behavior,* 49, 84-108.	Outcome was screen time (sedentary behavior).
Cohen, D.A., Han, B., Isacoff, J., Shulaker, B., Williamson, S., Marsh, T., et al. (2015). Impact of park renovations on park use and park-based physical activity. *J Phys Act Health,* 12, 289-295.	Assessed the number of people visiting pocket parks. Focused on adults only.
Cohen, D.A., Marsh, T., Williamson, S., Han, B., Derose, K.P., Golinelli, D., et al. (2014). The potential for pocket parks to increase physical activity. *Am J Health Promot,* 28, S19-26.	Only descriptive results based on observations were presented. All kinds of users observed, not specifically youth.
de Farias Junior, J.C., Lopes, A.d.S., Mota, J., Santos, M.P., Ribeiro, J.C., & Hallal, P.C. (2011). Perception of the social and built environment and physical activity among Northeastern Brazil adolescents. *Preventive Medicine,* 52, 114-119.	The study included 14-19 year-old, but no stratified analyses were conducted. About 40% were 18-19 years.
D'Haese, S., Gheysen, F., De Bourdeaudhuij, I., Deforche, B., Van Dyck, D., & Cardon, G. (2016). The moderating effect of psychosocial factors in the relation between neighborhood walkability and children's physical activity. *International Journal of Behavioral Nutrition and Physical Activity,* 13.	Focused on the moderating effect of psychosocial factors of the relationship between the built environment and physical activity.
Dzhambov, A., Hartig, T., Markevych, I., Tilov, B., & Dimitrova, D. (2018). Urban residential greenspace and mental health in youth: Different approaches to testing multiple pathways yield different conclusions. *Environmental Research,* 160, 47-59.	The study included youth and young adults only (15-25 years), and no stratified analyses were conducted.

Eichinger, M., Schneider, S., & De Bock, F. (2017). Subjectively and objectively assessed social and physical environmental correlates of preschoolers' accelerometer-based physical activity. *International Journal of Behavioral Nutrition and Physical Activity,* 14(1).	The study included preschoolers only (3-6 years)
Esliger, D.W., Sherar, L.B., & Muhajarine, N. (2012). Smart Cities, Healthy Kids: The Association Between Neighbourhood Design and Children's Physical Activity and Time Spent Sedentary. *Canadian Journal of Public Health-Revue Canadienne De Sante Publique,* 103, S22-S28.	Focused on overall neighborhood design and did not assessed the influence of the specific built environment determinants.
Evenson, K.R., Cho, G.-H., Rodriguez, D.A., & Cohen, D.A. (2018). Park use and physical activity among adolescent girls at two time points. *Journal of Sports Sciences,* 36, 2544-2550.	Independent variable was park visits and not the built environment per se.
Greer, A.E., Castrogivanni, B., & Marcello, R. (2017). Park Use and Physical Activity Among Mostly Low-to-Middle Income, Minority Parents and Their Children. *Journal of Physical Activity & Health,* 14, 83-87.	Independent variable was the family's park use and not the built environment per se.
Hager, E.R., Witherspoon, D.O., Gormley, C., Latta, L.W., Pepper, M.R., & Black, M.M. (2013). The perceived and built environment surrounding urban schools and physical activity among adolescent girls. *Ann Behav Med,* 45 Suppl 1, S68-75.	Focused on the school area and the immediate surroundings of school and not the neighborhood area.
Harmon, B.E., Nigg, C.R., Long, C., Amato, K., Anwar, Kutchman, E., et al. (2014). What matters when children play: Influence of Social Cognitive Theory and perceived environment on levels of physical activity among elementary-aged youth. *Psychology of Sport and Exercise,* 15, 272-279.	Focused on the school area and not the neighborhood. Built environment within schoolyards as independent variables.
Hayball, F., McCrorie, P., Kirk, A., Gibson, A.M., & Ellaway, A. (2018). Exploring Children's Perceptions of their Local Environment in Relation to Time Spent Outside. *Children & Society,* 32, 14-26.	Qualitative study.
Hinckson, E.A., McGrath, L., Hopkins, W., Oliver, M., Badland, H., Mavoa, S., et al. (2014). Distance to School is Associated with Sedentary Time in Children: Findings from the URBAN Study. *Frontiers in Public Health,* 2, 151.	The outcome was minutes of sedentary time during weekdays.
Klinker, C.D., Schipperijn, J., Christian, H., Kerr, J., Ersboll, A.K., & Troelsen, J. (2014). Using accelerometers and global positioning system devices to assess gender and age differences in children's school, transport, leisure and home based physical activity. *International Journal of Behavioral Nutrition & Physical Activity,* 11, 8.	Only descriptive results presented.
Laatikainen, T.E., Broberg, A., & Kyttä, M. (2017). The physical environment of positive places: Exploring differences between age groups. *Preventive Medicine,* 95, S85-S91.	The outcome was land-use at positive places.
Lachowycz, K., Jones, A.P., Page, A.S., Wheeler, B.W., & Cooper, A.R. (2012). What can global positioning systems tell us about the contribution of different types of urban greenspace to children's physical activity? *Health & Place,* 18, 586-594.	Only descriptive results presented.
Loebach, J., & Gilliland, J. (2016). Neighbourhood play on the endangered list: examining patterns in children's local activity and mobility using GPS monitoring and qualitative GIS. *Childrens Geographies,* 14, 573-589.	Outcomes were time spent in neighborhood zones and maximum path distance travelled.
Loebach, J.E., & Gilliland, J.A. (2016). Free Range Kids? Using GPS-Derived Activity Spaces to Examine Children's Neighborhood Activity and Mobility. *Environment and Behavior,* 48, 421-453.	Mix of quantitative and qualitative methods. Only descriptive/narrative results presented.
Mota, J., Santos, R., Pereira, M., Teixeira, L., & Santos, M.P. (2011). Perceived neighbourhood environmental characteristics and physical activity according to socioeconomic status in adolescent girls. *Annals of Human Biology,* 38, 1-6.	Independent variable was socioeconomic status and the dependent variable was environmental perceptions.
Moura, F., Cambra, P., & Goncalves, A.B. (2017). Measuring walkability for distinct pedestrian groups with a participatory assessment method: A case study in Lisbon. *Landscape and Urban Planning,* 157, 282-296.	Presented a participatory framework for assessment of walkability based on local circumstances and expertise.
Nicholson, L.M., Turner, L., Slater, S.J., Abuzayd, H., Chriqui, J.F., & Chaloupka, F. (2014). Developing a measure of traffic calming associated with elementary school students' active transport. *Transportation Research Part D-Transport and Environment,* 33, 17-25.	Validity study of a traffic-calming construct, and use aggregated school-level data only.

Panter, J., Griffin, S., & Ogilvie, D. (2014). Active commuting and perceptions of the route environment: a longitudinal analysis. *Prev Med, 67*, 134-140.	The study included adults only.
Pate, R.R., McIver, K.L., Colabianchi, N., Troiano, R.P., Reis, J.P., Carroll, D.D., et al. (2015). Physical Activity Measures in the Healthy Communities Study. *American Journal of Preventive Medicine,* 49, 653-659.	Study protocol.
Quigg, R., Gray, A., Reeder, A.I., Holt, A., & Waters, D.L. (2010). Using accelerometers and GPS units to identify the proportion of daily physical activity located in parks with playgrounds in New Zealand children. *Preventive Medicine,* 50, 235-240.	Only descriptive results presented.
Rothman, L., To, T., Buliung, R., Macarthur, C., & Howard, A. (2014). Influence of social and built environment features on children walking to school: an observational study. *Prev Med,* 60, 10-15.	Included kindergarten and elementary school, but individual-level data was not presented (ecological study design).
Sallis, J.F., Cain, K.L., Conway, T.L., Gavand, K.A., Millstein, R.A., Geremia, C.M., et al. (2015). Is Your Neighborhood Designed to Support Physical Activity? A Brief Streetscape Audit Tool. *Prev Chronic Dis,* 12, E141.	Evaluated a brief audit instrument MAPS-mini in relation to the full version of the tool.
Schmutz, E.A., Leeger-Aschmann, C.S., Radtke, T., Muff, S., Kakebeeke, T.H., Zysset, A.E., et al. (2017). Correlates of preschool children's objectively measured physical activity and sedentary behavior: a cross-sectional analysis of the SPLASHY study. *International Journal of Behavioral Nutrition and Physical Activity,* 14.	The study included preschoolers only (2-6 years).
Soltero, E.G., Cerin, E., Lee, R.E., & O'Connor, T.M. (2016). Associations Between Objective and Self-Report Measures of Traffic and Crime Safety in Latino Parents of Preschool Children. *Journal of Immigrant & Minority Health,* 28, 28.	The outcome was perceived safety.
Tandon, P.S., Zhou, C., & Christakis, D.A. (2012). Frequency of Parent supervised outdoor play of US preschool-aged children. *Arch Pediatr Adolesc Med,* 166, 707-712.	The study included preschoolers only (4-year old).
Timperio, A., Salmon, J., Ball, K., Velde, S.J.T., Brug, J., & Crawford, D. (2012). Neighborhood characteristics and TV viewing in youth: Nothing to do but watch TV? *Journal of Science and Medicine in Sport,* 15, 122-128.	The outcome was sedentary behavior.
van Sluijs, E.M.F., McMinn, A.M., Inskip, H.M., Ekelund, U., Godfrey, K.M., Harvey, N.C., et al. (2013). Correlates of Light and Moderate-to-Vigorous Objectively Measured Physical Activity in Four-Year-Old Children. *Plos One,* 8 (9) (no pagination).	The study included preschoolers only (4-year old)
Wood, C., Angus, C., Pretty, J., Sandercock, G., & Barton, J. (2013). A randomised control trial of physical activity in a perceived environment on self-esteem and mood in UK adolescents. *International Journal of Environmental Health Research,* 23, 311-320.	The built environment was not studied in natural settings. Not a natural experiment. Unspecified scenes and pictures of built and natural features in an experimental setting.
Yan, A.F., Voorhees, C.C., Clifton, K., & Burnier, C. (2010). 'Do you see what I see?' -- Correlates of multidimensional measures of neighborhood types and perceived physical activity-related neighborhood barriers and facilitators for urban youth. *Preventive Medicine,* 50, S18-23.	The outcome was physical activity related neighborhood barriers and facilitators.

Appendix III: Detailed characteristics and main findings of the studies reviewed.

Reference	Country	Age group	Sample size and gender	Study design	Health outcomes	Methods of measurement (outcomes)	Built environment (independent variables)	Methods of measurement (environment)	Key findings[a]	Quality rating
Aarts *et al.*[37]	Netherlands	7-9 years 10-12 years	**7-9 years** Total: 1357 Boys: 692 Girls: 665 **10-12 years** Total: 1046 Boys: 520 Girls: 526	Cross-sectional	***Outdoor play*** • Min/week	Parental reported	A. Residential density B. Land-use mix C. Count of play facilities D. Green space E. Presence of water F. Presence of sidewalks G. Presence of bike lanes H. Pedestrian crossings without traffic lights I. Pedestrian crossings with traffic lights J. Traffic lights K. Presence of refuges L. Speed bumps M. Home zones N. 30 km/h zone O. Roundabouts P. Intersections Q. Traffic speed R. Maintenance of houses	Direct observations	Relative rates (95% CI) **7-9 year old boys** C. 0.99 (0.99-1.00) H. 1.20 (1.11-1.29) K. 0.89 (0.85-0.93) L. 1.25 (1.13-1.37) N. 0.82 (0.76-0.89) O. 1.15 (1.06-1.24) P. 0.81 (0.73-0.90) **7-9 year old girls** C. 0.99 (0.98-0.99) I. 0.79 (0.68-0.92) J. 1.48 (1.28-1.72) O. 1.12 (1.01-1.25) P. 0.78 (0.69-0.88 **10-12 year old boys** C. 0.99 (0.99-1.00) K. 0.96 (0.93-1.00) N. 0.91 (0.86-0.97) O. 1.10 (1.04-1.16) P. 0.87 (0.79-0.97) **10-12 year old girls** C. 0.99 (0.98-1.00) F. 1.45 (1.05-2.01)	Good
Almanza *et al.*[38]	USA	8-14 years	Total: 208 Boys: 100 Girls: 108	Cross-sectional	***Outdoor activity*** • Daily minutes of neighborhood MVPA	Accelerometers	A. Greenness (NDVI) at activity locations B. Exposure to green space in minutes C. Mean neighborhood greenness (NDVI)	GIS-derived measure calculated at GPS-points and within 500 meters of home addresses	OR (95% CI) A. 1.34 (1.30-1.38) B. 2.11 (1.60-2.77) for those exposed between 1.5-20 min and 4.72 (3.09-7.20) for those exposed >20 min compared to those with near zero exposure to green space	Good
Amoly *et al.*[39]	Spain	7-10 years	Total: 2111 Boys: 1071 Girls: 1040	Cross-sectional	***Well-being*** • Total difficulties • Hyperactivity • Emotional symptoms • Conduct problems • Peer relationship problem • Prosocial behavior • ADHD • Inattention • Impulsivity	Parental reported	A. Proximity to green space B. Surrounding greenness (NDVI)	GIS-derived measure calculated within 100 m, 250 m and 500 m of home addresses. Proximity was measured within 300 m.	Percent change (95% CI) 100 m buffer B. *Total difficulties:* -3.6 (-6.6, -0.6) *Hyperactivity:* -5.0 (-8.2, 1.6) *ADHD:* -6.0 (-11.3, -0.2) *Inattention:* -6.2 -(11.6, -0.4) Percent change (95% CI) 250 m buffer *B. Total difficulties:* -3.8 (-6.4, -1.2) *Hyperactivity:* -4.5 (-7.4, -1.6) Percent change (95% CI) 500 m buffer *B. Total difficulties:* -4.0 (-6.7, -1.12) *Hyperactivity:* -4.1 (-7.1, -1.0) *Emotional symptom:* -4.3 (-8.1, -0.1)	Good

Babey *et al.*[40]	USA	12-17 years	Total: 3 638 Boys: 1 815 Girls: 1 823	Cross-sectional	***Outdoor activity*** • Physical activity during last park visit	Self-reported	A. Urbanicity *i. Urban* *ii. Suburban* iii. *Rural* B. Park/playground within walking distance	Self-reported	OR (95% CI) B. 2.12 (1.57-2.84)	Fair
Bird *et al.*[41]	Canada	8-10 years	Total: 380 Boys: 199 Girls: 181	Cross-sectional	***Unspecified PA*** • 15-minutes bouts of PA in a week • Variety of PA	Self-reported	A. Park typologies *i. No sport/play areas* *ii. No sport features or walking paths* *iii. No sport features; high incivility* *iv. Many sport features* *v. No sport features; not safe; walk and cycle infrastructure* *vi. Variety of activity installations; skate parks; high incivility* *vii. Many sport features* *viii. No sport features; esthetically pleasing* ix. *No sport features; cycle infrastructure; esthetically pleasing*	GIS was used to identify parks within 500/1000 m network buffers around home addresses. Parks were assessed through direct observation.	B (90% CI) **Bouts of PA** A.v: 2.2 (0.0-4.3) vi: 2.5 (0.2-4.7) vii: 2.5 (0.4-4.7) viii: 5.2 (2.3-8.1) **Variety of PA** A.v: 1.1 (0.0-2.2) vi: 1.4 (0.2-2.5) viii: 1.6 (0.1-3.1)	Fair
Bloemsma *et al.*[42]	Netherlands	17 years	Total: 1911 Boys: 937 Girls: 974	Cross-sectional	***Outdoor activity*** • Green space visits for different activity purposes	Self-reported	A. Level of urbanization B. Neighborhood greenness C. Distance to the nearest park D. Average NDVI E. Percentage urban green space F. Percentage agricultural green space G. Percentage natural green space	A: based on data from Statistics Netherlands B: self-reported C-G: GIS-derived measures calculated within 300 m, 1000 m and 3000 m buffers around home address	PR (95 % CI) **During winter only** B. *Little to no green:* 1.00 (Reference) *Moderately green:* 1.34 (0.79-2.25) *Green:* 1.78 (1.07-2.96) *Very green:* 1.71 (1.00-2.93) F. 0.87 (0.76-1.00)	Good
Bringolf-Isler *et al.*[43]	Switzerland	6-7 years 9-10 years 13-14 years	Total: 1081 Boys: 531 Girls: 550	Cross-sectional	***Outdoor play*** • Average min/day vigorous on weekdays and weekends	Parental reported	A. Problem to play because of traffic B. Availability of parks or gardens C. Length of main streets D. Length of side streets E. Length of small routes F. Number of people G. Number of buildings H. Amount of green space	A and B: parental reported C-H: GIS-derived measures calculated around home addresses. Roads within 100 m circular buffers, number of people and buildings in a square of 9 ha and green space in a square of 25 ha.	Mean (95% CI) and p-values **Primary school children** A. No: 82.4 (77.5-87.4) Yes: 70.3 (58.2-82.4) p=0.01 No associations found for adolescents	Fair

Broberg *et al.*[44]	Finland	11 years 14 years	Total: 901	Cross-sectional	***Active travel*** • Walking and cycling to meaningful places	Self-reported	A. Densely built-up residential areas B. Single family housing C. Traffic dominance D. Remote places E. Big buildings and public transport hubs	14 GIS-derived measures were calculated within 50 m circular buffers around meaningful places. A PCA-analysis resulted in five principal components (A-E)	OR (95% CI) A. 0.876 (0.785-0.977) B. 1.163 (1.038-1.303) C. 0.890 (0.800-0.990) E. 0.767 (0.644-0.913)	Poor
Broberg and Sarjala[45]	Finland	11 years 14 years	Total: 202	Cross-sectional	***Active travel*** • Walking to school • Cycling to school	Self-reported	A. Distance to school B. Number of streetlights C. Signalized intersection D. Total road length E. Length of primary road F. Length of major road G. Intersecting major road or railroad H. Building density I. Proportion of public building land-use J. Land-use mix K. Intersection density L. Proportion of 4-way intersections M. Number of public transport stops N. Proportion of parks and recreation areas O. Proportion of forests P. Proportion of single family housing Q. Length of walk-and bikeways R. Number of residents S. Residential density	GIS-derived measures calculated within 500 m circular buffers around home addresses and 100 m around route to school	OR (95% CI) Neighbourhood **Walking to school** A. 0.993 (0.990-0.995) H. 0.019 (0.002-0.226) **Cycling to school** A. 0.997 (0.996-0.998) H. 0.001 (0.000-0.017) OR (95% CI) Route to school **Walking to school** A. 0.993 (0.991-0.995) **Cycling to school** A. 0.998 (0.996-0.999) F. 0.192 (0.070-0.528) M. 0.659 (0.528-0.824)	Poor
Buck *et al.*[46]	Germany	6-10 years	Total: 596 Boys: 296 Girls: 300	Cross-sectional	***Active travel*** • Walking to school • Cycling to school ***Organized sports*** • Time doing sports ***Outdoor activity*** • Hours/day	Parental reported Parental reported Parental reported	A. Sidewalk density B. Bikeway density C. Density of facilities and/or amenities D. Moveability index	GIS-derived measures calculated within a child's school catchment area	β (SE) and p-values **Outdoor activity** C. 0.17 (0.074), p=0.023 D. 0.16 (0.077), p=0.038	Fair
Buck *et al.*[47]	Germany	6-9 years	Total: 300	Cross-sectional	***Unspecified PA*** • Min/day MVPA	Accelerometers	A. Residential density B. Land-use mix C. Playgrounds/km^2 D. Green areas/km^2 E. Parks/km^2 F. Intersections/km^2 G. Transit stops/km^2 H. Playgrounds and parks/km^2 I. Playgrounds, parks and green areas/km^2 J. Walkability index K. Moveability index (playground) L. Moveability index (playground and park) M. Moveability index (playground, park and green area)	GIS-derived measures calculated within 1000 m network buffers around home addresses	β and p-value A. 0.00005, p=0.02 C. 0.048, p=0.01 F. 0.003, p=0.04 G. 0.037, p=0.01 H. 0.040, p=0.01 K. 0.014, p=0.008 L. 0.014, p=0.007 M. 0.014, p=0.015	Good

Buliung *et al.*[48]	Canada	9-13 years	**Children walking to school** Total: 651 **Children walking home from school** Total: 708	Cross-sectional	***Active travel*** • Walking independently to and from school	Self- and parental reported	A. Distance to school B. Intersections crossed C. Missing sidewalks D. Land-use mix E. Density of traffic-calming features F. Density of street trees G. Urban structure H. Safe area to walk alone I. Busy street crossings	A-F: GIS-derived measures calculated along the route G: not specified H-I: self-and parental reported	OR and p-value **Walking to school** A. 0.463 (0.034) H. 3.368 (0.003) **Walking from school** H. 2.368 (0.041)	Poor
Butler *et al.*[49]	USA	6-17 years	Total: 64 076 Boys: 30 693 Girls: 33 292	Cross-sectional	***Well-being*** • Anxiety and depression • ADHD/disruptive behavior	Parental reported	A. Presence of neighborhood facilities such as playground, park, library, recreation or community center B. Presence of litter or garbage, poorly kept or dilapidated housing and vandalism C. Neighborhood safety	Parental reported	OR (95% CI) **Anxiety/depression** A. *One facility:* 1.49 (1.05-2.12) *Three facilities:* 1.30 (1.01-1.69) B. *Thee poor features:* 1.58 (1.01-2.46) **ADHD or disruptive behavior** B. *Three poor features:* 1.44 (1.01-1.99)	Fair
Cain *et al.*[50]	USA	**Children** Mean age 9.1 years (children) **Adolescent** Mean age 14.1 years	**Children** Total: 758 Boys: 379 Girls: 379 **Adolescents** Total: 897 Boys: 452 Girls: 445	Cross-sectional	***Active travel*** • Walking/biking for transport ***Outdoor activity*** • Neighborhood PA in streets, sidewalks and cul-de-sacs ***Leisure-time PA*** • Min/day MVPA during non-school hours	Parental reported (children) and self-reported (adolescents) Parental reported (children) and self-reported (adolescents) Accelerometers	A. Destinations and land-use B. Streetscape characteristics C. Aesthetics and social characteristics D. Crossings and/or intersections E. Street segments F. Cul-de-sac G. Total score	Direct observations conducted along a 400 m route from home towards selected destinations along the street network	Children B, p-values **Walking/biking** A. 3.289, $p \leq 0.01$ B. 2.760, $p \leq 0.01$ D. 2.577, $p \leq 0.05$ E. 4.912, $p \leq 0.01$ G. 5.543, $p \leq 0.001$ **Outdoor activity** C. 3.798, $p \leq 0.01$ E. 2.023, $p \leq 0.05$ F. 3.543, $p \leq 0.001$ **Leisure-time PA** A. 2.026, $p \leq 0.05$ G. 2.863, $p \leq 0.01$ Adolescents B, p-values **Walking/biking** B. 3.039, $p \leq 0.01$ G. 2.304, $p \leq 0.05$ **Outdoor activity** B. -2.007, $p \leq 0.05$ D. -2.082, $p \leq 0.05$ F. 2.714, $p \leq 0.001$ G. -2.297, $p \leq 0.05$	Fair

Carlson *et al.*[51]	USA	12-15 years	Total: 294 Boys: 155 Girls: 139	Cross-sectional	***Active travel*** • Trips/week to school	Self-reported	A. Land-use mix diversity B. Land-use mix access C. Street connectivity D. Walking facilities E. Aesthetics F. Traffic safety G. Pedestrian safety H. Distance to school I. Residential density J. Street connectivity K. Retail floor area ratio L. Land-use mix M. Cul-de sac density N. Number of parks	A-G: parental reported H-N: GIS-derived measures calculated within 1000 m network buffers around home and school addresses	OR (95% CI) **1-4 vs. no trips** C. 1.88 (1.05-3.36) H. 0.57 (0.35-0.95) I. 1.11 (1.03-1.19) J. 0.98 (0.95-1.00) **5-10 vs. no trips** G. 2.20 (1.16-4.17) H. 0.24 (0.14-0.40) I. 1.12 (1.04-1.20)	Fair
Carlson *et al.*[52]	USA	12-16 years	Total: 690 Boys: 342 Girls: 348	Cross-sectional	***Active travel*** • Min/day walking • Min/day cycling • Active mode share	Accelerometers	A. Residential density B. Intersection density C. Retail density D. Entertainment density E. Walkability index	GIS-derived measures calculated within 1000 m network buffers around home addresses	OR (95% CI) **Walking** A. 1.40 (1.02-1.92) B. 1.22 (1.04-1.43) D. 0.57 (0.37-0.64) E. 1.92 (1.38-2.65) **Cycling** B. 1.30 (1.06-1.60) E. 1.97 (1.30-2.98) **Active mode share** A. 1.64 (1.15-2.34) B. 1.34 (1.13-1.59) E. 2.25 (1.59-3.18)	Good
Carver *et al.*[53]	Australia	8-9 years (baseline) 13-15 years (baseline)	Total: 446 Boys: 206 Girls: 240 170 aged 8-9 years 276 aged 13-15 years	Longitudinal, 2-year follow-up	***Active travel*** • Two-year change in walking/cycling to destinations ***Leisure-time PA*** • Two-year change in MVPA - Before school - After school - Evening - Nonschool - Weekend days	Parental reported (8-9 years) and self-reported (13-15 years) Accelerometers	A. Length of local roads B. Local road index C. Number of intersections D. Residing on cul-de-sac E. Length of walking tracks F. Number of speed humps G. Number of gates/barriers H. Number of slow points or sections of road narrowing I. Number of traffic and/or pedestrian light	GIS-derived measures calculated within 800 m circular buffers around home addresses	B (95% CI) **Active travel** **13-15 year old boys** A. 0.03 (0.003-0.06) **13-15 year old girls** E. 0.002 (0.001-0.002) H. -0.54 (-1.03,-0.05) B (p-value) **Leisure-time PA** **13-15 year old girls** A. *Before school* 0.20, p<0.05 B. *After school* -0.17, p<0.01 B. *Nonschool hours* -0.23, p<0.01	Fair
Carver *et al.*[54]	England	9-10 years (baseline)	Total: 1121 (baseline) Boys: 483 Girls: 638 Total: 491 (follow-up) Boys: 193 Girls: 298	Longitudinal, 1-year follow-up	***Active travel*** • Walking/cycling independently to school	Self-reported measures at T1 and T2	A. Road density B. Proportion of primary roads C. Effective walkable area D. Connected node ratio E. Intersection density F. Land-use mix G. Number of streetlights H. Main road en route I. Proportion of route in an urban area J. Safe to walk/play K. Walkability score L. Traffic as a barrier	A-I: GIS-derived measures calculated within 800 m network buffers around home addresses and 100 m buffers around shortest route to school J-L: parental reported	OR (95% CI) T1 **Boys** C. 0.78 (0.63-0.96) J. 2.20 (1.31-3.68) L. 0.19 (0.07-0.55) **Girls** J. 1.71 (1.07-2.71) L. 0.37 (0.21-0.65) OR (95% CI) T2 **Girls** B. 0.67 (0.47-0.94) F. 1.38 (1.06-1.79)	Fair

Coombes *et al.*[55]	England	10-12 years (baseline)	Total: 518 Boys: 229 Girls: 289	Longitudinal, follow-up after transition to secondary school	***Active travel*** • Change in travel mode to school Stays active Passive→active Active→passive Stays passive	Accelerometers	A. Facility/amenity index (environmental supportiveness) including greenspace, road density and destinations	GIS-derived measure calculated within 800 m network buffers around home and school	No associations found.	Fair
Coombes *et al.*[56]	England	13-15 years	Total: 967 Boys: 413 Girls: 554	Cross-sectional	***Leisure-time PA*** • Light, moderate and vigorous • Daily, on weekday evenings and weekends	Accelerometers	A. Facility/amenity index (environmental supportiveness) including greenspace, road density and destinations	GIS-derived measure calculated within 800 m network buffers around home addresses	OR (95% CI) **Moderate** *More supportive:* 2.930 (2.919-2.941) *Less supportive:* 2.793 (2.779-2.804) *Difference:* -0.14, p≤ 0.001 **Vigorous** *More supportive:* 2.959 (2.948-2.971) *Less supportive:* 2.821 (2.807-2.835) *Difference:* -0.14, p≤ 0.001	Fair
Corder *et al.*[57]	England	9-10 years (baseline)	Total: 875 Boys: 363 Girls: 512	Longitudinal, 1-year follow-up	***Unspecified PA*** • 1-year change in moderate and vigorous PA on weekdays ***Leisure-time PA*** • 1-year change in moderate and vigorous PA on weekend days	Accelerometers	A. Residing on road containing a cul-de-sac B. Effective walkable area C. Proportion of woodland/green space D. Land-use mix E. Distance to green space F. Distance to sport venue G. Distance to school H. Available playgrounds, parks and sport halls	A-G: GIS-derived measures calculated within 800 m network buffers around home addresses H: self-reported	B (95% CI) **Moderate PA on weekday** D. 0.29 (-0.51, -0.06) **Vigorous PA on weekday** G. -0.10 (-0.18, -0.01)	Fair
Crawford *et al.*[58]	Australia	10-12 years	Total: 301 Boys: 128 Girls: 173	Longitudinal, 5-year follow-up	***Unspecified PA*** • Min/day MVPA	Accelerometers	A. Number of public open space B. Number of sport and recreation space C. Number of sport options D. Length of walk/cycle tracks E. Distance to school F. Number of intersections G. Proportion of 4-way intersections H. Number of cul-de-sacs I. Length of "access" tracks J. Heavy local traffic K. Road safety concerns L. No lights/crossings M. Busy road to cross N. Few sporting venues O.	A-I: GIS-derived measure calculated within 2000 m buffers around home addresses J-N: Parental reported	β (95% CI) **Boys** H. 0.07 (0.01-0.13) No associations found for girls	Fair
Currerio *et al.*[59]	USA	8-12 years	Total: 362 Boys: 167 Girls: 195	Cross-sectional	***Active travel*** • Walking to school	Self-reported	A. Perceived neighborhood safety B. Child perceived neighborhood safety C. Safety on school route D. Walking path length	A: parental reported B-C: self-report D: GIS and audit	OR (95% CI) A. 3.00 (1.70-5.29) D. 0.95 (0.92-0.97)	Fair

Da Silva *et al.*[60]	Brazil	18 years	Total: 3379	Cross-sectional	***Unspecified PA*** • Min/day MVPA ***Leisure-time PA*** • Min/day MVPA during leisure • Min/day leisure walking ***Active travel*** • Min/day	Accelerometers Self-reported Self-reported	A. Population density B. Density of the population aged 16-20 years C. Street connectivity D. Street lightening E. Paved streets F. Proportion of sidewalk G. Proportion of trees H. Public open spaces I. Walking paths/trails J. Football pitches K. Cycle paths/lanes L. Number of gyms M. Presence of beachfront	GIS-derived measures calculated within 500 m circular buffers around home address	β (95% CI) **Total PA** D. 2.2 (0.5, 3.9) E. -2.1 (-3.6, -0.7) OR (95% CI) **Leisure PA** M. 3.31 (1.37, 8.02) **Active travel** ***Middle SES*** D. 1.22 (1.01, 1.47) K. 1.77 (1.05, 2.96) ***High SES*** I. 0.87 (0.80, 0.95) K. 0.65 (0.50, 0.83)	Fair
Davidson *et al.*[61]	Canada	10-11 years[b]	Total: 3421 Boys: 1659 Girls: 1762	Cross-sectional	***Unspecified PA*** • Composite score of PA during a whole day	Self- and parental reported	A. Neighborhood services B. Neighborhood safety C. Sidewalks/parks	Parental reported	B (95% CI) A. 0.03 (0.01-0.05) B. 0.032 (0.01-0.05)	Good
De Meester *et al.*[62]	Belgium	13-15 years	Total: 513 Boys: 254 Girls: 259	Cross-sectional	***Unspecified PA*** • Counts/min • Min/day MVPA ***Active travel*** • To/from school • Leisure walking • Leisure cycling ***Organized sports*** • Leisure sports	Accelerometers Self-reported Self-reported	A. Walkability index B. Walkability x SES	GIS-derived measure calculated within statistical sectors	B (SE) and p-values **Activity counts/min** A. 0.053 (0.017), p<0.01 B. -0.73 (0.034), p<0.05 **Min/day MVPA** A. 0.091 (0.035) p<0.05 B. -0.228 (0.068) p<0.001	Fair
De Meester *et al.*[63]	Belgium	13-15 years	Total: 637 Boys: 315 Girls: 322	Cross-sectional	***Active travel*** • To/from school • Leisure walking • Leisure cycling	Self-reported	A.Residential density B. Land-use mix C. Distance to school D. Connectivity E.Walking infrastructure F.Cycling infrastructure G. Safety for cycling H. Aesthetics I. Safety for traffic J. Distance to facilities	Self-reported	β (95% CI) **To/from school** B. -0.11 (-0.21, -0.02) C. 0.16 (0.12, 0.21) D. 0.12 (0.00, 0.23) E. -0.09 (-0.18, -0.00) **Leisure walking** I. 0.12 (0.02, 0.22)	Fair
De Vries *et al.*[64]	Netherlands	6-11 years	Total: 448 Boys: 216 Girls: 232	Cross-sectional	***Active travel*** •Walking/cycling for transportation • Walking for transportation • Cycling for transportation • Walking/cycling to school • Walking to school • Cycling to school	Self- and parental reported	A. Play facilities B. Recreational facilities C. Green space D. Water E. Traffic safety F. Sidewalks G. Cycle-tracks H. Pedestrian crossing I. Traffic lights J. Traffic island K. Roundabouts L. Intersections	Direct observation	B (95% CI) **Walking/cycling for transport** F. 6.43 (1.32, 11.53) **Walking for transport** I. -7.29 (-10.71, -3.87) K. 11.14 (6.35, 15.94) **Cycling for transport** B. 1.66 (0.46, 2.86) H. 14.66 (5.96, 23.36) **Walking/cycling to school** G. 1.12 (0.18, 2.05) **Walking to school** C. -2.05 (-3.20, -0.91) H. 4.85 (1.65, 8.04) K. 3.59 (1.80, 5.39) **Cycling to school** B. 0.41 (0.19, 0.63) H. 3.41 (1.49, 5.33)	Fair

D'Haese *et al.*[65]	Belgium	11-12 years	Total: 696 Boys: 362 Girls: 334	Cross-sectional	***Active travel*** • Overall, to school • Biking vs. walking to school	Parental reported	A. Residential density B. Land-use mix access C. Land-use mix diversity D. Street connectivity E. Walking infrastructure F. Cycling infrastructure G. Aesthetics H. Traffic safety I. Distance to school	A-H: parental reported I: determined with an online route planner	OR (95% CI) **Active travel overall** B. 1.83 (1.38-2.44) **Biking** I. 7.24 (2.56-20.51)	Fair
D'Haese *et al.*[66]	Belgium	9-12 years	Total: 494 Boys: 223 Girls: 271	Cross-sectional	***Active travel*** • Leisure walking • Leisure cycling • To school ***Organized sports*** • Leisure sports ***Unspecified PA*** • Min/day MVPA	Self-reported Self-reported Accelerometers	A. Walkability index B. Walkability x SES	GIS-derived measure calculated within statistical sectors	β (SE), p-values **Leisure walking** A. 0.363 (0.096), p<0.001 B. -0.251 (0.126), p<0.05 **Leisure sport** A. -0.267 (0.113), p<0.05	Good
D'Haese *et al.*[67]	Belgium	Mean age 11.1 years (baseline)	Total: 321 Girls: 157 Boys: 164	Longitudinal, 2-year follow-up	***Active travel*** • To/from school • Leisure cycling • Leisure walking ***Organized sports*** • Leisure sport ***Unspecified PA*** • Mean daily steps	Self-reported Self-reported Accelerometers and pedometers	A. Residential density B. Land use mix diversity C. Land use mix access D. Street connectivity E. Availability of walking and cycling infrastructure F. Quality of walking and cycling infrastructure G. Aesthetics H. Safety for traffic I. Convenience of recreation facilities	Parental and self-reported	Girls β (SE), p-values **Leisure cycling** E. 0.055 (0.027), p=0.037 **Leisure sport** I. -3.305 (1.989), p=0.048 Boys β (SE), p-value **To/from school** G. 0.094 (0.043), p=0.028 **Leisure cycling** E. -0.083 (0.038), p=0.027 **Mean daily steps** D. 1074.77 (455.32), p=0.018	Fair
D'Haese *et al.*[68]	Belgium	9-12 years	Total: 563 Boys: 260 Girls: 303	Cross-sectional	***Unspecified PA*** • Min/day MVPA ***Outdoor activity*** • PA in public recreation spaces • PA in nearby streets and sidewalks	Parental reported	A. Residential density B. Land-use mix diversity C. Land-use mix access D. Street connectivity E.Walk/cycle facilities F. Aesthetics G. Traffic safety H. Convenience of recreational facilities	Parental reported	OR (95% CI) **PA in public recreation space** H. 1.62 (1.12-2.12) **PA in nearby streets and sidewalks** C. 1.70 (1.29-2.74) D. 0.47 (0.33-0.70)	Good
Ducheyne *et al.*[69]	Belgium	8-13 years	Total: 850 Boys: 432 Girls: 418	Cross-sectional	***Active travel*** • Always cycling to school	Parental reported	A. Residential density B. Walking/cycling facilities C. Connectivity D. Aesthetics E. Traffic safety F. Route along quiet road G. Route along busy road H. Route walking/cycling facilities I. Route along roads with streetlights J. Route along road with a steep incline K. Route along a busy intersection L. Route along the center of town M. Route along the countryside	Parental reported	OR (95% CI) E. 1.18 (1.07-1.31) H. 0.92 (0.88-0.97)	Fair

Duncan *et al.*[70]	England	Mean age 14.8 years	Total: 405 Boys: 223 Girls: 182	Cross-sectional	***Unspecified PA*** • Total weekly PA	Self-reported	A. Score including local facilities, aesthetics, traffic, crime, walking/cycling accessibility and housing types	Self-reported	R^2 and p-value A. 0.132, p=0.001	Poor
Duncan *et al.*[71]	USA	10-14 years	Total: 372 (only girls)	Cross-sectional	***Unspecified PA*** • Min/day MVPA ***Active travel*** • To/from school	Accelerometers Self- and parental reported	A. Perceived barriers/hazards such as traffic B. Accessibility of facilities C. Distance to park D. Distance to school E. Walkability index	A-B: self-reported C-E: GIS-derived measures calculated within 1600 m buffers around home addresses	Regression coefficients and p-values **Total PA** B. 2.032, p<0.05 **Active travel** B. 0.220, p<0.001 D. -0.689, p<0.001 E. 0.349, p<0.05	Fair
Durand *et al.*[72]	USA	Mean age 11.7 years	Total: 365 Boys: 186 Girls: 179	Cross-sectional	***Unspecified PA*** • Min/day MVPA ***Active travel*** • To school	Accelerometers Parental reported	A. Residential density B. Land-use mix diversity C. Land-use mix access D. Street connectivity E. Walking infrastructure F. Aesthetics G. Traffic hazards H. Hard parking I. Lack of cul-de-sacs J. Hilliness K. Physical barriers L. Walkways connecting cul-de-sacs	Parental reported	B (95% CI) **Min/day MVPA** E. 4.11 (0.67-7.54) I. 2.00 (0.10-3.89) OR (95% CI) **Travel to school** B. 0.65 (0.46-0.90) **Smart Growth** **Travel to school** E. 2.42 (1.18-4.95) F. 2.91 (1.31-6.46) G. 0.20 (0.08-0.51) J. 0.15 (0.02-1.02) K. 0.24 (0.07-0.87) L. 1.60 (1.00-2.56)	Fair
Edwards *et al.*[73]	Australia	12-15 years	Total: 1304 Boys: 642 Girls: 662	Cross-sectional	***Outdoor activity*** • Use of park and beach for PA - Summer - Winter	Self-reported	A. Distance to park <800 or >800 m B. Distance to beach <800 or >800 m C. Major road barrier to the park D. Major road barrier to the beach	GIS-derived measures calculated based on road network distances	OR (95% CI) **Summer** C. 0.72 (0.55-0.94) D. 0.45 (0.25-0.82) **Winter** A. 0.56 (0.40-0.79) B. 0.68 (0.50-0.93) C. 0.72 (0.54-0.95) D. 0.46 (0.33-0.62)	Poor
Edwards *et al.*[74]	Australia	12-15 years	Total: 1304 Boys: 642 Girls: 662	Cross-sectional	***Outdoor activity*** • Park use for PA	Self-reported	A. Activity space in parks B. Amenities in parks C. Attractiveness D. Activity space count E. Walking path present F. Park surrounded by major road G. Park size H. Distance park to beach I. Number of trees (>25) J. Tree canopy area K. Tree canopy coverage L. NDVI M.Number of participants	A-D: audited using a combination of web-based information and remote sensing F-M: GIS-derived measures	OR and p-values A. *Skateboard/BMX:* 6.41, p=0.011 B. *Barbeques:* 9.24, p=0.003 *Picnic tables:* 5.64, p=0.018 *Public toilets:* 13.93, p=0.002 *Lightening:* 6.09, p=0.012 D. 0.855, p=0.002 E. 4.64, p=0.021 I. 6.72, p=0.010	Poor
Feda *et al.*[75]	USA	12-15 years	Total: 68 Boys: 32 Girls: 36	Cross-sectional	***Well-being*** • Perceived stress	Self-reported	A. Proportion of park area B. Park area x gender	GIS-derived measure calculated within 800 m network distance around home	B (SE) and p-value A. -62.573 (27.792), p=0.028	Fair

Feng and Astell-Burt[76]	Australia	4-5 years (baseline) 12-13 years (8-years follow-up)	**Baseline** Total: 4968 Boys: 2526 Girls: 2442 **Follow-up** Total: 3853	Longitudinal, 2-, 4-, 6- and 8 years follow-up	***Well-being*** • Strengths and difficulties (SDQ) - Total - Internalizing - Externalizing	Parental reported	A. Green space quantity B. Quality of parks	A: Land-use data based on statistical area level B: Parental reported	B (95% CI) **Total SDQ** A. *6-20 %* -0.13 (-0.41, 0.16) *21-40 %* -0.54 (-0.86, -0.22) *≥ 41 %* -0.30 (-0.69, 0.08) B. *Agree* 0.19 (0.06, 0.32) *Disagree* 0.53 (0.34, 0.72) *Strongly disagree* 0.53 (0.26, 0.81)	Fair
Forthofer *et al.*[77]	USA	Mean age 10.6 years (baseline)	Total: 541 Boys: 236 Girls: 305	Longitudinal, 1-year follow-up	***Unspecified PA*** • Min/hour	Accelerometers	A. Barriers to physical activity B. Safe to play outdoors C. Access to facilities	A: self-reported B: parental reported C: GIS-derived measure calculated within 3200 m network buffer around home address	β (SE) and p-value **Pooled analysis** C. 0.01 (0.01), p<0.05 **Boys** C. 0.02 (0.01), p<0.05	Fair
Fueyo *et al.*[78]	Argentina	9-11 years	Total: 1777 Boys: 934 Girls: 843	Cross-sectional	***Leisure-time PA*** • Moderate and vigorous PA	Self-reported	A. Distance to park B. Distance to open space C. Environment for PA D. Safety for PA	Parental reported	No associations found	Fair
Galvez *et al.*[79]	USA	6-18 years	Total: 324 Boys: 94 Girls: 230	Cross-sectional	***Outdoor activity*** • >2 h/wk unscheduled ***Organized sports*** • ≥1 MET-h/wk of scheduled PA ***Unspecified PA*** • Average daily steps ≥11 000	Self-reported Self-reported Pedometer	A.Playgrounds B. Community gardens C. Sports fields D. Summer camps E. After-school programs F. Recreation centers G. Parks H. Pools	Direct observation to record facilities. GIS was used to geocode the facilities and match them to a child's census block	OR (95% CI) **Outdoor activity** A. 1.95 (1.11-3.43) **Organized sports** E. 3.25 (1.41-7.50)	Good
Garcia-Cervantes *et al.*[80]	Spain	8-18 years	Total: 1520 Boys: 770 Girls: 750	Cross-sectional	***Unspecified PA*** • Min/day moderate • Min/day vigorous • Min/day MVPA • Counts/min • PAQ-C score • PACE score ***Organized sports*** • FPAI score ***Active travel*** • Walking/cycling in leisure time	Accelerometers Self-reported Self-reported Self-reported	A. Total environmental perception score	Self-reported	B (95% CI) **Moderate PA** 0.279 (0.096-0.464) **Vigorous PA** 0.025 (0.008-0.042) **MVPA** 0.032 (0.014-0.050) **Counts/min** 2.673 (0.083-5.264) **PAQ-C** 0.022 (0.015-0.030) **PACE** 0.052 (0.030-0.073) **FPAI** 0.153 (0.104-0.202) **Active travel** 0.015 (0.003-0.027)	Good
Ghekiere *et al.*[81]	Australia	10-12 years	Total: 677 Boys: 315 Girls: 362	Cross-sectional	***Active travel*** • Weekly, to local destinations	Parental reported	A. Population density B. Number of intersections C. Number of cul-de-sacs D. Length of trails E. Number of parks F. Number of recreation G. Sport facilities H. Length of busy roads	GIS-derived measures calculated within 800 m circular buffers around home addresses	B (95% CI) A. 1.20 (0.19-2.21) B. 0.03 (0.02-0.05) F. 0.71 (0.05-1.36) G. 0.36 (0.07-0.66) **Cycling with parent** B. -0.02 (-0.05-0.00)	Good

Graham *et al.*[82]	USA	Mean age 14.8 years	Total: 192 Boys: 105 Girls: 87	Cross-sectional	***Unspecified PA*** • Min/day MVPA • 3-day recall of MVPA ***Organized sports*** • School and out-of-school sport	Accelerometers Self-reported Self-reported	A. Environmental resource score: • *Bicycle trails* • *Gyms* • *Parks* • *Athletic fields* • *School*	GIS-derived measures calculated within 800 m circular buffers around home addresses	No associations found	Good
Graham *et al.*[83]	USA	Mean age 14.4 years	Total: 2793 Boys: 1307 Girls: 1486	Cross-sectional	***Unspecified PA*** • Hours/week MVPA	Self-reported	A. Neighborhood safety B. Distance to park C. Proportion of parks D. Distance to and number of recreation centers E. Distance to and number of gyms F. Distance to walking/cycling trails G. Number of public transport stops H. Share of busy streets I. Count of access points J. Distance to school K. Population density	A: self-reported B-M: GIS-derived measures calculated within 1600 m network buffers around home addresses	β (SE) and p-value **Girls** G. 0.681 (0.230), p=0.003 No associations found for boys	Fair
Gropp *et al.*[84]	Canada	11-15 years	Total: 3997 Boys: 1930 Girls: 2067	Cross-sectional	***Active travel*** • To/from school	Self-reported	A. Sidewalk leading to school B. Proportion of roads with sidewalk C. Speed limit of school's roads (km/h) D.Total length of roads E. Street connectivity F. Litter in neighborhood G. Vacant/shabby housing	A-E: GIS-derived measures F-G: self-reported	RR (95% CI) F. *Major problem* 1.48 (1.17-1.58) No significant trends were identified	Fair
Guliani *et al.*[85]	Canada	10-11 years	Total: 720 Boys: 342 Girls: 378	Cross-sectional	***Active travel*** • Walking to school	Self-reported	A. Distance to school B. Presence of safety related features (traffic calming devices) C. Proportion of school route without sidewalk D. Major road on route E. Number of intersections/km F. Retail density G. Automobile safety H. Walking infrastructure	A-F: GIS-derived measures calculated along school travel route G-H: parental reported	B and p-values **Boys and girls** A. -0.506 B. 0.138 D. 0.138 E. -0.01 **Boys** A. -0.467 B. 0.140 C. -0.132 D. 0.119 G. 0.01 H. 0.142 **Girls** A. -0.540 B. 0.133 D. 0.154 E. -0.183 All p-values<0.05	Poor
Helbich *et al.*[86]	Netherlands	6-11 years	Total: 97	Cross-sectional	***Active travel*** • To/from school	Accelerometers	A. Distance to school B. Presence of major road/highway C. Distance to major road/highway D. Proportion cycling paths E. Proportion green space F. Proportion cul-de-sacs	GIS-derived measures calculated around route to/from school	β (SE) and p-value D. 0.055 (0.023), p=0.018	Fair

							G. Proportion 3-way intersections H. Proportion 4-way intersections I. Proportion >4-way intersections J. Land-use mix K. Building usage mix L. Building roughness index M. Betweenness index N. Closeness index O. Street density			
Hinckson *et al.*[87]	New Zealand	12-18 years	Total: 524 Boys: 233 Girls: 291	Cross-sectional	***Unspecified PA*** • Min/day MVPA	Accelerometers	A. Residential density B. Intersection density C. Cul-de-sac density D. Transit stop density E. Number of parks F. Land-use mix G. Activity-friendliness H. Residential density I. Land-use mix diversity J. Land-use mix access K. Street connectivity L. Walking facilities M. Aesthetics N. Activity-friendliness	A-G: GIS-derived measures calculated within 250 m, 500 m, 1000 m and 2000 m network buffers around home address H-N: self-reported	OR (95% CI) A. *In 2000 m buffers:* 1.025 (1.012-1.039) E. *In 2000 m buffers:* 1.003 (1.000-1.006) G. 1.025 (1.005-1.046) I. 1.049 (1.011-1.088) K. 1.063 (1.015-1.114) M. 1.052 (1.005-1.101) N. 1.025 (1.012-1.039)	Good
Hobin *et al.*[88]	Canada	14-18 years[b]	Total: 22 117 Boys: 11 192 Girls: 10 925	Cross-sectional	***Unspecified PA*** • Min/day MVPA	Self-reported	A. Count of facilities/km B. Land-use mix C. Number of intersections/km D. Number of households/km E. Walkability index	GIS-derived measures calculated within 1000 m circular buffers around school	β (SE) and p-values B. -20.82 (10.66), p<0.05 C. -2.56 (1.00), p=0.013	Fair
Hobin *et al.*[89]	Canada	14-18 years[b]	Total: 21754 Boys: 10973 Girls: 10781	Cross-sectional	***Unspecified PA*** • Min/day MVPA	Self-reported	A. Count of facilities/km B. Land-use mix C. Number of intersections/km D. Households/km E. Walkability index	GIS-derived measures calculated within 1000 m circular buffers around school	β (SE) and p-values **Girls** B. -26.14 (10.19), p<0.01 **Boys** E. -2.15 (0.9003), p=0.0196	Fair
Huynh *et al.*[90]	Canada	11-16 years	Total: 17249 Boys: 8196 Girls: 9053	Cross-sectional	***Well-being*** • Positive emotional well-being	Self-reported	A. Proportion of natural space (green and blue) B. Proportion of green space C. Proportion of blue space	GIS-derived measures calculated within 5000 m circular buffers around schools	P-values for trend C. p=0.04 (all) A. p=0.03 (small city) C. p=0.008 (small city) C. p=0.02 (metropolitan)	Good
Islam *et al.*[91]	Bangladesh	9-14 years	Total: 109 Boys: 67 Girls: 42	Cross-sectional	***Outdoor activity*** • Average time outdoors on weekdays	Self-reported	A. Building type with outdoor space B. Availability of adjacent space/facility C. Number of stories D. Residence floor level E. Residing on cul-de-sac F. Street width G. Street level H. Street capacity I. Number of intersections J. Overall street pattern K. Land-use	A-H: direct observation I-K: GIS-derived measures calculated within 150 m circular buffers around home	B (SE) and p-values B. 23.16 (6.216), p<0.001 D. -3.01 (1.46), p=0.042 E. 14.97 (6.16), p=0.017 K. -0.001 (0.000), p=0.007	Poor

Janssen and Rosu[92]	Canada	11-13 years	Total: 5138 Boys: 2376 Girls: 2762	Cross-sectional	***Leisure-time PA*** • Frequency, outside school hours	Self-reported	A. Proportion of meadows B. Proportion of treed areas	GIS-derived measures calculated within 1000 m circular buffers	OR (95% CI) B. 1.05 (1.01-1.10)	Fair
Katapally and Muhajarine[93]	Canada	10-14 years	Total: 331 Boys: 166 Girls: 165	Cross-sectional	***Unspecified PA*** • Mean MVPA/day	Accelerometers	A. Grid pattern B. Fractured-grid pattern C. Curvilinear pattern D. Destination diversity E. Destination density F. Safety from traffic G. Attractiveness H. Pedestrian access I. Universal accessibility J. Activity friendliness	Direct observation with audits	OR (95% CI) Children residing in B were less likely to accumulate MVPA compared to children residing in A 0.42 (0.24-0.89)	Poor
Kim and Lee[94]	USA	9-10 years[b]	Total: 11495	Cross-sectional	***Active travel*** • Walking to school	Self-reported	A. School centrality B. Walkability (school street conditions)	GIS and direct observation	β (95% CI) A. 4.93 (1.542-8.326) B. 3.69 (1.111-6.275)	Poor
Kim *et al.*[95]	USA	9-11 years	Total: 92 Boys: 35 Girls: 57	Cross-sectional	***Well-being*** • Health-related QoL	Self- and parental reported	**Landscape spatial patterns of forests/trees** A. Percentage landscape B. Number of patches C. Mean patch size D. Mean shape index E. Nearest neighborhood F. Cohesion index	GIS-derived measures calculated within 400 and 800 m circular buffers	β and p-value **400-meter** A. 0.357, p=0.023 B. 0.382, p=0.016 E. 0.608, p=0.001 **800-meter** B. 0.385, p=0.020 E. 0.534, p=0.004	Good
Klinker *et al.*[96]	Denmark	11-16 years	Total: 170 Boys: 83 Girls: 87	Cross-sectional	***Unspecified PA*** • Min/day MVPA	Accelerometers	A.School grounds B. Clubs C. Sport facilities D. Playgrounds E. Green space F. Shopping centers G. Other places	All GPS-points from the children were digitalized in GIS and mapped	B (95% CI) A. 23.5 (21.1-25.9) B. 11.2 (9.4-13.0) C. 18.6 (16.8-20.3) D. 16.4 (15.6-17.3) E. 20.2 (18.4-21.9) F. 17.3 (13.7-20.9) G. 5.5 (2.9-8.1)	Fair
Kopcakova *et al.*[97]	Slovakia, Czech Republic, Germany and Poland	13-16 years	Total: 13800 Boys: 6822 Girls: 6978	Cross-sectional	***Unspecified PA*** • Sufficient or less sufficient	Self-reported	A. Perceived environment • *Neighborhood safety* • *Children in the neighborhood* • *Somewhere to play* • *Playground and parks close to home* • *Playgrounds and fields at school*	Self-reported	OR (95% CI) A. 1.11 (1.05 - 1.18)	Good
Kowaleski-Jones *et al.*[98]	USA	6-17 years	Total: 2706 Boys: 1357 Girls: 1349	Cross-sectional	***Unspecified PA*** • Minutes in MVPA bouts of at least 1 min duration	Accelerometers	A. Population density B. Distance to park C. Number of intersections/km^2	GIS-derived measures calculated within census tracts	B and p-values **6-11 years** A. -2.93, p<0.01 B. -4.31, p<0.01 **Boys** A. -3.27, p<0.01 B. -6.57, p<0.05 **Girls** A. -1.28, p<0.05 B. -1.83, p<0.05 **12-17 years** A. 2.24, p<0.01 B. -1.43, p<0.05 C. 0.99, p<0.01 **Boys** A. 2.51, p<0.01 B. -2.34, p<0.01 C. 3.03, p<0.01	Good

Kyttä *et al.*[99]	Finland	10-12 years 13-15 years	Total: 1837 Boys: 937 Girls: 900	Cross-sectional	***Active travel*** • To/from school ***Well-being*** • Self-perceived health	Self-reported	A. Proportion of green structure B. Residential density C. Population density, the proportion of 0-15-year-old	GIS-derived measure calculated within 500 m of home addresses	OR (95% CI) **Active travel** A. 0.64 (0.59-0.70) B. 1.53 (1.40-1.67) C. 0.64 (0.58-0.71) **Self-perceived health** A. 1.08 (1.01-1.16)	Fair
Larsen *et al.*[100]	Canada	12-14 years[b]	Total: 614 Boys: 273 Girls: 314	Cross-sectional	***Active travel*** • To/from school	Self-reported	A. Distance to school B. Road segment with high traffic volume C. Land-use dedicated to single detached homes D. Land-use mix E. Number of trees within 5 m of road edge in groups of 10/km^2 F. Number of major streets crossed G. Number of intersections/km^2	GIS-derived measures calculated along a 100 meter wide travel corridor based on shortest network distance between home address and school	OR (95% CI) **To school** A. 0.171 (0.16-0.25) B.0.969 (0.949-0.99) C.0.223 (0.062-0.80) D.0.257 (0.077-0.86) E.1.005 (1.00-1.009) **From school** A. 0.125 (0.08-0.192) B. 0.964 (0.94-0.985) F. 0.656 (0.462-0.93)	Fair
Larsen *et al.*[101]	Canada	6-13 years[b]	Total: 559	Cross-sectional	***Active travel*** • Walking to school	Parental or guardian reported	A. Intersections/km^2 B. Length of streets/km^2 C. Length of local streets/km^2 D. Number of major and local road intersections E. Transport stops/km^2 F. Number of people/km^2 G. Land-use mix H. Distance to school	GIS-derived measures calculated within postal code-based neighborhoods	OR and p-values A. 0.985, p<0.001 H. 0.141, p<0.001	Poor
Larsen *et al.*[102]	Canada	10-12 years[b]	Total: 687 Boys: 328 Girls: 359	Cross-sectional	***Active travel*** • Walking to/from school	Parental reported	A. Distance to school B. Major intersections crossed on route C. Intersections crossed on route D. Density of street trees E. Proportion of route with sidewalks missing on both sides of street F. Density of safety related features G. Land-use mix	GIS-derived measures calculated for self-mapped and shortest route to/from school	OR and p-value **Mapped (to)** A. 0.049, p<0.001 C. 0.870, p=0.001 F. 1.279, p=0.028 **Shortest (to)** A. 0.044, p<0.001 B. 0.807, p<0.001 D. 1.006, p=0.016 E. 0.035, p<0.001 G. 133.39, p<0.001 **Mapped (from)** A. 0.034, p<0.001 C. 0.895, p=0.040 D. 1.001, p=0.007 E. 0.050, p=0.024 **Shortest (from)** D. 1.010, p=0.012 E. 0.082, p=0.002 G. 201.25, p<0.001	Fair

Lee *et al.*[103]	USA	6-10 years[b]	**Cases** Total: 601 Boys: 276 Girls: 325 **Control** Total: 601 Boys: 282 Girls: 319	Case-control	***Active travel*** • Walking to/from school	Parental reported	A. Distance to school close for walking B. Park en-route C. Convenience store en-route D. Busy road en-route E. Sidewalk condition F. Convenience of walking to school	Parental report	OR (95% CI) **Walking vs. driving** A. 1.507 (1.00-2.267) B. 1.847 (1.14-2.999) C. 0.700 (0.494-0.992) D. 0.865 (0.756-0.99) E. 1.289 (1.099-1.51)	Fair
Leslie *et al.*[104]	Australia	10-14 years	Total: 2961 Boys: 1442 Girls: 1519	Cross-sectional	***Active travel*** • To/from school	Self-reported	A. Recreational facilities close to home B. Safe to walk/jog in the neighborhood C. Barriers to walk/jog in the neighborhood	Self-reported	OR (95% CI) **To school for boys** A. 1.19 (1.08-1.32) B. 1.12 (1.00-1.25) **From school for boys** A. 1.18 (1.06-1.31) B. 1.14 (1.02-1.29) **To school for girls** A. 1.17 (1.06-1.29) **From school for girls** A. 1.13 (1.02-1.24) B. 1.12 (1.01-1.25)	Fair
Magalhães *et al.*[105]	Portugal	13 years (baseline)	Total: 969 Boys: 443 Girls: 524	Longitudinal, 4-year follow-up	***Leisure-time PA*** • Change in leisure-time PA	Self-reported	A. Distance to greenspace B. Distance to sport facilities	GIS-derived measures based on street network distances	No associations found	Fair
Markevych *et al.*[106]	Germany	10 years	Total: 1932 Boys: 994 Girls: 938	Cross-sectional	***Well-being*** • Total behavior problem score • Emotional symptoms • Conduct problems • Hyperactivity or inattention • Peer problems	Parental reported	A. Distance to greenspace	GIS-derived measures based on straight-line distances	OR (95% CI) **Hyperactivity** *(abnormal vs. borderline/normal)* A. 1.20 (1.01-1.42) **Peer problems** A. 1.20 (1.02-1.40)	Good
Markevych *et al.*[107]	Germany	15 years	Total: 1192 Boys: 551 Girls: 641 **Munich area** Total: 688 **Wesel area** Total: 504	Cross-sectional	***Unspecified PA*** • Total MVPA • Total light PA ***Leisure-time PA*** • Leisure MVPA • Leisure light PA	Accelerometers and activity diaries	A. Proportion of green space (NDVI) B. Proportion of tree cover **Only for Munich data** C. Green space presence D. Presence of forests E. Presence of sport facilities F. Presence of leisure facilities	GIS-derived measures calculated within 500 m circular buffers around home address	Munich, Count ratios (95% CI) **Total MVPA** E. 1.09 (1.01-1.17) **Leisure MVPA** E. 1.09 (1.01-1.18) No associations found for Wesel	Good
Massougbodji *et al.*[108]	Canada	13-17 years	Total: 61 860 Boys: 30 749 Girls: 31 111	Cross-sectional	***Leisure-time PA*** • Leisure time	Self-reported	A. Number of parks or green spaces/leisure amenities B. Distance to park C. Distance to green space/leisure amenity D. NDVI E. Residential density F. Land-use ratio G. Intersection density H. Presence of a highway I. Walkability index	GIS-derived measures calculated within 250 m, 500 m, 750 m, 1000 m and 1500 m network buffers around school address	OR (95% CI) **Boys** A. 0.90 (0.82-0.97) within 750 m buffer No associations found for girls	Good

McCormack *et al.*[109]	Australia	10-12 years	Total: 927 Boys: 424 Girls: 503	Cross-sectional	***Unspecified PA*** • Daily step counts	Pedometers	A. Distance to friend B. Distance to relative C. Have to drive to park with equipment D. Traffic E. Neighborhood friendliness F. Number of facilities	Parental report	OR (95% CI) A. 0.62 (0.47-0.82) F. 0.93 (0.88-0.99)	Good
McCracken *et al.*[110]	Scotland	8-11 years	Total: 276 Boys: 122 Girls: 154	Cross-sectional	***Well-being*** • Total QoL score • Physical wellbeing • Emotional wellbeing • Self-esteem	Self-reported	A. Proportion of green space	GIS-derived measure calculated within 500 m circular buffers from cluster center	No associations found	Poor
McGrath *et al.*[111]	New Zealand	Mean age 9.3 years	Total: 227 Boys: 109 Girls: 118	Cross-sectional	***Leisure-time PA*** • Steps/hours in school commune, after school and in weekends • MVPA in school commute, after school and in weekend	Accelerometers	A. Distance to school B. Recreational amenities C. Food outlets D. Walkability index E. Pedestrian safety index F. Pedestrian amenities index G. Streetscape esthetics index H. Local destination index	A-D: GIS-derived measures calculated within 800 m of a population-weighted centroid E-H: direct observation with audits	Direction and p-values A. Commute, +, p=0.01 After, +, p=0.1 B. Commute, +, p=0.01 After, -, p=0.1 Weekend, -, p=0.1 C. Commute, -, p=0.1 Weekend, -, p=0.1 D. After, +, p=0.1 Weekend, +, p=0.1 E. Commute, +, p=0.01 After, -, p=0.1 Weekend, -, p=0.1 F. Commute, +, p=0.1 Weekend, -, p=0.1 G. Commute, +, p=0.1 Weekend, +, p=0.1 H. After, +, p=0.1	Poor
McMinn *et al.*[112]	Scotland	8-9 years	Total: 39 Boys: 27 Girls: 12	Cross-sectional	***Outdoor activity*** • MVPA at GPS-points	Accelerometers	A.Greenspace B. Road/track/path C. Other natural area D. Man-made area	GPS-points were digitalized in GIS and assigned a land-use category	OR (95% CI) B. 0.32 (0.19-0.52) C. 1.23 (1.02-1.48)	Poor
Mecredy *et al.*[113]	Canada	11-15 years	Total: 8535	Cross-sectional	***Leisure-time PA*** • Hours/week MVPA outside school hours	Self-reported	A. Street connectivity B.Neighborhood safety C. Perceived litter	GIS-derived measures calculated within 5000 m buffers around home addresses	RR (95% CI) A. High (ref.) Low: 1.21 (1.09-1.34) B. Low (ref.) High: 1.47 (1.34-1.49) C. None (ref.) Lots: 1.13 (1.01-1.26)	Good
Mitchell *et al.*[114]	Canada	9-14 years	Total: 435 Boys: 177 Girls: 258	Cross-sectional	***Leisure-time PA*** • Min/day MVPA	Accelerometers	A. Parks/km^2 B. Parks with at least one open sport field/km^2 C. Parks with at least one playground/km^2 D. Parks with one sport and playground/km^2 E. Distance to school F. Distance to recreational site G. Multi-use path space H. Land-use mix I. Intersections/km^2	GIS-derived measures calculated within 500 and 800 m circular buffers around home addresses	B and p-values **500-meter** A. 0.929, p=0.016 G. 1.407, p=0.018 **800-meter** B. 2.653, p=0.020 C. 0.584, p=0.031 **Boys 500-meter** B. 1.363, p=0.020 C. -3.403, p=0.042 **Boys 800-meter** B. 3.657, p=0.048 C. -8.082, p=0.026	Fair

Molina-Garcia and Queralt[115]	Spain	10-12 years	Total: 310 Boys: 158 Girls: 152	Cross-sectional	***Active travel*** • Trips/week to and from school	Parental reported	A. Walkability	GIS-derived measure calculated within an administrative including a 100 m circular buffer around the perimeter of each census block	β (95% CI) A. -.2.58 (-3.26, -1,91) Children living in more walkable areas reported more active travel per week compared with those living in less walkable areas (9.1 vs. 6.5 trips/week)	Good
Molina-Garcia *et al.*[116]	Spain	14-18 years	Total: 325 Boys: 149 Girls: 176	Cross-sectional	***Unspecified PA*** • Min/day MVPA on weekday ***Leisure-time PA*** • Min/day MVPA on weekend day • Days/week of ≥ 60 min physical activity outside of school ***Organized sports*** • Number of sports teams or physical activity classes outside of school ***Active travel*** • Trips/week to and from school	Accelerometers Accelerometers Self-reported Self-reported Self-reported	A. Walkability	GIS-derived measure calculated within census blocks	P-value **Active travel** A. p=0.001 Adolescents living in lower walkable neighborhoods reported 1.5 more trips per week compared with higher walkable areas (8.3 trips vs. 6.8 trips)	Fair
Moore *et al.*[117]	USA	10-14 years[b]	Total: 284	Cross-sectional	***Unspecified PA*** • Min/day MVPA	Accelerometers	A. Nearest distance to different facilities B. Walkers/bikers are easily visible C. High traffic makes it difficult to walk D. Places to go within walking distance	A: GIS-derived measure calculated based on the street network B-D: self-reported	B (SE) and p-values **Rural** A. -1.20 (0.61), p<0.05 **Urban** A. 0.91 (2.22), p<0.05 C. 4.78 (2.12), p<0.05	Fair
Moore *et al.*[118]	USA	8-17 years	Total: 711 Boys: 313 Girls: 398	Cross-sectional	***Unspecified PA*** • Min/day MVPA	Accelerometers	A. Safe to walk/jog B. Sidewalks on streets C. Cycle/walking trails D. Total environmental score	Self-reported	B (95% CI) **Interaction analyses** D x gender 1.78 (0.48-3.08)	Poor
Moran *et al.*[119]	Israel	10-12 years	Total: 573 Boys: 287 Girls: 286	Cross-sectional	***Active travel*** • Walking to school • Walking to destinations • Cycling to destinations • Leisure cycling	Self-reported	A. Residential density B. Total building density C. Distance to store D. Distance to park E. Distance to school	GIS-derived measures calculated within 400 m circular buffers around home addresses	OR (95% CI) **Walk to school** A. 2.57 (1.29-5.10) E. 0.12 (0.07-0.20) **Walk to destinations** B. 2.21 (1.24-3.94) **Cycle to destinations** A. 0.48 (0.20-0.69) **Leisure cycling** A. 0.36 (0.18-0.71)	Poor

Moran *et al.*[120]	Israel	10-12 years	Total: 573 Boys: 287 Girls: 286	Mixed method with a cross-sectional survey	***Outdoor play*** • Times/week outdoor play in the afternoon at different types of locations - Park - Public facility - Street	Self-reported	A. Child-friendly environment - Places to walk to - Things to look at - Parks/playgrounds - Many nice places to play at - Fun to play outside in the streets	Self-reported	OR (95% CI) for outdoors play at least three times a week **Park** A. 1.23 (1.06-1.43) **Public facility** A. 1.17 (1.01-1.35) **Street** A. 1.29 (1.10-1.52)	Poor
Nguyen *et al.*[121]	Canada	10-13 years	Total: 458 Boys: 230 Girls: 228	Cross-sectional	***Outdoor play*** • Daily time	Accelerometers	A. Pedestrian safety i. *Traffic calming* ii. *Pedestrian infrastructure*	Self-reported and GIS-derived measures based on a 1000 m network buffer around the home address	B (SE) and p-values **Traffic calming measured with GIS** *Low:* 0 (Ref.) *Moderate:* -0.29 (0.11), $p<0.05$ *High:* -0.07 (0.13)	Good
Nichol *et al.*[122]	Canada	11-16 years[b]	Total: 9114 Boys: 4322 Girls: 4791	Cross-sectional	***Leisure-time PA*** • Hours/week MVPA	Self-reported	A. Neighborhood safety B. Number of facilities	A: self-reported B: GIS-derived measure calculated within 5000 m circular buffers around schools	A. Associated with MVPA in all subgroups	Good
Nicosia and Datar[123]	USA	Mean age 13.5 years (baseline)	Total: 749 Boys: 382 Girls: 367	Quasi-experimental	***Unspecified PA*** • Min/week of moderate and vigorous physical activity	Self-reported	A. Number of fitness and recreational facilities	GIS-derived measure calculated within 3200 m buffers around home address	B (SE) and p-values **Moving X facilities** 17.67 (8.99), $p<0.05$ The association between access to facilities and physical activity among movers was positive and significant.	Fair
Noonan *et al.*[124]	England	9-10 years	Total: 194 Boys: 87 Girls: 107	Cross-sectional	***Active travel*** • To/from school	Self-reported	A. Residential density B. Land-use mix diversity C. Land-use mix access D. Recreational facilities E. Street connectivity F. Walking/cycling facilities G. Aesthetics H. Traffic safety	Parental reported	OR (95% CI) B. 1.86 (1.16-2.96) E. 1.66 (1.01-2.73) G. 0.65 (0.44-0.95)	Poor
Oliveira *et al.*[125]	Portugal	15-18 years	Total: 948 Boys: 405 Girls: 543	Cross-sectional	***Unspecified PA*** • Active/non-active based on 75th percentile values	Pedometer	A. Safety B. Aesthetics C. Facilities D. Transportation	Self-reported	OR (95% CI) D. 1.442 (1.048-1.983)	Fair
Oliver *et al.*[126]	New Zealand	6.5-15 years	Total: 217 Boys: 111 Girls: 105	Cross-sectional	***Active travel*** • To school	Self-reported	A. Distance to school	GIS-derived measure	OR (95% CI) A. 0.02 (0.003-0.10)	Good

Oliver *et al.*[127]	New Zealand	9-13 years	Total: 236 Boys: 104 Girls: 132	Cross-sectional	***Leisure-time PA*** • Proportion MVPA on weekdays and weekends ***Active travel*** • Proportion of active trips on weekdays and weekends	Accelerometers Accelerometers	A. Street connectivity B. Residential density C. Neighborhood destination accessibility index D. Distance to school E. Proportion of high speed roads F. Streetscapes	A-E: GIS-derived measures calculated within 1000 m buffers around home addresses F: audited street segments within 800 m network buffers around schools	B (95% CI) **Week MVPA** E. 0.04 (-4.91,-0.16) F. 1.87 (0.14-3.59) **Week active trips** A. 3.88 (1.87-5.88) C. -10.5 (-13.7,-7.2) **Weekend MVPA** C. -0.05 (-0.1,-0.002) **Weekend active trips** A. 3.97 (1.40-6.55) D. -3.27 (-6.4,-0.12)	Fair
Oluyomi *et al.*[128]	USA	9-10 years[b]	Total: 830 Boys: 412 Girls: 418	Cross-sectional	***Active travel*** • Walking to school	Parental reported	**En-route to school** A. Available sidewalks B. Quality of sidewalks C. Safe road crossings D. Traffic safety E. Traffic amount/speed F. Sidewalks G. Safety at intersections H. Crossing guard **Near school** I. Available sidewalks J. Quality of sidewalks K. Trees along the streets L. Bike lanes/trails M. Quality of lanes/trails N. Bike racks O. Safe road crossings P. Attractive buildings or natural things to see Q. Abandoned houses or vacant lots R. Well-maintained home, apartment and gardens	Parental reported	OR (95% CI) A. 2.69 (1.66-4.35) B. 2.20 (1.30-3.71) C. 2.61 (1.51-4.49) D. 2.86 (1.51-4.49) E. 3.87 (2.19-6.86) F. 3.38 (1.94-5.89) G. 4.75 (2.54-8.89) H. 4.90 (2.29-10.46) I. 3.07 (1.71-5.50) J. 1.88 (1.06-3.35) K. 2.07 (1.12-3.82) L. 1.75 (1.13-2.70) O. 2.06 (1.06-4.00)	Fair
Olvera *et al.*[129]	USA	Mean age 10.0 years	Total: 132 Boys: 77 Girls: 55	Cross-sectional	***Unspecified PA*** • Min/day MVPA	Accelerometers	A. Too much traffic B. No crosswalks C. No signals at crosswalks D. No lightening	Self- and parental reported	B (SE) and p-value **Parental report** B. -8.39(3.86), p=0.036	Poor
Oreskovic *et al.*[130]	USA	9-10 years[b]	Total: 149 Boys: 70 Girls: 79	Cross-sectional	***Active travel*** • To school ***Unspecified PA*** • Min/day MVPA	Self-reported Accelerometers	A. Presence and width (m) of sidewalks B. Land-use mix C. Count of intersections D. Count of traffic signals E. Density of police stations and storefronts F. Presence and width (m) of bicycle paths G. Length of major roads H. Amount of park area	GIS-derived measures calculated within 400, 800 and 1600 m network buffers around schools	B (SE) and p-values **Active travel** H. -0.008 (0.004), p=0.03 **Min/day MVPA** B. 60.0 (24.3), p=0.02 C. -5.57 (2.62), p=0.04 D. 0.68 (5.68), p=0.04	Fair
Page *et al.*[131]	England	10-11 years	Total: 1300 Boys: 631 Girls: 639	Cross-sectional	***Active travel*** • Walking/cycling from school ***Outdoor play*** • Likelihood of participating every day ***Organized sports*** • Likelihood of participating every day	Self-reported	A. Aesthetics B. Traffic safety C. Access to school and friend's house D. Access to facilities E. Play space F. Distance to school	A-E: Self-reported F: GIS-derived measure	OR (95% CI) **Active travel boys** C. 1.87 (1.04-3.36) D. 2.07 (1.34-3.21) F. 0.99 (0.98-0.99) **Active travel girls** F. 0.99 (0.98-0.99) **Outdoor play girls** B. 1.63 (1.14-2.34) **Organized sport boys** C. 1.62 (1.01-2.66) **Organized sport girls** C. 1.65 (1.07-2.53) D. 1.45 (1.07-1.98) F. 1.41 (1.04-1.91)	Fair

Panter *et al.*[132]	England	9-10 years	Total: 2012 Boys: 899 Girls: 1113	Cross-sectional	***Active travel*** • Walking to school • Cycling to school	Self-reported	A. A major or minor road adjacent to home B. Road density C. Share of primary roads D. Building density E. Sidewalk density F. Effective walkable area G. Connected node ratio H. Intersection density I. Land-use mix J. Urban-rural status K. Streetlight density L. Presence of main road M. Main/secondary road N. Route directedness O. Proportion of route within an urban area P. Land-use mix Q. Distance to school R. Cycle racks S. Land-use mix T. Sidewalks U. Cycle path V. Traffic-calming W. Pedestrian crossing	A-J: GIS-derived measures calculated within 800 m network buffers around home addresses K-Q: GIS-derived measures calculated within 100 m buffers around route to school R-W: direct observation	OR (95% CI) **Walking** B. *Low (Ref.)* 3.22 (2.09-4.94) G. 0.49 (0.31-0.76) L. 0.65 (0.48-0.89) N. 0.47 (0.36-0.61) Q. 0.10 (0.06-0.11) **Cycling** L. 0.50 (0.32-0.78) N. 0.62 (0.43-0.90) Q. 0.27 (0.18-0.39)	Fair
Panter *et al.*[133]	England	9-10 years	Total: 2012	Cross-sectional	***Active travel*** • Walking to school • Cycling to school	Self-reported	A. Safety to walk B. Traffic danger C. Lack of pavements D. Lack of cycle paths E. Neighborhood safety F. Neighborhood walkability G. Urban-rural status of home address	A-F: Self- and parental reported G: GIS-derived measure based on existing classifications	OR (95% CI) Cycling **Distance <1km** E. 2.50 (1.28-4.88) F. 1.04 (1.02-1.05) G. *Town/fringe:* 2.29 (1.46-4.70) **Distance 1-2 km** F. 1.05 (1.03-1.06) G. *Village:* 3.85 (2.01-6.91) Walking **Distance <1km** E. 1.84 (1.07-3.20) F. 1.02 (1.00-1.03) **Distance >2km** F. 1.05 (1.02-1.09)	Fair
Panter *et al.*[134]	England	9-10 years	Total: 912 Boys: 373 Girls: 539	Longitudinal with 1-year follow-up	***Active travel*** • Taking up active travel school • Remaining an active traveler	Self-reported at T1 and T2	A. Perceived walkability B. Route safety C. Safety to play D. Road density E. Proportion of primary roads F. Streetlights/km roads G. Effective walkable area H. Connected node ratio I. Junction density J. Land-use mix K. Urban-rural status L. Distance to school M. Streetlights/km route N. Presence of main road O. Route length ratio P. Land-use mix (route) Q. Route in an urban area	A-C: self-reported D-K: GIS-derived measures	OR (95% CI) **Taking up AT** B. 2.67 (1.42-5.03) K. *Urban:* 4.18 (1.41-12.40) L. 4.73 (1.97-11.32) O. 0.41 (0.19-0.89)	Fair

Patnode *et al.*[135]	USA	10-17 years	Total: 294 Boys: 149 Girls: 145	Cross-sectional	***Unspecified PA*** • Min/day MVPA	Accelerometers	A. Neighborhood safety B. Walking infrastructure C. Distance to park D. Distance to recreation center E. Distance to gym F. Distance to trail G. Distance to school H. Walkability index	A-B: self-reported C-H: GIS-derived measures calculated within 1600 m network buffers around home addresses	β and p-values **Girls** G.-0.20, p<0.05 No associations found for boys	Good
Plotnikoff *et al.*[136]	Australia	12-14 years	Total: 357 (only girls)	Cross-sectional	***Unspecified PA*** • Counts/min • Min/day MVPA	Accelerometers	A. Access to equipment, places for PA and safety from traffic	Self-reported	No associations found	Fair
Prins *et al.*[137]	Australia	Mean age 14.5 years	Total: 209 Boys: 96 Girls: 113	Cross-sectional	***Unspecified PA*** • Min/week MVPA	Accelerometers	A. Number of parks B. Number of sport facilities	GIS-derived measures calculated within 400, 800 and 2000 m buffers around home	No associations found	Fair
Reimers *et al.*[138]	Germany	11-17 years	Total: 1768 Boys: 903 Girls: 865	Cross-sectional	***Organized sports*** • Indoor sports during leisure	Self-reported	**Distance to** A. Gym B. Tennis court C. Indoor pool	GIS-derived measures based on straight-line distances	OR (95% CI) for girls A. 0.76 (0.64-0.91)	Good
Remmers *et al.*[139]	Netherlands	8-11 years	Total: 587 Boys: 280 Girls: 307	Cross-sectional	***Leisure-time PA*** • Light PA after school • MVPA after school	Accelerometers	A. Playability index: - *Playground size (m^2)* - *Accessibility* - *Opening hours* - *Maintenance status* - *Number of facilities* - *Age appropriateness of facilitates for 8-11 years old children*	Direct observation	β (95% CI) **Light PA** A. *End of school day* 0.042 (0.026-0.06) A. *16:00-18:00* 0.018 (0.002-0.03) A. *20:00-22:00* 0.052 (0.032-0.07) **MVPA** A. *End of school day* 0.029 (0.008-0.05) *A. 16:00-18:00* 0.028 (0.012-0.05)	Fair
Ries *et al.*[140]	USA	Mean age 15.6 years	Total: 327 Boys: 136 Girls: 192	Cross-sectional	***Unspecified PA*** • Min/week MVPA	Accelerometers	A. Availability of public and private facilities B. Public and private facility quality C. Number of public recreational facilities D. Number of private recreational facilities	A-B: self-reported C-D: GIS-derived measures calculated within 1600 m circular buffers around home addresses	No associations found	Fair
Rodríguez *et al.*[141]	USA	15-18 years	Total: 293 (only girls)	Longitudinal, 1-year follow-up	***Outdoor activity*** • Different intensities of PA in outdoor settings	Accelerometers	A. Population density B. Road length C. Presence of physical activity facilities D. Presence of parks E. Presence of school F. Number of food outlets G. Presence of fast food outlets	GIS-derived measures calculated within 50 m buffers around each GPS-point	OR (95% CI) Sedentary vs. MVPA **San Diego** A. 1.01 (1.00-1.02) B. 0.38 (0.28-0.51) E. 1.69 (1.29-2.20) F. 0.73 (0.67-0.80) **Minneapolis** A. 1.04 (1.02-1.07) B. 0.43 (0.25-0.74) D. 1.86 (1.51-2.31) E. 2.14 (1.30-3.53) F. 0.71 (0.60-0.82)	Fair

Sallis *et al.*[142]	USA	12-16 years	Total: 928 Boys: 460 Girls: 468	Cross-sectional	***Unspecified PA*** • Min/day MVPA • Days/week ≥ 60 minutes of physical activity ***Active travel*** • Walking/cycling to destinations • To/from school ***Outdoor activity*** • Typical frequency ***Organized sports*** • Outside of school	Accelerometers Self-reported Self-reported Self-reported Self-reported	A. Walkability	GIS-derived measure calculated within census blocks	Significant main effects **MVPA (3METS cut points):** p=0.008 **MVPA (Evenson cut points):** p<0.001 **Walking/cycling to destinations:** p<0.001	Fair
Sanders *et al.*[143]	Australia	Mean age 4.2 years (baseline)	**Baseline** Total: 4983 Boys: 2537 Girls: 2446 **Follow-up** Total: 3956 Boys: 2021 Girls: 1933	Longitudinal, 2-, 4-, 6- and 8-year follow-up	***Unspecified PA*** • Mean min of PA on weekdays ***Leisure-time PA*** • Mean min of PA on weekends	Self- and parental reported	A. Proportion of greenspace/open space	Land-use data based on statistical area level	Boys β (95% CI) **Total PA** A. 1.88 (0.23-3.53) **Leisure-time PA** A. 3.01 (0.37-5.66) At 2- and 4-year follow-up	Fair
Schipperijn *et al.*[144]	Denmark	15 years (baseline)	Total: 177 Boys: 76 Girls: 101	Longitudinal, 6-year follow-up	***Unspecified PA*** • Min/day MVPA	Accelerometers	A. Moveability index B. Residential density C. Recreational facilities D. Daily destinations E. Intersections	GIS-derived measures calculated within 2000 m network buffers around home addresses	Baseline β (95% CI) **All** A. 9.54 (0.65-18.44) E. 35.6 (12.3-58.8) **Girls** A. 12.0 (0.92-23.09) E. 37.5 (8.50-66.54) Follow-up results not considered	Fair
Singh and Ghandour[145]	USA	6-17 years	Total: 62804 Boys: 32124 Girls: 30680	Cross-sectional	***Well-being*** • Behavioral problem index • Serious behavioral problem	Parental reported	A. Neighborhood safety B. Presence of garbage/litter C. Poor/dilapidated housing D. Vandalism	Self-reported	β (SE) and p-value **Problem index** A. 3.88 (0.78) B. 4.37 (0.64) C. 5.03 (0.65) D. 3.98 (0.76) All p-values<0.001 OR (95% CI) **Serious problem** B. 1.61 (1.20-2.20) C. 1.68 (1.25-2.28)	Fair
Tappe *et al.*[146]	USA	6-11 years	Total: 724 Boys: 367 Girls: 357	Cross-sectional	***Unspecified PA*** • Min/day MVPA - 3+METs - Evenson cut ***Leisure-time PA*** • Days/week with 60+ minutes of activity outside school hours (5+) ***Outdoor activity*** • Days/week of neighborhood activity (4+) • Times/week of park activity (2+)	Accelerometers Parental reported Parental reported	A. Traffic safety B. Street connectivity C. Aesthetics D. Walk/cycle facilities E. Proximity to stores F. Proximity to play areas G. Barriers to walk/cycle H. Lack of play areas I. Physical activity environment	A-H: parental reported I: GIS-derived measure calculated based on the census block. Parks were audited.	B (95% CI) **MVPA (3+MET)** F. 4.12 (0.66-7.58) **MVPA (Evenson)** F. 2.12 (0.30-3.95) OR (95% CI) **Leisure-time PA** F. 1.29 (1.05-1.60) **Neighborhood activity** B. 0.77 (0.62-0.96) C. 1.57 (1.21-2.03) H. 0.74 (0.58-0.95) **Park activity** C. 1.38 (1.06-1.80) D. 1.40 (1.16-1.71) H. 0.74 (0.57-0.96)	Fair

Timperio *et al.*[147]	Australia	5-6 years (baseline) 10-12 years (baseline)	**Baseline** Total: 788 Boys: 386 Girls: 402 **Follow-up** Total: 351	Longitudinal, 5-year follow-up	***Leisure-time PA*** • Min/day MVPA (non-school hours on weekdays and weekends)	Accelerometers	**A. Cluster 1:** *Few land-uses, playgrounds and sports facilities, low street connectivity and traffic* **B. Cluster 2:** *Few land-uses, playgrounds and sport venues, and high street connectivity* **C. Cluster 3:** *Mixed land-use, few playgrounds and sports venues, low intersection density* **D. Cluster 4:** *Mixed land-use and many playgrounds and sport venues*	GIS-variables calculated within 800 m network buffers around home. Cluster analysis was performed to derive at four different neighborhood typologies.	Baseline B (95% CI) **10-12 year-olds** J. -3.4 (-6.8-0.0) K. 5.0 (2.6-7.4) No associations found for 5-6 year olds Follow-up No associations found	Fair
Trapp *et al.*[148]	Australia	10-12 years	Total: 1197 Boys: 573 Girls: 624	Cross-sectional	***Active travel*** • Cycling to/from school	Self-reported	A. Neighborhood safety B. Steep hills C. Cross a busy road D. No safe crossings E. High traffic F. Walkability G. Road traffic volume H. Low traffic and high walkability I. Connectivity J. Distance to school	A-E: self- and parental report F-J: GIS-derived measures	OR (95% CI) **Boys** A. 1.74 (1.08-2.80) H. 5.58 (1.11-27.96) J. 0.70 (0.63-0.99) **Girls** C. 0.44 (0.25-0.76)	Good
Trapp *et al.*[149]	Australia	9-13 years	Total: 1298 Boys: 617 Girls: 681	Cross-sectional	***Active travel*** • Walking to/from school	Self-reported	A. Neighborhood safety B. Steep hills C. Not enough footpaths D. Cross a busy road E. No safe crossings F. High traffic G. Walkability H. Road traffic volume I. Low traffic and high walkability J. Connectivity K. Distance to school	A-F: self- and parental reported G-K: GIS-derived measures	OR (95% CI) **Boys** D. 0.49 (0.28-0.88) H. 0.22 (0.08-0.60) I. 3.37(1.23-9.24) K. 0.40 (0.25-0.66) **Girls** K. 0.21 (0.09-0.46)	Good
Tung *et al.*[150]	Malaysia	9-12 years	Total: 259 Boys: 105 Girls: 145	Cross-sectional	***Unspecified PA*** • Overall physical activity level over the course of a week	Self-reported	A. Residential density B. Land-use mix diversity C. Land-use mix access D. Street connectivity E. Walking/cycling facilities F. Aesthetics G. Traffic hazards H. Hilly streets I. Physical obstacles J. Not many cul-de-sacs	Parental reported	β (SE) and p-value C. 0.13 (0.05), p=0.011	Fair
Uys *et al.*[151]	South Africa	9-11 years	Total: 258 Boys: 113 Girls: 145	Cross-sectional	***Leisure-time PA*** • Min/day MVPA - Before school - After school - Weekends	Accelerometers	A. Availability of PA facilities B. Proximity to facilities C. Neighbourhood safety D. Traffic safety E. Walkability	A: GIS-derived measure calculated within 500 m circular buffer around home addresses B-E: Parental report	β (SE) and p-value **Before school** B. 1.50 (0.51), p=0.003	Good

Van Dyck *et al.*[152]	Belgium	17-18 years	Total: 1281 Boys: 547 Girls: 734	Cross-sectional	***Active travel*** • Walking/cycling to school	Self-reported	A. Residential density B. Land-use mix diversity C. Land-use mix access D. Street connectivity E. Walking infrastructure F. Cycling infrastructure G. Traffic safety H. Walkability Z-score I. Distance to school	A-H: self-reported I: measured with Routenet online route planner	OR (95% CI) **Active travel** H. 1.10 (1.02-1.17)	Fair
Van Dyck *et al.*[153]	Belgium	13-15 years	Total: 477 Boys: 240 Girls: 237	Cross-sectional	***Active travel*** • Min/week walking and cycling	Self-reported	A. Residential density B. Land-use mix diversity C. Barriers to walking D. Street connectivity E. Presence of cul-de-sacs F. Availability and quality of walking and cycling infrastructure G. Safety for cycling H. Aesthetics I. Safety from traffic J. Walkability score	Self-reported	No associations found	Good
Van Loon *et al.*[154]	Canada	8-11 years	Total: 366 Boys: 174 Girls: 192	Cross-sectional	***Unspecified PA*** • Min/day MVPA	Accelerometers	A. Commercial density B. Residential density C. Land-use mix D. Intersection density E. Cul-de-sac density F. Proportion of low speed limit streets G. Number of parks H. Proportion of population comprised by children I. Neighborhood environment index (walkability)	GIS-derived measures calculated within 200-, 400 -, 800- and 1600-m network buffers around home addresses	B and p-values **Boys** I. 2.64, p<0.001 **Girls** E. 9.60, p<0.001 F. 7.68, p<0.05	Fair
Vanwolleghem *et al.*[155]	Belgium	10-12 years	Total: 126 Boys: 46 Girls: 80	Cross-sectional	***Active travel*** • Trips/day walking • Trips/day cycling • Min/day walking • Min/day cycling	Self-reported Accelerometers and GPS-units	A. Residential density B. Land-use mix C. Street connectivity D. Walk/cycle facilities E. Aesthetics F. Traffic safety	Parental report	OR and 95% CI **Trips/day cycling on weekdays** B. 1.13 (1.01-1.27) D. 0.83 (0.73-0.94) **Min/day cycling on weekdays** B. 1.46 (1.11-1.92) D. 0.72 (0.54-0.97) β (95% CI) **Min/day walking on weekdays** A. 0.10 (0.01-0.19) E. 4.69 (0.75-8.64)	Fair
Veitch *et al.*[156]	Australia	8-9 years	Total: 187 Boys: 99 Girls: 88	Cross-sectional	***Outdoor play*** • Playing in yard • Playing in street, court or footpath • Playing in park or playground	Parental reported	A. Safe to play in streets B. No/very small yard C. Lives in main arterial/busy road D. Lives in cul-de-sac E. Satisfaction with quality of parks and playgrounds	Parental report	OR (95% CI) **Playing in street, court or footpath** A. 6.01 (2.68-13.47) D. 3.49 (1.49-8.16)	Fair

Voorhees *et al.*[157]	USA	11-12 years	Total: 890 Girls: 890	Cross-sectional	***Active travel*** • Walking trips to/from school	Self-reported	A. Places to walk B. Sidewalks C. Bike/walking trails D. Safe to walk E. Traffic F. Things to look at G. Streets are lit H. Destinations I. Distance to school J. Count of facilities K. Population density L. Street connectivity M. Block size N. Land-use mix	A-H: self-reported I-N: GIS-derived measures calculated within 800 m network buffers around home addresses	OR (95% CI) A. 1.82 (1.16-2.85) D. 1.84 (1.09-3.10) I. 0.14 (0.09-0.22) J. 1.38 (1.24-1.54) M. 0.80 (0.67-0.97)	Fair
Wang *et al.*[158]	USA	12-16 years	Total: 928 Boys: 460 Girls: 468	Cross-sectional 2x2 design	***Active travel*** • Active Transport Index	Self-reported	A. Walkability index B. Number of parks and recreation facilities C. Streetscape quality	A-B: GIS-derived measures C: Direct observation	B (95% CI) A. 0.10 (0.057-0.143) B. 0.04 (0.023-0.062) C. 0.024 (0.009-0.04)	Good
Ward *et al.*[159]	New Zealand	11-14 years	Total: 72 Boys: 31 Girls: 41	Cross-sectional	***Outdoor activity*** • Time in MVPA ***Well-being*** • Life satisfaction • Happiness • Well-being	Accelerometers Self-reported	A. Greenspace exposure	GIS-derived measure calculated at activity locations	β (95% CI) **Outdoor activity** A. 0.95 (0.47-1.44) **Mental health** A. *Life satisfaction:* 0.66 (0.37-0.96) *Happiness:* 0.36 (0.17-0.55) *Well-being:* 2.67 (.1.29-4.05)	Fair
Wheeler *et al.*[160]	England	10-11 years	Total: 1053 Boys: 495 Girls: 558	Cross-sectional	***Leisure-time PA*** • Epoch exceeding MVPA	Accelerometers and GPS-units	A.Indoors (ref.) B. Greenspace C. Non-greenspace	GIS-derived measure determining land-use at each GPS-point	OR (95% CI) **Boys** B. 5.77 (5.08-6.64) C. 4.22 (3.81-4.66) **Girls** B. 5.12 (4.52-5.79) C. 4.75 (4.29-5.24)	Fair
Williams *et al.*[161]	Canada	10-13 years	Total: 367 Boys: 185 Girls: 182	Cross-sectional	***Active travel*** • Average min/day	Accelerometers	A. Walkability B. Proximity to destinations C. Connectivity D. Pedestrian safety	GIS-derived measures calculated within 1000 m buffers around home address	Significant linear trend in active travel across walkability index quartiles, p<0.001 Significant linear trend also observed for B, C and D	Fair
Wilson *et al.*[162]	USA	Mean age 11.4 years	Total: 198 Boys: 94 Girls: 104	Cross-sectional	***Unspecified PA*** • Min/day MVPA	Accelerometers	A. Neighborhood environmental support for PA	Parental report	B (SE) and p-value A. 4.27 (2.15), p<0.05	Good
Young *et al.*[163]	USA	Mean age 12.0 years Mean age 14.0 years Mean age 16.9 years	**6th graders** Total: 1576 Girls 1576 **8th graders** Total: 3085 Girls: 3085 **11th graders** Total: 589 Girls: 589	Cross-sectional	***Unspecified PA*** • Min/day MVPA	Accelerometers	A. Distance to own school B. Distance to nearest school C. Number of parks D. Proportion of circuits/loops in a network relative to the number of possible routes, given number of intersections E. Access to recreational facilities F. Places to go within walking distance G. Sidewalks in neighborhood H. Safety to walk/jog	A-D: GIS-derived measures calculated within 1600 m circular buffers around home addresses E-H: self-reported	Reg. coefficient (SE) and p-values **6th graders** E. 0.21 (0.10), p=0.03 **8th graders** A. 0.37 (0.09), p<0.001 H. 0.41 (0.18), p=0.03 **11th graders** B. 2.38 (1.17), p=0.04 G. -1.40 (0.42), p<0.001	Fair

Abbreviations: PA, physical activity; NDVI, Normalized Difference Vegetation Index; GIS, geographical information systems; CI, confidence interval; PR, prevalence ratio; MVPA, moderate-to-vigorous physical activity; OR, odds ratio; PCA, principal component analysis; SE, standard error; GPS, Global Positioning System; SES, socioeconomic status; MET, Metabolic Equivalent of Task; PAC-Q, Physical Activity Questionnaire for Children; PACE, Patient-centered Assessment and Counseling for Exercise; FPAI, Finnish Physical Activity Index; QoL, Quality of Life.

[a] *We have assigned a letter to each determinant measured in the separate studies (see the built environment column). The letters in the key findings column represent determinants that were significantly associated with an outcome. Almanza et al.,[38] found that more greenness (higher NDVI) at activity locations increased the odds of being MVPA (OR=1.34, 1.30-1.38).*
[b] *Converted from grade to age.*

Appendix IV: Results from assessment of methodological quality.

Cross-sectional studies

Reference	Q1	Q2	Q3	Q4*	Q5	Q6	Q7	Q8	Score
Aarts *et al.*[37]	Y	Y	Y	N/A	Y	Y	Y	Y	7
Almanza *et al.*[38]	Y	Y	Y	N/A	Y	Y	Y	Y	7
Amoly *et al.*[39]	Y	Y	Y	N/A	Y	Y	Y	Y	7
Babey *et al.*[40]	Y	Y	N	N/A	Y	Y	N	Y	5
Bird *et al.*[41]	N	Y	Y	N/A	Y	Y	Y	Y	6
Bloemsma *et al.*[42]	Y	Y	Y	N/A	Y	Y	Y	Y	7
Bringolf-Isler *et al.*[43]	Y	Y	Y	N/A	Y	Y	Y	N	6
Broberg *et al.*[44]	N	N	Y	N/A	N	Y	N	Y	3
Broberg and Sarjala *et al.*[45]	N	N	Y	N/A	N	Y	Y	Y	4
Buck *et al.*[46]	N	Y	Y	N/A	Y	Y	Y	Y	6
Buck *et al.*[47]	Y	Y	Y	N/A	Y	Y	Y	Y	7
Buliung *et al.*[48]	N	N	Y	N/A	N	Y	Y	Y	4
Butler *et al.*[49]	Y	Y	N	N/A	Y	Y	Y	Y	6
Cain *et al.*[50]	N	Y	Y	N/A	Y	Y	Y	Y	6
Carlson *et al.*[51]	N	Y	Y	N/A	Y	N	Y	Y	5
Carlson *et al.*[52]	Y	Y	Y	N/A	Y	Y	Y	Y	7
Coombes *et al.*[56]	Y	N	Y	N/A	Y	Y	Y	Y	6
Currerio *et al.*[59]	Y	Y	Y	N/A	Y	Y	N	Y	6
Da Silva *et al.*[60]	Y	N	Y	N/A	Y	Y	Y	Y	6
Davidson *et al.*[61]	Y	Y	Y	N/A	Y	Y	Y	Y	7
De Meester *et al.*[62]	N	Y	Y	N/A	Y	Y	Y	Y	6
De Meester *et al.*[63]	N	Y	Y	N/A	Y	Y	Y	Y	6
De Vries *et al.*[64]	N	Y	Y	N/A	Y	Y	Y	Y	6
D'Haese *et al.*[65]	Y	N	Y	N/A	Y	Y	Y	Y	6
D'Haese *et al.*[66]	Y	Y	Y	N/A	Y	Y	Y	Y	7
D'Haese *et al.*[68]	Y	Y	Y	N/A	Y	Y	Y	Y	7
Ducheyne *et al.*[69]	Y	Y	Y	N/A	Y	Y	Y	N	6
Duncan *et al.*[70]	N	Y	U	N/A	N	N	Y	Y	3
Duncan *et al.*[71]	Y	Y	Y	N/A	U	Y	Y	Y	6
Durand *et al.*[72]	Y	Y	Y	N/A	N	Y	U	Y	5
Edwards *et al.*[73]	U	Y	Y	N/A	N	Y	N	Y	4
Edwards *et al.*[74]	Y	Y	Y	N/A	N	N	N	Y	4
Feda *et al.*[75]	Y	Y	Y	N/A	Y	N	Y	Y	6
Fueyo *et al.*[78]	U	Y	N	N/A	Y	Y	Y	Y	5
Galvez *et al.*[79]	Y	Y	Y	N/A	Y	Y	Y	Y	7
Garcia-Cervantes *et al.*[80]	Y	Y	Y	N/A	Y	Y	Y	Y	7
Ghekiere *et al.*[81]	Y	Y	Y	N/A	Y	Y	Y	Y	7
Graham *et al.*[82]	Y	Y	Y	N/A	Y	Y	Y	Y	7
Graham *et al.*[83]	Y	N	Y	N/A	Y	Y	Y	Y	6
Gropp *et al.*[84]	Y	Y	Y	N/A	U	Y	Y	Y	6
Guliani *et al.*[85]	Y	Y	Y	N/A	N	Y	U	U	4
Helbich *et al.*[86]	Y	Y	Y	N/A	N	Y	Y	U	5
Hinckson *et al.*[87]	Y	Y	Y	N/A	Y	Y	Y	Y	7
Hobin *et al.*[88]	Y	Y	Y	N/A	N	Y	N	Y	5
Hobin *et al.*[89]	Y	Y	Y	N/A	N	Y	N	Y	5
Huynh *et al.*[90]	Y	Y	Y	N/A	Y	Y	Y	Y	7
Islam *et al.*[91]	U	Y	Y	N/A	Y	N	Y	U	4
Janssen and Rosu[92]	Y	Y	Y	N/A	Y	Y	U	Y	6
Katapally and Muhajarine[93]	N	Y	Y	N/A	N	U	Y	Y	4
Kim and Lee[94]	N	N	Y	N/A	N	N	Y	Y	3
Kim *et al.*[95]	Y	Y	Y	N/A	Y	Y	Y	Y	7
Klinker *et al.*[96]	Y	Y	Y	N/A	Y	Y	Y	N	6

Kopcakova *et al.*[97]	Y	Y	Y	N/A	Y	Y	Y	Y	7
Kowaleski-Jones *et al.*[98]	Y	Y	Y	N/A	Y	Y	Y	Y	7
Kyttä *et al.*[99]	N	Y	Y	N/A	N	Y	Y	Y	5
Larsen *et al.*[100]	Y	Y	Y	N/A	N	Y	N	Y	5
Larsen *et al.*[101]	Y	N	Y	N/A	N	Y	N	Y	4
Larsen *et al.*[102]	Y	Y	Y	N/A	N	Y	N	Y	5
Leslie *et al.*[104]	Y	Y	Y	N/A	N	Y	Y	Y	6
Markevych *et al.*[106]	Y	Y	Y	N/A	Y	Y	Y	Y	7
Markevych *et al.*[107]	Y	Y	Y	N/A	Y	Y	Y	Y	7
Massougbodji *et al.*[108]	Y	Y	Y	N/A	Y	Y	Y	Y	7
McCormack *et al.*[109]	Y	Y	Y	N/A	Y	Y	Y	Y	7
McCracken *et al.*[110]	Y	Y	Y	N/A	N	Y	N	Y	5
McGrath *et al.*[111]	N	Y	Y	N/A	U	N	Y	Y	4
McMinn *et al.*[112]	N	N	N	N/A	N	N	Y	Y	2
Mecredy *et al.*[113]	Y	Y	Y	N/A	Y	Y	Y	Y	7
Mitchell *et al.*[114]	Y	Y	Y	N/A	N	Y	Y	U	5
Molina-García and Quealt[115]	Y	Y	Y	N/A	Y	Y	Y	Y	7
Molina-García *et al.*[116]	Y	Y	Y	N/A	N	Y	Y	Y	6
Moore *et al.*[117]	Y	Y	Y	N/A	N	Y	Y	Y	6
Moore *et al.*[118]	N	N	N	N/A	N	N	Y	Y	2
Moran *et al.*[119]	Y	Y	Y	N/A	N	N	Y	N	4
Moran *et al.*[120]	Y	N	Y	N/A	N	N	Y	Y	4
Nguyen *et al.*[121]	Y	Y	Y	N/A	Y	Y	Y	Y	7
Nichol *et al.*[122]	Y	Y	Y	N/A	Y	Y	Y	Y	7
Noonan *et al.*[124]	Y	N	Y	N/A	N	Y	U	Y	4
Oliveira *et al.*[125]	Y	N	Y	N/A	Y	Y	Y	Y	6
Oliver *et al.*[126]	Y	Y	Y	N/A	Y	Y	Y	Y	7
Oliver *et al.*[127]	Y	N	Y	N/A	N	Y	Y	Y	5
Oluyomi *et al.*[128]	N	Y	Y	N/A	Y	Y	Y	Y	6
Olvera *et al.*[129]	Y	Y	Y	N/A	N	N	Y	N	4
Oreskovic *et al.*[130]	U	U	Y	N/A	Y	Y	Y	Y	5
Page *et al.*[131]	Y	N	Y	N/A	N	Y	Y	Y	5
Panter *et al.*[132]	Y	Y	Y	N/A	Y	N	U	Y	5
Panter *et al.*[133]	Y	Y	Y	N/A	Y	N	U	Y	5
Patnode *et al.*[135]	Y	Y	Y	N/A	Y	Y	Y	Y	7
Plotnikoff *et al.*[136]	Y	Y	Y	N/A	N	N	Y	Y	5
Prins *et al.*[137]	Y	N	Y	N/A	Y	Y	Y	Y	6
Reimers *et al.*[138]	Y	Y	Y	N/A	Y	Y	Y	Y	7
Remmers *et al.*[139]	Y	Y	Y	N/A	U	Y	Y	Y	6
Ries *et al.*[140]	Y	Y	N	N/A	Y	U	Y	Y	5
Sallis *et al.*[142]	Y	Y	Y	N/A	Y	U	Y	Y	6
Singh and Gandor[145]	N	Y	Y	N/A	Y	Y	Y	Y	6
Tappe *et al.*[146]	Y	Y	Y	N/A	Y	Y	Y	N	6
Trapp *et al.*[148]	Y	Y	Y	N/A	Y	Y	Y	Y	7
Trapp *et al.*[149]	Y	Y	Y	N/A	Y	Y	Y	Y	7
Tung *et al.*[150]	Y	Y	Y	N/A	Y	N	Y	Y	6
Uys *et al.*[151]	Y	Y	Y	N/A	Y	Y	Y	Y	7
Van Dyck *et al.*[152]	N	Y	Y	N/A	Y	Y	Y	Y	6
Van Dyck *et al.*[153]	Y	Y	Y	N/A	Y	Y	Y	Y	7
Van Loon *et al.*[154]	Y	Y	Y	N/A	N	Y	Y	Y	6
Vanwolleghem *et al.*[155]	Y	N	Y	N/A	Y	Y	Y	Y	6
Veitch *et al.*[156]	Y	Y	Y	N/A	Y	N	Y	Y	6
Voorhees *et al.*[157]	Y	Y	Y	N/A	N	Y	U	Y	5
Wang *et al.*[158]	Y	Y	Y	N/A	Y	Y	Y	Y	7
Ward *et al.*[159]	Y	Y	Y	N/A	N	Y	U	Y	5
Wheeler *et al.*[160]	Y	Y	Y	N/A	N	Y	Y	Y	6
Williams *et al.*[161]	Y	Y	Y	N/A	Y	Y	Y	N	6
Wilson *et al.*[162]	Y	Y	Y	N/A	Y	Y	Y	Y	7

Young *et al.*[163]	Y	Y	Y	N/A	Y	N	Y	Y	6
Total (%)	78	83	94	0	65	81	83	90	-

Note: Y, yes; N, no; N/A, not applicable; U, unclear.
* Question not applicable to this non-medical review of research on the built environment determinants of activity participation and well-being in healthy children and adolescents
JBI critical appraisal checklist for analytical cross-sectional studies: Q1 = Were the criteria for inclusion in the sample clearly defined? Q2 = Were the study subjects and the setting described in detail? Q3 = Was the exposure measured in a valid and reliable way? Q4 = Were objective, standard criteria used for measurement of the condition? Q5 = Were confounding factors identified? Q6 = Were strategies to deal with confounding factors stated? Q7 = Were the outcomes measured in a valid and reliable way? Q8 = Was appropriate statistical analysis used?

Longitudinal studies

Reference	Q1	Q2	Q3	Q4	Q5	Q6*	Q7	Q8	Q9	Q10	Q11	Score
Carver *et al.*[53]	Y	Y	Y	Y	N	N/A	Y	Y	N	N	Y	7
Carver *et al.*[54]	Y	Y	Y	Y	Y	N/A	Y	Y	N	N	Y	8
Coombes *et al.*[55]	Y	Y	Y	Y	Y	N/A	Y	Y	Y	N	Y	9
Corder *et al.*[57]	Y	Y	Y	Y	Y	N/A	Y	Y	Y	N	Y	9
Crawford *et al.*[58]	Y	Y	Y	Y	Y	N/A	Y	Y	N	N	Y	8
D'Haese *et al.*[67]	Y	Y	Y	Y	Y	N/A	Y	Y	N	N	Y	8
Feng and Astell-Burt[76]	Y	Y	Y	Y	Y	N/A	Y	Y	N	N	Y	8
Forthofer *et al.*[77]	Y	Y	Y	Y	Y	N/A	Y	Y	Y	N	Y	9
Magalhães *et al.*[105]	Y	Y	Y	Y	Y	N/A	Y	Y	Y	N	Y	9
Panter *et al.*[134]	Y	Y	Y	Y	Y	N/A	U	Y	Y	N	Y	8
Rodríguez *et al.*[141]	Y	Y	Y	Y	Y	N/A	U	Y	U	N	Y	7
Sanders *et al.*[143]	Y	Y	Y	Y	Y	N/A	Y	Y	N	N	Y	8
Schipperijn *et al.*[144]	Y	Y	Y	Y	Y	N/A	Y	Y	N	N	Y	8
Timperio *et al.*[147]	Y	Y	Y	Y	Y	N/A	Y	Y	Y	N	Y	9
Total (%)	100	100	100	100	93	0	86	100	43	0	100	-

Note: Y, yes; N, no; N/A, not applicable; U, unclear.
* Question not applicable to this non-medical review of research on the built environment determinants of activity participation and well-being in healthy children and adolescents. The studies were longitudinal and assessed changes in outcomes over specific periods in time.
JBI critical appraisal checklist for cohort studies: Q1 = Were the two groups similar and recruited from the same population (i.e., was the sample representative of the population as a whole)? Q2 = Were the exposures measured similarly to assign people to both exposed and unexposed groups (i.e., were exposures measured similarly across all participants)? Q3 = Was the exposure measured in a valid and reliable way? Q4 = Were confounding factors identified? Q5 = Were strategies to deal with confounding factors stated? Q6 = Were the groups/participants free of the outcome at the start of the study (or at the moment of exposure)? Q7 = Were the outcomes measured in a valid and reliable way? Q8 = Was the follow up time reported and sufficient to be long enough for outcomes to occur? Q9 = Was follow up complete, and if not, were the reasons to loss to follow up described and explored? Q10 = Were strategies to address incomplete follow up utilized? Q11 = Was appropriate statistical analysis used?

Case-Control studies

Reference	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Score
Lee *et al.*[103]	N	Y	Y	Y	Y	Y	Y	N	N	Y	7
Total (%)	0	100	100	100	100	100	100	0	0	100	-

Note: Y, yes; N, no; N/A, not applicable; U, unclear.
Q1 = Were the groups comparable other than the presence of activity in cases or the absence of activity in controls? Q2 = Were cases and controls matched appropriately? Q3 = Were the same criteria used for identification of cases and controls? Q4 = Was exposure measured in a standard, valid and reliable way? Q5 = Was exposure measured in the same way for cases and controls? Q6 = Were confounding factors identified? Q7 = Were strategies to deal with confounding factors stated? Q8 = Were outcomes assessed in a standard, valid and reliable way for cases and controls? Q9 = Was the exposure period of interest long enough to be meaningful? Q10 = Was appropriate statistical analysis used?

Quasi-Experiemental studies

Reference	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Score
Nicosia and Datar[123]	Y	N	N	Y	Y	U	Y	Y	Y	6
Total (%)	100	0	0	100	100	0	100	100	100	-

Note: Y, yes; N, no; N/A, not applicable; U, unclear.
Q1 = Is it clear in the study what is the 'cause' and what is the 'effect' (i.e., there is no confusion about which variable comes first)? Q2 = Were the participants included in any comparisons similar? Q3 = Were the participants included in any comparisons receiving similar treatment/care, other than the exposure or intervention of interest? Q4 = Was there a control group? Q5 = Were there multiple measurements of the outcome both pre and post the intervention/exposure? Q6 = Was follow up complete and if not, were differences between groups in terms of their follow up adequately described and analyzed? Q7 = Were the outcomes of participants included in any comparisons measured in the same way? Q8 = Were outcomes measured in a reliable way? Q9 = Was appropriate statistical analysis used?

Paper III

Neighborhood Green Spaces, Facilities and Population Density as Determinants of Activity Participation among 8-Year-Olds: A Cross-Sectional GIS Study Based on the Norwegian Mother and Child Cohort Study

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Abstract

Background: A rapidly growing body of research suggests that qualities of the built environment can promote active living among children and youth. Nevertheless, shortcomings in the current evidence for understanding which built environment characteristics provide opportunities for taking part in activities in childhood remain. This study aimed to examine whether population density, green spaces, and facilities are associated with participation in leisure-time physical activity (PA), organized activities, and social activities with friends and peers in Norwegian 8-year-olds.

Methods: Data from a sample of 23 043 children from the Norwegian Mother and Child Cohort Study (MoBa) were linked with geospatial data about the built environment. The questionnaire data reported by mothers provided information on the children's leisure activities. We computed exposure to neighborhood population density and access to green spaces and facilities within 800- and 5 000-m radii of the participants' home addresses using geographic information systems. Associations were estimated using logistic regression models.

Results: We found beneficial associations between having a park within 800-m and more leisure-time PA during the summer. Furthermore, children living in neighborhoods with higher proportions of green space participated in more PA during the winter. More densely populated areas and access to facilities were associated with participation in organized and social activities. Specifically, we observed that more playgrounds/sport fields in the neighborhood were the strongest and most consistent correlate of activity participation in Norwegian 8-year-olds by being related to more socialization with friends and peers.

Conclusion: This population-based study underscores the importance of access to a variety of venues and opportunities for different activities in the immediate neighborhood surroundings and in the greater community to support participation in physical activity and organized and social activities in childhood.

Keywords: Built environment; Geographic information systems; Children; Physical activity, Organized activity; Social activity; Well-being; The Norwegian Mother and Child Cohort Study.

Introduction

Participating in leisure activities is essential for children's health and well-being [1, 2]. Involvement in different organized activities, such as team and individual sports, music activities, and social clubs, has been associated with increased academic achievement, positive social relationships, higher self-rated health and life satisfaction, and better mental health [2-4]. The health benefits of physical activity in childhood are also widely known and supported [5], and a substantial amount of evidence has highlighted the importance of social activities with friends for physical, psychological, and social well-being [6, 7]. All kinds of activities take place in different contexts and environmental features can influence participation [8, 9]. This paper investigates neighborhood green spaces, facilities, and population density as determinants of participation in leisure-time physical activity (PA), organized activities and social activities with friends and peers among Norwegian 8-year-olds.

The neighborhood acts as an arena for activities that children can enjoy. Thus, knowledge about the environmental determinants, and whether they facilitate activity participation, is important for children's right to engage in activities that can promote their well-being [10]. A growing body of research has identified characteristics of the built environment that seem to promote active living among children and adolescents [11-13]. Studies reported that neighborhoods with low traffic exposure and high safety, high walkability, pedestrian infrastructure for walking and cycling, and access to facilities support active travel [12, 14, 15]. Furthermore, built environments characterized by mixed land-use, versatile facilities, high street connectivity, and direct pedestrian access may promote physical activity; however, these findings are more inconsistent and inconclusive [13, 16]. In addition, there is evidence that access to green space and safety from traffic and crime are related to children's outdoor play [17]. Some studies have linked shorter distances to green spaces and recreation facilities (such as sports fields, swimming pools, and parks) to increased participation in sport activities [18, 19]. Several studies have also shown that densely populated areas are associated with higher levels of physical activity [20, 21] and outdoor activity [22] compared to less populated areas. However, several other studies did not show the same results [23-25].

Nevertheless, we see several shortcomings in the evidence for understanding the ways in which the built environment provides opportunities for activity participation in childhood. First, the majority of the studies mentioned above focused on total physical activity or active travel. However, the built environment influences other activities that are important for children's well-being, but these activities have not been fully examined. Few empirical studies addressed built environment determinants as facilitators of participation in organized activities and informal social activities with friends and peers. Second, previous studies focused on children or adolescents older than 10 years, whereas less attention has been paid to the influence of the built environment on 5- to 8-years-olds' activities [16]. From a public health and developmental perspective, 8-year-olds are interesting because children at this age are increasingly getting their parents' permission to explore new territory and the children's spatial world is expanding. Relationships with friends and peers are also extremely important in this phase of social development, and participation in sports and group activities is highly appreciated [26]. Third, few large-scale studies that include children across diverse geographical areas have been conducted. Use of geographic information systems (GIS) facilitates the examination of objectively measured built environment determinants in large population studies [27, 28]. There has been a call for more studies from a broader range of countries that use GIS-derived measures to examine relations between the built environment and children's health and well-being [16]. To address these gaps, the aim of this study was to examine whether the built environment determinants population density, green spaces, and facilities are associated with participation in leisure-time PA, organized and social activities with friends in a large and geographically diverse sample of 8-year-old children in Norway.

Materials and methods

Study design and data sources

In this study, we applied a cross-sectional design in which data from the Norwegian Mother and Child Cohort Study (MoBa) were linked to geospatial data about the built environment around the participants' home addresses. MoBa is a nationwide prospective population-based pregnancy cohort conducted by the Norwegian Institute of Public Health. Detailed descriptions of the cohort have been published elsewhere [29]. Pregnant women were recruited from all over Norway during the years 1999–2008. Of the eligible mothers, 41% consented to participate. The cohort comprises 95 200 mothers and 114 500 children. The present study is based on version IX of the quality-assured data files released for research in November 2015. We used the 8-year follow-up surveys completed by the mothers and obtained available data from those children who turned 8-years old in 2011, 2012, 2013, 2014 and 2015.

Subjects

Questionnaire data reported by mothers were available for 32 076 children at the time of access. To be included in this study, the exposure variables had to be successfully linked to each participant's geocoded residential address. We excluded children with specific diagnoses. Children living in post-separation families were also excluded as the exposures were computed around the mothers' addresses only. Additionally, we excluded children with unknown year of participation in the follow-up, resulting in a total sample of 23 043 children. All these children turned 8-years old between 2011 and 2015. We removed participants with missing data for key variables, and consequently, 21 146 eight-year-olds were included in the analytical sample. The participant flow diagram is displayed in Figure 1.

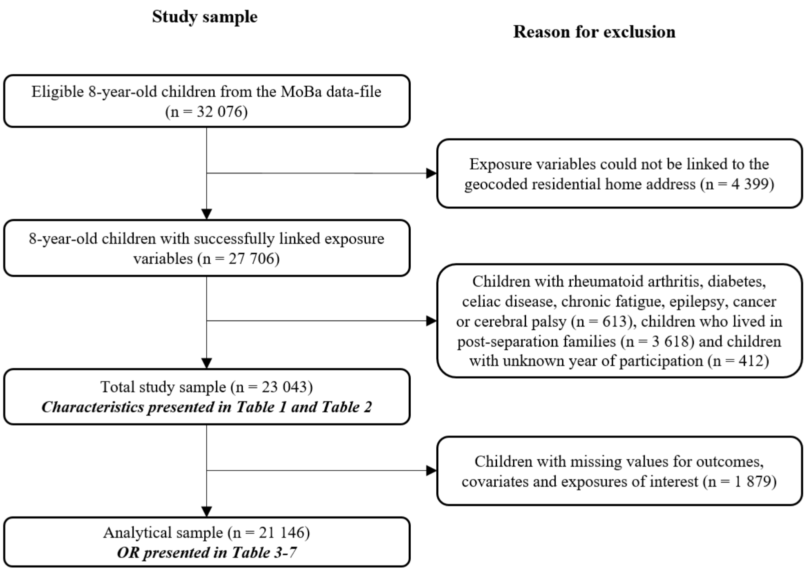

Figure 1. Participant flow diagram.

Outcome variables

The questionnaire provided information about the child's leisure activities, friends, and general health, as well as demographic information of the mother. Outcome variables and covariates were derived from this material.

To measure *leisure-time PA* we used two questions to elicit how much time the child spent on physical activity outside school hours during the summer and winter. The selectable six options were "< 1," "1–2," "3– 4," "5–7," "8–10," and "≥ 11" h/week. We recoded the answers into a dichotomous variable "≥5 h/week" opposed to "4≤ h/week," a threshold that concurs with recommendations from the Norwegian health authorities of 60 min/day (7 h/week) of moderate-to-vigorous PA [30]. The remaining hours of physical activity would be expected to occur at school, during either recess or physical education classes.

To measure *participation in organized activities*, one question addressed how many days per week the child participated in any kind of organized leisure activity (e.g., sport, music, or theater). The response categories were "never/seldom," "once a week," "2–3," "4–5," and "6–7 days/week". The answers were recoded into a dichotomous variable: "2 days or more/week" instead of "once a week or less" based on that Norwegian children on average participate in 1.7 organized activities [31].

We measured *informal social activity with friends and peers* with a question that elicited how many days per week the child spent time with friends and peers, excluding school hours and organized activities. This outcome variable was dichotomized into the categories "2 days or more/week" and "once a week or less." This threshold is grounded in surveys showing that nearly 60% of Norwegian children spend time with their friends at least twice a week [32].

Assessment and linkage of exposure variables

To calculate exposure to population density, facilities/amenities and neighborhood green space, we used GIS (ArcGIS 10.3 and QGIS 2.14). We downloaded geographic data from 2016 and up until January 2017. The built environment determinants were calculated within 800- and 5 000-m circular buffers of the geo-referenced residential addresses. The smaller radius represented the neighborhood surroundings, and the larger radius represented the greater community. Both radii were selected based on previous research on different spatial units that can capture associations between the built environment and activities [28, 33-36], as well as the Norwegian context characterized by low centrality in many areas [37]. Statistics Norway linked the exposure data to each child in MoBa.

Operationalization of the built environment determinants

Population density

We used the Statistical Grid Dataset (250-m × 250-m) with population data from 2016 from Statistics Norway to assess the population density. Population density was operationalized as the total number of residents per square kilometers around the residential home address of each child. Due to the high computational burden, we calculated this measure within the 800-m radius only. We divided the variable into four categories: ≤ 200 residents (reference), 201–799 (low), 800–1 649 (moderate) and ≥1 650 (high). The quartiles were derived statistically while taking into account the Statistics Norway's definition of densely populated areas, which states that such areas are characterized by settlements > 200 inhabitants where the distance between the houses does not exceed 50 m [38].

Facility and amenity measures

We used the national building and land-use datasets, provided by the Norwegian Mapping Authority, to capture facilities/amenities within the two zones of the residential home addresses. We calculated the total number of facilities/amenities that could serve as potential venues for the studied activities, including schools, libraries, churches, cinemas, indoor pools, shopping malls, and community centers. We also computed the total number of playgrounds/sports fields. Both variables were divided into quartiles. Additionally, we calculated access to school within the zones, which was dichotomized into the "presence of a school" (yes/no).

Neighborhood green space

We used national land-cover and land-use datasets to calculate the total area (square kilometers) of green spaces within the defined radii and applied two different measures. For measuring total green space, we considered forests, marshland, parks, and golf courses. Due to the high computational burden, we calculated this measure within the 800-m radius only. We converted the area of green space into the proportion of the total area within the zone and then split the variable into quartiles. We also calculated a separate measure for parks within 800- and 5 000-m of the participants' home addresses. Parks were defined according to the Norwegian Mapping Authority as built-up and maintained green areas larger than 2 000 m^2 and wider than 30 m, with lawns, plants, water features, seating, etc. We dichotomized this measure into the "presence of a park" (yes/no) within the defined radii.

Covariates

We selected potential confounders *a priori* based on previous studies and directed acyclic graphs, depicting the links between the variables (see Additional file, Figure S1). The following individual-level covariates were adjusted for in the analyses: child's sex, mother's age and level of education, and after-school care. In trying to account for potential urban and rural differences, we treated population density as an area-level confounder in addition to considering it as a determinant for activity participation.

Statistical analyses

Differences in frequencies between the genders were examined using the standard chi-square statistics. We used logistic regression to model the odds of participating in different activities dependent on the built environment determinants and we fitted crude and adjusted models. In the adjusted models, we considered only determinants that were statistically significantly related to participation in activities ($p < 0.05$) in the crude models. As including multiple environmental variables in statistical models can provoke multicollinearity, we computed Spearman's rho and the variance inflation factor (VIF) before we fit the regression models. The correlation coefficients revealed that population density, facilities/amenities (the 5 000-m radius) and playgrounds/sports fields (800- and 5 000-m radii) were highly correlated (rho > 0.7). Similarly, the VIF values of the variables exceeded 2.5, indicating potential multicollinearity [39].

To remedy this problem, we estimated separate adjusted odds ratios (ORs) for each built environment determinant. We performed the adjustment in two steps. First, we simultaneously added and adjusted for all individual-level covariates. Next, we added population density with the individual-level covariates. We adjusted for population density only in the absence of multicollinearity between population density and the particular environmental exposure of interest. Researchers have previously reported differences between boys and girls in environmental supportiveness for physical activity [21, 40], and all analyses were stratified according to sex. Finally, we conducted a sensitivity analysis on a sub sample of children (n = 8 311) who participated in the 8-year follow-up in 2014 and 2015 to assess the robustness of the results.

We reported the odds ratios and the corresponding 95% confidence interval (CI), as well as *p*-values for the trend resulting from models in which the exposures were treated as continuous variables. All analyses were performed using IBM SPSS Statistics 25, and we considered *p*-values less than 0.05 to be statistically significant.

Results

Profile of the participants

Individual-level characteristics are presented in Table 1. Within this sample of 23 043 Norwegian 8-year-olds, there were 11 176 (48.5%) girls. The mothers' educational attainment was high; 38.8% had more than 4 years of university education. Overall, the children were most active during the summer. Statistically significantly more boys participated in $\geq$ 5 h/week of leisure-time PA in the summer and winter compared to girls ($p < 0.001$). The majority of the children participated in organized activities (71.3%) and were together with friends $\geq$ 2 days/week (82.8%). The distribution of the built environment determinants is shown in Table 2. We did not observed differences for the exposure variables between the sexes. Among those excluded, there were slightly more girls, the mothers were younger and less educated, and the children participated less in activities compared to the study sample ($p < 0.05$). Additionally, those excluded lived in neighborhoods with higher population density and more facilities in the immediate surroundings of their home (data not shown).

Table 1. Individual-level characteristics for all children and by gender from 23 043 MoBa participants.

	N (%)			
Characteristics	Total (n = 23 043)	Boys (n = 11 826)	Girls (n = 11 176)	P-value[a]
Hours of leisure-time PA (summer)				<0.001
$\leq$ 4 h/week	8 758 (38.0)	3 658 (30.9)	5 086 (45.5)	
$\geq$ 5 h/week	14 085 (61.1)	8 071 (68.3)	5 987 (53.6)	
Missing	200 (0.9)	97 (0.8)	103 (0.9)	
Hours of leisure-time PA (winter)				<0.001
$\leq$ 4 h/week	11 375 (49.4)	5 110 (43.2)	6 247 (55.9)	
$\geq$ 5 h/week	11 457 (49.7)	6 597 (55.8)	4 837 (43.3)	
Missing	211 (0.9)	119 (1.0)	92 (0.8)	
Participation in organized activities				0.003
Once a week or less	6 562 (28.5)	3 467 (29.3)	3 078 (27.6)	
2 days or more/week	16 430 (71.3)	8 333 (70.5)	8 073 (72.2)	
Missing	51 (0.2)	26 (0.2)	25 (0.2)	
Informal social activity with friends/peers				0.007
Once a week or less	3 627 (15.7)	1 934 (16.4)	1 684 (15.1)	
2 days or more/week	19 084 (82.8)	9 719 (82.2)	9 333 (83.5)	
Missing	332 (1.5)	173 (1.4)	159 (1.4)	
After school care				0.516
No	6 096 (26.4)	3 162 (26.7)	2 918 (26.1)	
Yes	16 503 (71.6)	8 449 (71.5)	8 026 (71.8)	
Missing	444 (2.0)	214 (1.8)	230 (2.1)	
Maternal age (years) at recruitment				0.063
$\leq$ 29	8 967 (38.9)	4 679 (39.6)	4 288 (38.4)	
$\geq$ 30	14 035 (60.9)	7 147 (60.4)	6 888 (61.6)	
Missing	41 (0.2)	0 (0.0)	0 (0.0)	
Maternal level of education				0.731
High school or less	4 624 (20.1)	2 392 (20.2)	2 229 (19.9)	
University $\leq$ 4 years	8 904 (38.6)	4 603 (38.9)	4 286 (38.4)	
University > 4 years	8 951 (38.8)	4 576 (38.7)	4 355 (39.0)	
Missing	564 (2.5)	255 (2.2)	306 (2.7)	

Note: PA, physical activity.
[a]Results from χ^2 comparing boys and girls.

Table 2. Distribution of the built environment determinants for 23 043 children from MoBa.

	N (%)			
Built environment determinant	Total (n = 23 043)	Boys (n = 11 826)	Girls (n = 11 176)	P-value[a]
Total green and open spaces				0.187
≤ 13.0 % (ref.)	5 593 (24.3)	2 866 (24.2)	2 717 (24.3)	
13.1 – 29.9 %	5 664 (24.6)	2 846 (24.1)	2 811 (25.2)	
30 – 49.9 %	5 983 (26.0)	3 085 (26.1)	2 887 (25.8)	
≥ 50.0 %	5 803 (25.2)	3 029 (25.6)	2 761 (24.7)	
Missing	0 (0.0)	0 (0.0)	0 (0.0)	
Park within 800 m				0.671
No	19 279 (83.7)	9 882 (83.6)	9 362 (83.8)	
Yes	3 764 (16.3)	1 944 (16.4)	1 814 (16.2)	
Missing	0 (0.0)	0 (0.0)	0 (0.0)	
Park within 5 000 m				0.517
No	8 493 (36.9)	4 384 (37.1)	4 097 (36.7)	
Yes	14 550 (63.1)	7 442 (62.9)	7 079 (63.3)	
Missing	0 (0.0)	0 (0.0)	0 (0.0)	
Number of facilities/amenities 800 m				0.325
0 (ref.)	10 837 (47.0)	5 600 (47.4)	5 220 (46.7)	
1	4 687 (20.3)	2 429 (20.5)	2 253 (20.2)	
2-3	4 542 (19.7)	2 311 (19.5)	2 219 (19.9)	
≥ 4	2 977 (12.9)	1 486 (12.6)	1 484 (13.3)	
Missing	0 (0.0)	0 (0.0)	0 (0.0)	
Number of facilities/amenities 5 000 m				0.689
≤ 5 (ref.)	6 007 (26.1)	3 096 (26.2)	2 901 (26.0)	
6-14	5 512 (23.9)	2 856 (24.2)	2 647 (23.7)	
15-29	5 257 (22.8)	2 665 (22.5)	2 582 (23.0)	
≥ 30	6 267 (27.2)	3 209 (27.1)	3 046 (27.3)	
Missing	0 (0.0)	0 (0.0)	0 (0.0)	
Number of playgrounds/sports fields 800 m				0.355
≤ 1 (ref.)	3 666 (15.9)	1 928 (16.3)	1 733 (15.5)	
2-5	4 002 (17.4)	2 058 (17.4)	1 935 (17.3)	
6-10	3 748 (16.3)	1 900 (16.1)	1 846 (16.5)	
≥ 11	11 627 (50.5)	5 940 (50.2)	5 662 (50.7)	
Missing	0 (0.0)	0 (0.0)	0 (0.0)	
Number of playgrounds/sports fields 5 000 m				0.176
≤ 35 (ref.)	5 845 (25.4)	3 031 (25.6)	2 805 (25.1)	
36-119	5 654 (24.5)	2 839 (24.0)	2 806 (25.1)	
120-419	5 690 (24.7)	2 965 (25.1)	2 716 (24.3)	
≥ 420	5 854 (25.4)	2 991 (25.3)	2 846 (25.5)	
Missing	0 (0.0)	0 (0.0)	0 (0.0)	
School within 800 m				
No	16 540 (71.8)	8 540 (72.2)	7 974 (71.3)	0.145
Yes	6 503 (28.2)	3 286 (27.8)	3 202 (28.7)	
Missing	0 (0.0)	0 (0.0)	0 (0.0)	
School within 5 000 m				0.363
No	4 941 (21.4)	2 565 (21.7)	2 369 (21.2)	
Yes	18 102 (78.6)	9 261 (78.3)	8 807 (78.8)	
Missing	0 (0.0)	0 (0.0)	0 (0.0)	
Population density				0.072
≤ 200 (ref.)	4 747 (20.6)	2 515 (21.3)	2 227 (19.9)	
201-799	6 679 (29.0)	3 397 (28.7)	3 271 (29.3)	
800-1 649	5 832 (25.3)	3 004 (25.4)	2 817 (25.2)	
≥ 1 650	5 649 (24.5)	2 853 (24.1)	2 783 (24.9)	
Missing	136 (0.6)	58 (0.5)	78 (0.7)	

[a]Results from χ^2 comparing boys and girls.

Leisure-time PA during summer and winter

Only a few of the built environment determinants were associated with leisure-time PA in summer and winter in the crude analyses (Table 3). After adjustment for individual-level confounders, children with 2–5 and ≥ 11 playgrounds/sport fields within 800 m had 16% and 20% reduced odds of ≥ 5 h/week PA during the summer, respectively, compared to children with 6–10 and ≤ 1 playgrounds/sports fields (Table 4). We also found negative associations with leisure-time PA during the winter across all quartiles of playgrounds/sports fields within 800 m. Access to school was related to decreased odds of ≥ 5 h/week leisure-time PA in the summer, but an additional adjustment for population density removed the association. Only neighborhood green spaces were positively associated with leisure-time PA. In the summer, children with a park within 800 m of their home had 12% higher odds of $\geq$ 5 h/week leisure-time PA ($p < 0.01$). Similarly, we found a statistically significant trend of more leisure-time PA during the winter with greater proportions of total neighborhood green space (p_{trend} = 0.002).

Organized activities

Children with the greatest number of facilities/amenities and playgrounds/sports fields, both within a radius of 5 000 m, had 17% higher odds of participating in organized activities $\geq$ 2 days/week. Playgrounds/sports fields within 800 m also supported participation, reaching 29% greater odds for children with $\geq$ 11 playgrounds/sports fields in their neighborhood (p_{trend} <0.001). Furthermore, we found higher odds of participation for children who lived in more densely populated areas, with the greatest odds ratio for areas with moderate density (Table 4). In the individual- and area-level adjusted analyses, 8-year-olds with one facility within 800 m of their home had higher odds of participating in organized activities compared to children without any facilities ($p < 0.01$), but we did not observe a linear trend (Table 4). Access to school within 800 m was associated with 8% increased odds of participating in organized activities ($p < 0.01$).

Informal social activities with friends/peers

Population density, facilities/amenities (5 000-m radius) and playgrounds/sports fields (800- and 5 000-m radii) remained statistically significantly associated with informal social activity with friends and peers $\geq$ 2 days/week after adjustment for individual-level covariates (Table 4). The associations were consistent across all quartiles, and the relation exhibited linear trends, except for facilities/amenities within 5 000 m (p_{trend} = 0.500). The magnitude of the association was greatest for playgrounds/sports fields within 800 m. In the fully adjusted analyses, access to a park and school within 5 000 m of home was related to 21% and 19% higher odds of participating in social activities $\geq$ 2 days/week, respectively. We did not identify any supportive associations for total neighborhood green space. Children who lived in neighborhoods classified as the lower (13.1–29.9% green space) and the upper ($\geq$ 50.0% green space) quartiles had reduced odds of being together with friends and peers.

Table 3. Crude associations between environmental characteristics and activity participation in all children from MoBa.

	All children (n = 21 146) Crude OR (95 % CI)			
	≥ 5 h/week leisure-time PA (summer)	≥ 5 h/week leisure-time PA (winter)	Organized activities ≥ 2 days/week	Friends and peers ≥ 2 days/week
Total green space 800 m				
≤ 13 % (ref.)	1	1	1	1
13.1 – 29.9 %	1.03 (0.96–1.12)	1.14 (1.06–1.23)**	1.02 (0.93–1.11)	0.86 (0.78–0.96)**
30.0 – 49.9 %	1.05 (0.99–1.16)	1.13 (1.05–1.22)**	0.93 (0.86–1.02)	0.93 (0.83–1.03)
≥ 50.0 %	1.08 (0.99–1.16)	1.20 (1.11–1.29)**	0.85 (0.78–0.93)**	0.73 (0.66–0.81)**
P for trend	0.114	0.001	0.019	<0.001
Park within 800 m				
No (ref.)	1	1	1	1
Yes	1.09 (1.01–1.17)*	1.05 (0.98–1.13)	1.13 (1.04–1.22)**	1.06 (0.95–1.16)
Park within 5 000 m				
No (ref.)	1	1	1	1
Yes	0.98 (0.93–1.04)	1.04 (0.98–1.10)	1.19 (1.12–1.26)**	1.42 (1.31–1.53)**
Facilities/amenities 800 m				
0 (ref.)	1	1	1	1
1	0.94 (0.87–1.01)	1.01 (0.94–1.08)	1.20 (1.11–1.30)**	1.30 (1.17–1.43)**
2-3	0.98 (0.91–1.06)	0.99 (0.93–1.07)	1.19 (1.10–1.29)**	1.37 (1.24–1.52)**
≥ 4	0.94 (0.86–1.02)	0.99 (0.92–1.09)	1.25 (1.13–1.37)**	1.13 (1.01–1.27)*
P for trend	0.349	0.411	<0.001	0.593
Facilities/amenities 5 000 m				
≤ 5 (ref.)	1	1	1	1
6-14	1.07 (0.99–1.16)	1.05 (0.97–1.13)	1.04 (0.96–1.13)	1.35 (1.22–1.49)**
15-29	1.01 (0.93–1.09)	1.02 (0.95–1.11)	1.16 (1.06–1.26)**	1.49 (1.34–1.65)**
≥ 30	0.99 (0.91–1.06)	1.07 (0.99–1.15)	1.34 (1.23–1.46)**	1.32 (1.20–1.45)**
P for trend	0.719	0.004	<0.001	0.329
Playgrounds/sports fields 800 m				
≤ 1 (ref.)	1	1	1	1
2-5	0.87 (0.79–0.96)**	0.88 (0.80–0.97)**	1.16 (1.05–1.28)**	2.66 (2.35–3.00)**
6-10	0.96 (0.86–1.05)	0.96 (0.88–1.06)	1.24 (1.12–1.37)**	2.71 (2.39–3.06)**
≥ 11	0.90 (0.83–0.97)*	0.92 (0.85–0.99)*	1.42 (1.31–1.55)**	2.58 (2.35–2.84)**
P for trend	0.001	<0.001	<0.001	<0.001
Playgrounds/sports fields 5 000 m				
≤ 35 (ref.)	1	1	1	1
36-119	0.99 (0.91–1.07)	0.98 (0.91–1.06)	0.98 (0.90–1.06)	1.68 (1.51–1.86)**
120-419	0.98 (0.90–1.06)	0.95 (0.88–1.03)	1.19 (1.09–1.29)**	1.69 (1.52–1.87)**
≥ 420	0.96 (0.88–1.04)	1.02 (0.95–1.10)	1.36 (1.25–1.47)**	1.51 (1.36–1.65)**
P for trend	0.079	0.953	<0.001	<0.001
School within 800 m				
No	1	1	1	1
Yes	0.94 (0.88–0.99)*	1.00 (0.94–1.06)	1.19 (1.11–1.28)**	1.16 (1.07–1.26)**
School within 5 000 m				
No	1	1	1	1
Yes	0.94 (0.88–1.01)	0.98 (0.92–1.05)	1.27 (1.19–1.37)**	1.51 (1.39–1.64)**
Population density 800 m				
≤ 200 (ref.)	1	1	1	1
201-799	0.96 (0.88–1.03)	0.95 (0.88–1.03)	1.10 (1.02–1.20)**	2.18 (1.96–2.43)**
800-1649	0.96 (0.89–1.03)	0.99 (0.92–1.07)	1.30 (1.20–1.41)**	2.07 (1.87–2.30)**
≥ 1650	0.94 (0.87–1.02)	1.03 (0.96–1.11)	1.35 (1.24–1.47)**	1.56 (1.41–1.71)**
P for trend	0.735	0.041	<0.001	0.514

Note: OR, odds ratio; PA, physical activity. *p<0.05. **p<0.01.

Table 4. Adjusted associations between environmental characteristics and activity participation in all children from MoBa.

	All children (n = 21 309) Adjusted OR (95 % CI)							
	≥ 5 h/week leisure-time PA (summer)		≥ 5 h/week leisure-time PA (winter)		Organized activities ≥ 2 days/week		Friends and peers ≥ 2 days/week	
	Step 1[a]	Step 2[b]	Step 1[a]	Step 2[b]	Step 1[a]	Step 2[b]	Step 1[a]	Step 2[b]
Total green space 800 m								
≤ 13 % (ref.)			1	1	1	1	1	1
13.1 – 29.9 %	NI	NI	1.15 (1.06–1.24)**	1.14 (1.05–1.23)**	1.02 (0.93–1.11)	1.02 (0.94–1.12)	0.87 (0.75–0.96)**	0.85 (0.76–0.95)**
30.0 – 49.9 %			1.17 (1.08–1.26)**	1.15 (1.06–1.24)**	0.96 (0.88–1.04)	0.98 (0.90–1.07)	0.91 (0.82–1.02)	0.95 (0.85–1.07)
≥ 50.0 %			1.27 (1.17–1.37)**	1.23 (1.13–1.33)**	0.89 (0.82–0.97)**	0.93 (0.85–1.02)	0.71 (0.64–0.79)**	0.83 (0.74–0.93)**
P for trend			<0.001	0.002	0.164	0.813	<0.001	0.001
Park within 800 m								
No (ref.)	1	1	NI	NI	1	1	NI	NI
Yes	1.02 (0.95–1.11)	1.12 (1.03–1.22)**			1.06 (0.97–1.15)	1.00 (0.91–1.09)		
Park within 5 000 m								
No (ref.)	NI	NI	NI	NI	1	1	1	1
Yes					1.09 (1.02–1.16)**	1.01 (0.94–1.09)	1.53 (1.42–1.65)**	1.21 (1.10–1.34)**
Facilities/amenities 800 m								
0 (ref.)					1	1	1	1
1	NI	NI	NI	NI	1.17 (1.08–1.27)**	1.13 (1.04–1.22)**	1.33 (1.20–1.47)**	1.08 (0.97–1.20)
2-3					1.13 (1.05–1.23)**	1.09 (0.99–1.19)	1.43 (1.29–1.58)**	1.12 (1.00–1.26)
≥ 4					1.13 (1.03–1.25)**	1.08 (0.97–1.20)	1.19 (1.06–1.34)**	0.94 (0.82–1.07)
P for trend					0.009	0.205	0.214	0.005
Facilities/amenities 5 000 m								
≤ 5 (ref.)					1		1	
6-14	NI	NI	NI	NI	0.99 (0.91–1.08)		1.41 (1.27–1.57)**	
15-29					1.08 (0.99–1.18)	NE	1.60 (1.43–1.78)**	NE
≥ 30					1.17 (1.07–1.27)**		1.49 (1.34–1.65)**	
P for trend					0.003		0.500	
Playgrounds/sports fields 800 m								
≤ 1 (ref.)	1		1		1		1	
2-5	0.84 (0.76–0.93)**		0.84 (0.76–0.93)**		1.15 (1.04–1.27)**		2.78 (2.46–3.14)**	
6-10	0.90 (0.81–1.00)	NE	0.89 (0.80–0.98)*	NE	1.17 (1.05–1.30)**	NE	2.91 (2.56–3.29)**	NE
≥ 11	0.80 (0.73–0.86)**		0.78 (0.72–0.85)**		1.29 (1.17–1.41)**		2.94 (2.67–3.24)**	
P for trend	<0.001		<0.001		<0.001		<0.001	
Playgrounds/sports fields 5000 m								
≤ 35 (ref.)					1		1	
36-119					0.93 (0.86–1.02)		1.76 (1.59–1.95)**	
120-419	NI	NI	NI	NI	1.09 (0.99–1.19)	NE	1.84 (1.66–2.04)**	NE
≥ 420					1.17 (1.07–1.28)**		1.76 (1.58–1.95)**	
P for trend					<0.001		<0.001	
School within 800 m								
No	1	1	NI	NI	1	1	1	1
Yes	0.89 (0.83–0.95)**	0.94 (0.88–1.01)			1.12 (1.05–1.20)**	1.08 (1.01–1.16)*	1.19 (1.10–1.30)**	0.99 (0.91–1.09)
School within 5 000 m								
No	NI	NI	NI	NI	1	1	1	1
Yes					1.17 (1.09–1.26)**	1.11 (1.03–1.21)*	1.63 (1.49–1.77)**	1.19 (1.08–1.32)**
Population density 800 m								
≤ 200 (ref.)					1		1	
201-799	NI	NI	NI	NI	1.05 (0.97–1.15)	-	2.28 (2.05–2.54)**	-
800-1 649					1.20 (1.10–1.30)**		2.25 (2.03–2.50)**	
≥ 1 650					1.17 (1.07–1.27)**		1.80 (1.62–1.99)**	
P for trend					0.413		0.027	

Note: OR, odds ratio; PA, physical activity; NI, not included due to non-significance in bivariate models; NE, not estimated due to multicollinearity. *p<0.05. ** p<0.01.

[a] Adjusted for sex, participation in after-school care, mother's age and level of education.

[b] Additional adjustment for population density.

Differences between boys and girls

Stratified analyses showed that associations varied between boys and girls (Table 5, 6, and 7). Negative associations were observed between the number of playgrounds/sports fields (800-m) and leisure-time PA in the summer among boys, whereas playgrounds/sports fields (800- and 5 000-m radii) and population density were negatively associated with leisure-time PA among girls. In the winter, these determinants were also related to decreased odds of $\geq$ 5 h/week leisure-time PA among girls. Greater proportions of total neighborhood green spaces were related to more leisure-time PA during the winter for both sexes. Several determinants were positively related to boys' participation in organized activities, but few determinants supported such participation among girls. Population density, playgrounds/sports fields (800- and 5 000-m radii) and facilities/amenities (5 000-m radius) were associated with increased odds of social activity with friends and peers $\geq$ 2 days/week for both sexes.

Results from the sensitivity analysis

Table S1 (Additional file) presents the results from the sensitivity analysis. In general, the pattern and the magnitude of the estimated ORs across all outcomes were consistent with the main results shown in Table 4, although several significant associations vanished (mainly for organized activities). The positive significant associations observed between the built environment and participation in social activity with friends remained significant and strong, or were even slightly stronger, in the sub sample of children who participated in the 8-year follow-up in 2014 and 2015.

Table 5. Crude associations between environmental characteristics and activity participation by gender.

	Boys (n = 10 932) Crude OR (95 % CI)				Girls (n = 10 214) Crude OR (95 % CI)			
	≥ 5 h/week leisure-time PA (summer)	≥ 5 h/week leisure-time PA (winter)	Organized activities ≥ 2 days/week	Friends and peers ≥ 2 days/week	≥ 5 h/week leisure-time PA (summer)	≥ 5 h/week leisure-time PA (winter)	Organized activities ≥ 2 days/week	Friends and peers ≥ 2 days/week
Total green space 800 m								
≤ 13 % (ref.)	1	1	1	1	1	1	1	1
13.1 – 29.9 %	1.08 (0.96–1.21)	1.16 (1.04–1.30)**	1.01 (0.89–1.14)	0.84 (0.72–0.97)*	1.01 (0.91–1.13)	1.14 (1.02–1.27)*	1.03 (0.91–1.16)	0.89 (0.76–1.04)
30.0 – 49.9 %	1.11 (0.99–1.25)	1.12 (1.01–1.25)*	0.91 (0.81–1.02)	0.90 (0.78–1.05)	1.05 (0.94–1.17)	1.15 (1.03–1.28)*	0.96 (0.85–1.09)	0.95 (0.81–1.12)
≥ 50.0 %	1.07 (0.95–1.20)	1.18 (1.06–1.32)**	0.84 (0.75–0.94)**	0.71 (0.61–0.81)**	1.08 (0.96–1.21)	1.21 (1.08–1.35)**	0.87 (0.77–0.98)*	0.77 (0.67–0.89)**
P for trend	0.288	0.015	0.082	<0.001	0.297	0.045	0.117	0.001
Park within 800 m								
No (ref.)	1	1	1	1	1	1	1	1
Yes	1.07 (0.96–1.19)	1.04 (0.94–1.15)	1.14 (1.02–1.28)*	1.06 (0.92–1.22)	1.10 (0.99–1.22)	1.06 (0.95–1.17)	1.11 (0.98–1.25)	1.04 (0.90–1.21)
Park within 5 000 m								
No (ref.)	1	1	1	1	1	1	1	1
Yes	1.00 (0.92–1.09)	1.08 (0.99–1.16)	1.27 (1.17–1.38)**	1.41 (1.28–1.57)**	0.97 (0.89–1.05)	1.01 (0.93–1.09)	1.10 (1.01–1.21)*	1.42 (1.27–1.59)**
Facilities/amenities 800 m								
0 (ref.)	1	1	1	1	1	1	1	1
1	0.98 (0.88–1.09)	1.07 (0.97–1.18)	1.20 (1.08–1.34)**	1.28 (1.11–1.46)**	0.90 (0.81–1.00)	0.93 (0.84–1.04)	1.19 (1.06–1.34)**	1.33 (1.14–1.54)**
2-3	1.01 (0.91–1.13)	1.05 (0.94–1.16)	1.24 (1.11–1.39)**	1.37 (1.19–1.58)**	0.96 (0.86–1.06)	0.95 (0.86–1.06)	1.14 (1.01–1.28)*	1.38 (1.18–1.60)**
≥ 4	0.97 (0.85–1.10)	1.07 (0.95–1.21)	1.21 (1.06–1.37)**	1.13 (0.97–1.33)	0.93 (0.82–1.05)	0.93 (0.82–1.05)	1.29 (1.12–1.48)**	1.12 (0.95–1.32)
P for trend	0.912	0.041	0.005	0.976	0.254	0.503	0.001	0.441
Facilities/amenities 5 000 m								
≤ 5 (ref.)	1	1	1	1	1	1	1	1
6-14	1.04 (0.93–1.17)	1.08 (0.97–1.20)	1.14 (1.02–1.28)*	1.36 (1.18–1.57)**	1.10 (0.99–1.23)	1.02 (0.91–1.14)	0.94 (0.83–1.06)	1.33 (1.15–1.55)**
15-29	1.08 (0.97–1.22)	1.11 (1.00–1.24)	1.27 (1.13–1.42)**	1.68 (1.45–1.95)**	0.95 (0.85–1.07)	0.95 (0.85–1.06)	1.04 (0.92–1.18)	1.31 (1.12–1.52)**
≥ 30	1.03 (0.92–1.15)	1.16 (1.04–1.28)**	1.45 (1.30–1.62)**	1.31 (1.14–1.49)**	0.95 (0.86–1.06)	0.99 (0.89–1.10)	1.23 (1.09–1.38)**	1.33 (1.15–1.54)**
P for trend	0.288	<0.001	<0.001	0.107	0.232	0.589	<0.001	0.815
Playgrounds/sports fields 800 m								
≤ 1 (ref.)	1	1	1	1	1	1	1	1
2-5	0.86 (0.75–0.99)*	0.90 (0.79–1.02)	1.25 (1.09–1.44)**	2.81 (2.38–3.32)**	0.88 (0.77–1.01)	0.86 (0.75–0.99)*	1.06 (0.92–1.23)	2.49 (2.09–2.97)**
6-10	0.98 (0.85–1.13)	1.00 (0.88–1.15)	1.29 (1.12–1.48)**	2.75 (2.32–3.26)**	0.95 (0.83–1.09)	0.94 (0.82–1.08)	1.18 (1.01–1.37)*	2.64 (2.20–3.17)**
≥ 11	0.97 (0.87–1.10)	1.01 (0.90–1.12)	1.54 (1.37–1.72)**	2.66 (2.35–3.02)**	0.84 (0.75–0.94)**	0.85 (0.76–0.95)**	1.30 (1.15–1.47)**	2.49 (2.17–2.85)**
P for trend	0.529	0.052	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Playgrounds/sports fields 5000 m								
≤ 35 (ref.)	1	1	1	1	1	1	1	1
36-119	1.08 (0.96–1.21)	1.08 (0.97–1.20)	1.00 (0.89–1.12)	1.56 (1.35–1.79)**	0.93 (0.83–1.04)	0.90 (0.81–1.01)	0.95 (0.84–1.07)	1.81 (1.56–2.11)**
120-419	1.05 (0.94–1.18)	1.02 (0.91–1.13)	1.24 (1.11–1.40)**	1.86 (1.61–2.14)**	0.91 (0.81–1.01)	0.88 (0.79–0.99)*	1.12 (0.99–1.27)	1.52 (1.31–1.76)**
≥ 420	1.04 (0.93–1.16)	1.12 (1.01–1.24)*	1.46 (1.30–1.64)**	1.42 (1.24–1.62)**	0.90 (0.81–1.00)	0.94 (0.84–1.05)	1.24 (1.10–1.41)**	1.62 (1.40–1.88)**
P for trend	0.603	0.262	<0.001	0.006	0.059	0.311	<0.001	<0.001
School within 800 m								
No	1	1	1	1	1	1	1	1
Yes	0.96 (0.88–1.05)	1.06 (0.98–1.15)	1.23 (1.12–1.35)**	1.14 (1.02–1.28)*	0.92 (0.84–1.00)	0.95 (0.87–1.04)	1.15 (1.04–1.27)**	1.18 (1.05–1.34)**
School within 5 000 m								
No	1	1	1	1	1	1	1	1
Yes	1.00 (0.91–1.11)	1.09 (0.99–1.19)	1.33 (1.21–1.47)**	1.37 (1.23–1.54)**	0.90 (0.82–0.99)*	0.88 (0.80–0.97)*	1.21 (1.09–1.34)**	1.67 (1.48–1.89)**
Population density 800 m								
≤ 200 (ref.)	1	1	1	1	1	1	1	1
201-799	1.03 (0.92–1.16)	1.05 (0.94–1.17)	1.16 (1.03–1.30)**	2.15 (1.86–2.48)**	0.92 (0.82–1.03)	0.88 (0.79–0.98)*	1.03 (0.92–1.17)	2.21 (1.89–2.59)**
800-1649	1.05 (0.94–1.17)	1.06 (0.95–1.18)	1.35 (1.20–1.51)**	2.27 (1.97–2.62)**	0.89 (0.80–0.99)*	0.94 (0.84–1.05)	1.25 (1.10–1.41)**	1.87 (1.61–2.17)**
≥ 1650	1.06 (0.94–1.18)	1.15 (1.03–1.28)**	1.46 (1.30–1.64)**	1.48 (1.30–1.69)**	0.87 (0.78–0.97)**	0.94 (0.84–1.05)	1.23 (1.09–1.39)**	1.64 (1.42–1.90)**
P for trend	0.064	0.003	<0.001	0.381	0.273	0.942	0.101	0.065

Note: OR, odds ratio; PA, physical activity. *p<0.05. **p<0.01.

Table 6. Adjusted associations between environmental characteristics and activity participation in boys from MoBa.

	Adjusted OR (95 % CI) in boys (n = 10 932)							
	≥ 5 h/week leisure-time PA (summer)		≥ 5 h/week leisure-time PA (winter)		Organized activities ≥ 2 days/week		Friends and peers ≥ 2 days/week	
	Step 1[a]	Step 2[b]	Step 1[a]	Step 2[b]	Step1[a]	Step 2[b]	Step 1[a]	Step 2[b]
Total green space 800 m								
≤ 13 % (ref.)			1	1	1	1	1	1
13.1 – 29.9 %	NI	NI	1.16 (1.04–1.29)*	1.16 (1.03–1.29)*	1.01 (0.90–1.14)	1.03 (0.91–1.16)	0.84 (0.73–0.98)*	0.82 (0.71–0.95)*
30.0 – 49.9 %			1.15 (1.04–1.28)**	1.15 (1.03–1.28)*	0.93 (0.83–1.04)	0.97 (0.86–1.10)	0.89 (0.77–1.03)	0.92 (0.79–1.07)
≥ 50.0 %			1.26 (1.13–1.40)**	1.25 (1.11–1.40)**	0.87 (0.78–0.98)*	0.95 (0.84–1.08)	0.69 (0.59–0.79)**	0.80 (0.68–0.93)**
P for trend			0.001	0.004	0.237	0.823	<0.001	0.002
Park within 800 m								
No (ref.)	NI	NI	NI	NI	1	1	NI	NI
Yes					1.09 (0.97–1.22)	0.99 (0.87–1.12)		
Park within 5000 m								
No (ref.)	NI	NI	NI	NI	1	1	1	1
Yes					1.18 (1.09–1.29)**	1.07 (0.97–1.19)	1.54 (1.37–1.71)**	1.20 (1.05–1.37)**
Facilities/amenities 800 m								
0 (ref.)					1	1	1	1
1	NI	NI	NI	NI	1.17 (1.05–1.31)**	1.11 (0.99–1.24)	1.31 (1.14–1.50)**	1.06 (0.92–1.22)
2-3					1.19 (1.07–1.34)**	1.09 (0.97–1.24)	1.44 (1.25–1.66)**	1.14 (0.97–1.33)
≥ 4					1.11 (0.97–1.27)	0.99 (0.86–1.15)	1.21 (1.03–1.42)**	0.96 (0.80–1.15)
P for trend					0.089	0.968	0.503	0.022
Facilities/amenities 5000 m								
≤ 5 (ref.)			1		1		1	
6-14	NI	NI	0.99 (0.90–1.11)	NE	1.10 (0.98–1.24)		1.44 (1.25–1.65)**	NE
15-29			0.99 (0.88–1.10)		1.20 (1.06–1.35)**	NE	1.82 (1.57–2.11)**	
≥ 30			0.93 (0.83–1.04)		1.30 (1.16–1.47)**		1.51 (1.31–1.74)**	
P for trend			0.862		0.001		0.920	
Playgrounds/sports fields 800 m								
≤ 1 (ref.)	1				1		1	
2-5	0.84 (0.73–0.96)*				1.24 (1.08–1.43)**		2.97 (2.52–3.52)**	NE
6-10	0.92 (0.80–1.06)	NE	NI	NE	1.23 (1.06–1.42)**	NE	2.98 (2.51–3.54)**	
≥ 11	0.87 (0.77-0.98)*				1.42 (1.26–1.60)**		3.09 (2.70–3.52)**	
P for trend	<0.001				<0.001		<0.001	
Playgrounds/sports fields 5000 m								
≤ 35 (ref.)			1		1		1	
36-119	NI	NI	1.00 (0.89–1.11)	NE	0.96 (0.86–1.08)		1.65 (1.43–1.90)**	
120-419			0.89 (0.79–0.99)*		1.16 (1.03–1.31)*	NE	2.04 (1.77–2.37)**	NE
≥ 420			0.88 (0.78–0.98)*		1.30 (1.15–1.47)**		1.68 (1.45–1.94)**	
P for trend			0.004		<0.001		<0.001	
School within 800 m								
No	NI	NI	NI	NI	1	1	1	1
Yes					1.18 (1.07–1.29)**	1.09 (0.99–1.21)	1.18 (1.06-1.33)**	0.98 (0.86–1.11)
School within 5000 m								
No	NI	NI	NI	NI	1	1	1	1
Yes					1.24 (1.13–1.37)**	1.14 (1.02–1.28)*	1.50 (1.33–1.69)**	1.05 (0.92–1.21)
Population density 800 m								
≤ 200 (ref.)			1		1		1	
201-799	NI	-	0.98 (0.88–1.09)	-	1.11 (0.99–1.25)	-	2.26 (1.94–2.61)**	-
800-1649			0.94 (0.84–1.04)		1.27 (1.13–1.52)**		2.49 (2.15–2.88)**	
≥ 1650			0.91 (0.82–1.02)		1.30 (1.15–1.47)**		1.74 (1.52–2.01)**	
P for trend			0.537		0.031		0.617	

Note: OR, odds ratio; PA, physical activity; NI, not included due to non-significance in bivariate models; NE, not estimated due to multicollinearity. *p<0.05. ** p<0.01.
[a] Adjusted for participation in after-school care, mother's age and level of education.
[b] Additional adjustment for population density.

Table 7. Adjusted associations between environmental characteristics and activity participation in girls from MoBa.

	Adjusted OR (95 % CI) in girls (n = 10 214)							
	≥ 5 h/week leisure-time PA (summer)		≥ 5 h/week leisure-time PA (winter)		Organized activities ≥ 2 days/week		Friends and peers ≥ 2 days/week	
	Step 1[a]	Step 2[b]	Step 1[a]	Step 2[b]	Step 1[a]	Step 2[b]	Step 1[a]	Step 2[b]
Total green space 800 m								
≤ 13 % (ref.)			1	1	1	1	1	1
13.1 – 29.9 %	NI	NI	1.14 (1.02–1.27)*	1.13 (1.01-1.26)*	1.03 (0.91–1.17)	1.02 (0.90–1.16)	0.89 (0.76–1.04)	0.88 (0.75–1.04)
30.0 – 49.9 %			1.19 (1.06–1.33)**	1.15 (1.02-1.29)*	1.00 (0.88–1.13)	0.99 (0.87–1.13)	0.94 (0.80–1.10)	1.00 (0.85–1.18)
≥ 50.0 %			1.28 (1.15–1.44)**	1.20 (1.07-1.36)**	0.91 (0.81–1.04)	0.92 (0.80–1.05)	0.75 (0.64–0.88)**	0.88 (0.75–1.04)
P for trend			0.005	0.115	0.456	0.604	<0.001	0.108
Park within 800 m								
No (ref.)	NI	NI	NI	NI	NI	NI	NI	NI
Yes								
Park within 5000 m								
No (ref.)	NI	NI	NI	NI	1	1	1	1
Yes					0.99 (0.90–1.09)	0.94 (0.84–1.05)	1.51 (1.35–1.69)**	1.23 (1.07–1.41)**
Facilities/amenities 800 m								
0 (ref.)					1	1	1	1
1	NI	NI	NI	NI	1.16 (1.03–1.31)*	1.17 (1.03–1.32)*	1.35 (1.17–1.57)**	1.10 (0.94–1.29)
2-3					1.07 (0.95–1.20)	1.08 (0.95–1.23)	1.41 (1.21–1.64)**	1.11 (0.94–1.31)
≥ 4					1.16 (1.01–1.33)*	1.17 (1.01–1.37)*	1.17 (0.99–1.38)	0.91 (0.76–1.10)
P for trend					0.047	0.066	0.270	0.089
Facilities/amenities 5000 m								
≤ 5 (ref.)					1		1	
6-14	NI	NI	NI	NI	0.88 (0.78–1.00)		1.38 (1.19–1.61)**	NE
15-29					0.96 (0.84–1.09)	NE	1.38 (1.18–1.61)**	
≥ 30					1.03 (0.90–1.16)		1.47 (1.26–1.71)**	
P for trend					0.383		0.280	
Playgrounds/sports fields 800 m								
≤ 1 (ref.)	1		1		1		1	
2-5	0.85 (0.74–0.97)*		0.83 (0.72–0.95)**		1.04 (0.90–1.21)		2.57 (2.15–3.07)**	
6-10	0.88 (0.76–1.01)	NE	0.85 (0.74–0.98)*	NE	1.10 (0.94–1.28)	NE	2.82 (2.34–3.39)**	NE
≥ 11	0.73 (0.65–0.82)**		0.72 (0.64–0.80)**		1.15 (1.01–1.31)*		2.78 (2.41–3.21)**	
P for trend	<0.001		<0.001		0.061		<0.001	
Playgrounds/sports fields 5000 m								
≤ 35 (ref.)			1		1		1	
36-119			0.84 (0.75–0.94)**		0.90 (0.80–1.02)		1.89 (1.63–2.21)**	
120-419	NI	NE	0.77 (0.68–0.86)**	NE	1.01 (0.89–1.15)	NE	1.63 (1.41–1.90)**	NE
≥ 420			0.74 (0.66–0.83)**		1.04 (0.91–1.18)		1.85 (1.58–2.16)**	
P for trend			<0.001		0.289		<0.001	
School within 800 m								
No	NI	NI	NI	NI	1	1	1	1
Yes					1.07 (0.97–1.18)	1.06 (0.95–1.18)	1.21 (1.07–1.37)**	1.01 (0.88–1.16)
School within 5000 m								
No	1	1	1	1	1	1	1	1
Yes	0.81 (0.74–0.90)**	0.91 (0.82–1.02)	0.78 (0.70–0.86)**	0.84 (0.75-0.94)**	1.09 (0.98–1.22)	1.08 (0.96–1.23)	1.79 (1.58–2.03)**	1.38 (1.19–1.59)**
Population density 800 m								
≤ 200 (ref.)	1		1		1		1	
201-799	0.87 (0.77–0.97)*		0.82 (0.74–0.92)**		0.99 (0.87–1.11)		2.30 (1.97–2.69)**	
800-1649	0.79 (0.70–0.88)**	-	0.82 (0.73–0.92)**	-	1.12 (0.98–1.27)	-	2.01 (1.73–2.34)**	-
≥ 1650	0.71 (0.63–0.80)**		0.75 (0.67–0.84)**		1.03 (0.91–1.18)		1.86 (1.60–2.17)**	
P for trend	<0.001		0.002		0.275		0.008	

Note: OR, odds ratio; PA, physical activity; NI, not included due to non-significance in bivariate models; NE, not estimated due to multicollinearity. *p<0.05. ** p<0.01.
[a] Adjusted for participation in after-school care, mother's age and level of education.
[b] Additional adjustment for population density.

Discussion

Main findings

This study showed that children with access to a park in their neighborhood were more physically active during the summer than those without such access. Moreover, children who lived in neighborhoods with higher proportions of green space participated more in PA during the winter than children who lived in neighborhoods with low proportions of green space. More densely populated areas and access to facilities such as playgrounds/sports fields and schools were related to participation in organized activities and social activities. A higher number of playgrounds/sports fields in the neighborhood was the strongest correlate of leisure-activities in the Norwegian 8-year-olds, which consistently was linked more socialization with friends. We also found differential associations by sex. Several built environment characteristics were negatively related to leisure-time PA in the summer and the winter among girls but not among boys. Further, there were few supportive associations between the built environment and girls' participation in organized activities. More playgrounds/sports fields in the neighborhood was strongly related to social activity with friend and peers among both boys and girls.

The built environment and leisure-time PA

The findings of neighborhood green spaces as potential supportive determinants of leisure-time PA in children agree with previously reported results [21, 41]. However, several studies did not support favorable associations between access to green spaces and PA [42, 43]. The present results add to this body of equivocal literature [13, 16, 44]. Interestingly, we observed that associations between neighborhood green spaces and leisure-time PA were somewhat more pronounced in the winter than in the summer. The Norwegian climate is generally characterized by large seasonal variations with relatively warm summers and cold winters with snow in parts of the season. Furthermore, Norway is a country with strong outdoor traditions throughout the year. The majority of the population, including children, spend time outdoors almost regardless of the weather [45, 46]. These seasonal variations and cultural factors, which allow children to engage in a broad range of outdoor activities, can explain the results. It is highly conceivable that neighborhood parks serve as venues for summer activities (like ball games, biking, and running), whereas in the winter, neighborhood green spaces (like forests, marshland, and other open areas) afford more opportunities for common activities such as skiing and tobogganing.

We found that access to playgrounds/sports fields and schools was associated with reduced odds of PA among 8-year-olds, particularly for girls. These results diverge from what is widely accepted for the general population [11], but they agree with a meta-analysis of GIS studies that identified negative relations between access to play space and facilities among children [16]. Parental concerns and restrictions are the prevailing explanations for these results [16, 34]. In particular, concerns about traffic safety are reported as common reasons why parents restrict children from using their neighborhood surroundings [47, 48]. This explanation likely applies to the present study and to parents of Norwegian 8-year-olds. Even if opportunities for activities are present near home, they might not be reached or be used for other reasons, which unfortunately, we were not able to consider in this study.

Another aspect that can shed light on these results is that the majority (78.0%) of the Norwegian population lives in detached houses, duplexes, or terraced houses, of which detached houses are most common (56.6%) [49]. Thus, Norwegian children likely spend a great amount of their leisure-time PA in their private gardens or backyards. The participants did not provide information about housing, but we assume that many children in this sample have access to private spaces that provide opportunities for PA. This can also explain why neighborhood facilities were less and even negatively related to children's PA. Access to gardens and backyards could be important determinants of PA among children in Norway and warrant more attention.

The built environment and participation in organized activities

We did not measured participation in specific activities, but the survey questions considered organized activities broadly. Thus, the results provide some novel insights by showing that facilities, playgrounds/sports fields and school within 800- and 5 000 m of children's home were related to participation in organized activities among Norwegian 8-year-olds. Few studies have investigated relations between the built environment and children's participation in organized activities using GIS-derived measures. The existing studies mainly considered organized sports [20, 50]. Neither Buck et al. [20] nor Galvez et al. [50] reported statistically significant associations between access to facilities and organized sports among children.

Samdal and coworkers [51] reported that Norwegian adolescents engage most often in team or individual sports. This finding likely applies to children as well. In Norway, schools are important community arenas, and team and individual sports (e.g., handball, soccer, dancing, and martial arts) commonly take place at schools. It is highly conceivable that the school is the most relevant venue for team and individual sports, which could explain the present finding. Likewise, we observed that access to more facilities was positively related to engagement in both organized and social activities. A recent study revealed that children find their meaningful places for activities in both educational, commercial, recreational, traffic and religious behavior settings [52]. The total facility measure used the present study included activity venues such as indoor pools, churches, shopping malls and community centers. Assuming that more facilities are linked to a greater mix of facilities, our results suggest that many facilities could be essential for meeting children's different activity preferences and thus, support participation.

The built environment and socialization with friends/peers

Only a handful of studies have examined the relation between the built environment and social activity with friends and peers among children [17]. A study of U.S. children showed that living in neighborhoods with poor physical conditions and few facilities is linked to less time spent in peer play [53]. We add to this limited evidence by unveiling that higher population density and greater access to facilities, as well as park areas, promote participation in social activity with friends. Across all built characteristics, access to playgrounds/sports fields within 800 m of the child's residence was the strongest correlate of socialization with friends and peers. Mouratidis [54] recently reported similar results showing that shorter distances to facilities and higher population density facilitate more frequent socializing among Norwegian adults.

Unlike access to facilities, total neighborhood green space decreased the odds of social activity with friends and peers. This result is likely underpinned by the fact that greener areas are less dense. We found the highest likelihood of participating in organized activities for children in neighborhoods with moderate population density. Greatest likelihood of engagement in social activity was observed for children in the quartile described as low density closely followed by moderate density. In Finland, researchers have shown that moderate urban density has child-friendly characteristics, such as ensuring shorter distances to meaningful places [55]. Based on this study and the increased centralization in settlement patterns in Norway [56], the role of density in creating health-promoting and supportive childhood environments should be further explored within the Norwegian context.

The neighborhood and the larger community

Determinants within the 800- and 5 000-m radii were associated with participation in organized and social activity, whereas only determinants within the 800-m radius were relevant for PA. One reason for the observed difference could be that parents are more involved in children's organized and social activities, while leisure-time PA is more self-governed. Dunton et al. [57] provided support for the importance of parents' presence showing that children's leisure-activities often occur with family members. Traffic safety and other parental restrictions and concerns are significantly less prominent when parents accompany their children to activities. Thus, parents expand children's spatial territory, which can explain why other determinants and larger spatial areas were related to participation in organized and social activities with friends and peers. Interestingly, Kenney [53] found that parent-perceived neighborhood safety was not linked to peer play. Children might be allowed to roam more and actualize affordances when they are with friends and peers, which provides support for the present results.

Strengths and limitations

The strengths of this study lie in the large sample of 8-year-olds from across Norway linked to rich environmental data about the determinants. This large sample provided a unique opportunity to investigate associations between the built environment and activity participation in childhood. Unlike previous research, we were able to study participation in organized and social activities, as well as examine leisure-time PA across seasons. Although there is lack of consensus about how to define the areas of exposure and determinants of interest, we operationalized the GIS measures based on previous empirical work of measures applied among children and adolescents [28]. Use of objectively measured exposures also eliminated the potential risk of single source bias.

We could not infer causal relations from this cross-sectional design. Although we identified and adjusted for the most important confounders, other variables not included in the MoBa, could confound the associations between the built environment and activity outcomes. Environmental variables not measured, such as traffic exposure and safety aspects, could also confound the results. Furthermore, the results are vulnerable to residential self-selection bias stemming from the non-random selection of children into neighborhoods based on their parents' preferences [58]. Young women and mothers living alone were underrepresented in the MoBa [59]. Additionally, children of younger and lower-educated mothers were less likely to be included in our analyses, which also increased the risk of selection and attrition bias. However, Nilsen et al. [59], who compared participants in MoBa with the Medical Birth Registry in Norway, identified little bias in other exposure–outcome associations, indicating that selection bias may not be a serious problem in studies such as the present study.

Considering misclassification, we were not able to compute a child's actual exposure to the built environment and used buffer zones around residences as proxies. To reduce the likelihood of error, we excluded children living in post-separation families to make certain that the child lived at the actual address used for the calculation. The children participated in the 8-year follow-up between 2011 and 2015, whereas we obtained GIS-data from 2016 and January 2017 only. Thus, we did not establish the temporal sequencing from exposure to outcome. New parks, playgrounds, and facilities may have been developed, which potentially could have led to misclassification of exposures, and the risk of misclassification is highest for children participating in 2011. We are aware of these issues, but the built environment is postulated to transform slowly [60]. As such, large infrastructural changes to the built environment between 2011 and 2016 is less likely. Further, the risk of error due to changes in the built environment is expected to be minor for children followed-up in 2014 and 2015. In support of these notions, the sensitivity analysis in the sub-sample of children participating in 2014 and 2015 showed virtually equal ORs. That several significant results disappeared could be explained by a lower number of participants reducing the power to detect smaller differences. Thus, the results seem to be less susceptible to information bias, but if such bias are present, we suggest that the exposure most likely is non-differentially misclassified.

We did not measured the use and quality of the facilities and green spaces. It must be acknowledged that factors other than provision, such as safety and aesthetics, might influence the actualization of affordances [11]. Although we did not conduct a formal assessment, it was evident while we completed the GIS measures that many of the playgrounds were small and had limited space for activities such as running. As the literature suggests [28], qualities of green spaces and other venues for activities should be more extensively studied among children in Norway, as well as elsewhere.

Lastly, the results specifically apply to the Norwegian context. Norway is characterized by rich access to green space and low population density [61]. Inevitably, the study findings may not be widely generalizable to other countries.

Conclusion

This first Norwegian population-based study using GIS-derived measures of the built environment provides confirmatory and novel empirical evidence of the determinants that promote activity participation in childhood. Green spaces, facilities, playgrounds/sports fields, and population density supported participation in leisure-activities. Each determinant likely provide opportunities for different activities that are important for children's health and well-being. Although the results should be interpreted with caution, they underscore the importance of having access to a variety of venues and affordances for different activities in the immediate neighborhood surroundings, as well as in the greater community. In particular, the present results point to the importance of providing access to playgrounds/sports fields. These findings convey some suggestions that can inform health-promoting strategies and planning decisions to secure future development of neighborhoods that are inclusive for all. This has the capacity to enhance children's well-being and public health in general. This study also elucidates that creating health-promoting environments is complex and not straightforward, which points to the importance of integrative planning practices and solutions, as well as closer collaboration among researchers, policy makers, planners, and public health professionals.

List of abbreviations

PA: physical activity, MoBa: The Norwegian Mother and Child Cohort Study, GIS: geographic information systems, VIF: variance inflation factor, CI: confidence interval, OR: odds ratio.

Declarations

Ethics approval and consent to participate

The establishment and data collection in MoBa were previously based on a license from the Norwegian Data Protection Authority (ref. 01/4325) and approval from the Regional Committee for Medical Research Ethics (ref. S-97045, S-95113), and is now based on regulations related to the Norwegian Health Registry Act. A written informed consent was obtained from the mothers at enrollment to the cohort. We obtained additional approval for the use of data and linking of GIS variables in this present study from the Norwegian Center for Research Data (ref. 48426/3/AMS, 48426/6/AMS/LR).

Consent for publication

Not applicable.

Availability of data and material

The data that support the findings of this study are available from the Norwegian Institute of Public Health but restrictions apply to the availability due to agreements and approvals involving data security for participants from the Norwegian Data Protection Authority, Regional Committee for Medical Research Ethics as well as regulations in the Norwegian Health Registry Act. Data are however available from the authors upon reasonable request and with permission of the data owner if requestors wish to access the data for the purposes of checking analyses.

Competing interests

The authors declare they have no actual or potential competing financial interests.

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Authors' contributions

All authors conceived and designed this study. ECAN performed the GIS computations, data preparation and statistical analyses, interpreted the findings, and wrote the first draft of the manuscript. GA guided on both the GIS analyses and the statistical analyses. GA, RKR and HN contributed to the interpretation of the results. All authors revised the manuscript for important intellectual content, and reviewed and approved the final version of the manuscript.

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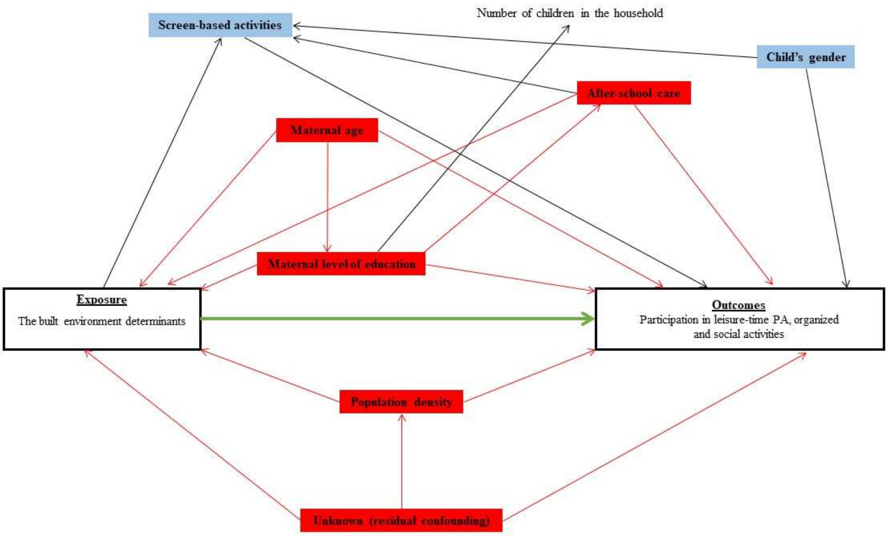
Additional file 1



Note: The read arrows and boxes represent confounded paths and the related confounding variables. The black arrows are unconfounded paths. The blue boxes represent covariates that are related to both the exposures and the outcomes, but not considered as confounders. To estimate the overall association between the built environment determinants and the activity outcomes minimal sufficient adjustment were identified to include the following confounders and covariates: child's gender, maternal age and level of education, after-school care and population density.

Figure S1. Directed acyclic graph depicting the relations between the exposures, outcomes and potential covariates.

Additional file 2

Table S1. Sensitivity analysis of selected children who participated in the 8-year follow-up in 2014 and 2015.

	Selected children (N = 8 311) Adjusted OR (95 % CI)							
	≥ 5 h/week leisure-time PA (summer)		≥ 5 h/week leisure-time PA (winter)		Organized activities ≥ 2 days/week		Friends and peers ≥ 2 days/week	
	Step 1[a]	Step 2[b]	Step 1[a]	Step 2[b]	Step 1[a]	Step 2[b]	Step 1[a]	Step 2[b]
Total green space 800 m								
≤ 13 % (ref.)			1	1	1	1	1	1
13.1 – 29.9 %	NI	NI	1.19 (1.06–1.35)**	1.18 (1.04–1.33)**	1.00 (0.87–1.15)	0.99 (0.86–1.13)	0.90 (0.77–1.06)	0.89 (0.76–1.05)
30.0 – 49.9 %			1.11 (0.98–1.26)	1.08 (0.95–1.23)	0.93 (0.81–1.07)	0.91 (0.79–1.05)	0.94 (0.80–1.11)	1.00 (0.84–1.19)
≥ 50.0 %			1.31 (1.16–1.49)**	1.26 (1.10–1.44)**	0.92 (0.80–1.06)	0.89 (0.77–1.04)	0.77 (0.66–0.91)**	0.84 (0.79–1.12)
P for trend			<0.001	0.017	0.916	0.792	0.001	0.241
Park within 800 m								
No (ref.)	1	1	NI	NI	1	1	NI	NI
Yes	1.01 (0.90–1.15)	1.09 (0.96–1.23)			1.01 (0.89–1.14)	1.02 (0.90–1.17)		
Park within 5 000 m								
No (ref.)	NI	NI	NI	NI	1	1	1	1
Yes					0.95 (0.86–1.06)	0.94 (0.83–1.07)	1.60 (1.42–1.81)**	1.26 (1.08–1.46)**
Facilities/amenities 800 m								
0 (ref.)					1	1	1	1
1	NI	NI	NI	NI	1.13 (0.99–1.28)	1.14 (1.00–1.31)	1.32 (1.14–1.54)**	1.05 (0.90–1.24)
2-3					1.08 (0.95–1.23)	1.12 (0.97–1.28)	1.44 (1.23–1.68)**	1.12 (0.94–1.33)
≥ 4					1.06 (0.92–1.23)	1.11 (0.94–1.31)	1.24 (1.05–1.48)*	0.96 (0.79–1.17)
P for trend					0.534	0.386	0.802	0.005
Facilities/amenities 5 000 m								
≤ 5 (ref.)					1		1	
6-14	NI	NI	NI	NI	1.00 (0.86.–1.15)		1.55 (1.32–1.82)**	
15-29					1.04 (0.90–1.20)	NE	1.76 (1.49–2.09)**	NE
≥ 30					1.05 (0.92–1.21)		1.66 (1.42–1.93)**	
P for trend					0.333		0.491	
Playgrounds/sports fields 800 m								
≤ 1 (ref.)	1		1		1		1	
2-5	0.90 (0.77–1.07)		0.91 (0.78-1.07)		0.99 (0.83–1.17)		2.76 (2.27–3.35)**	
6-10	0.95 (0.80–1.12)	NE	0.99 (0.85–1.16)	NE	1.05 (0.88–1.25)	NE	2.97 (2.44–3.62)**	NE
≥ 11	0.84 (0.73–0.96)**		0.84 (0.73–0.96)**		1.01 (0.88–1.17)		2.98 (2.56–3.47)**	
P for trend	0.001		<0.001		0.924		<0.001	
Playgrounds/sports fields 5000 m								
≤ 35 (ref.)					1		1	
36-119	NI	NI	NI	NI	0.93 (0.81–1.07)		1.90 (1.61–2.24)**	
120-419					0.97 (0.84–1.11)	NE	1.91 (1.62–2.26)**	NE
≥ 420					1.03 (0.89–1.19)		1.94 (1.66–2.28)**	
P for trend					0.584		<0.001	
School within 800 m								
No	1	1	NI	NI	1	1	1	1
Yes	0.92 (0.83–1.02)	0.96 (0.86–1.07)			1.07 (0.97–1.19)	1.08 (0.97–1.22)	1.15 (1.01–1.30)*	0.93 (0.81–1.07)
School within 5 000 m								
No	NI	NI	NI	NI	1	1	1	1
Yes					1.08 (0.96–1.23)	1.13 (0.98–1.30)	1.68 (1.47–1.93)**	1.16 (0.99–1.37)
Population density 800 m								
≤ 200 (ref.)					1		1	
201-799	NI	NI	NI	NI	0.96 (0.83–1.11)	-	2.32 (1.96–2.73)**	-
800-1 649					1.04 (0.90–1.20)		2.51 (2.13–2.96)**	
≥ 1 650					0.96 (0.83–1.10)		1.95 (1.67–2.27)**	
P for trend					0.302		0.438	

Note: OR, odds ratio; PA, physical activity; NI, not included due to non-significance in bivariate models; NE, not estimated due to multicollinearity. *p<0.05. ** p<0.01.

[a] Adjusted for sex, participation in after-school care, mother's age and level of education.

[b] Additional adjustment for population density.

Paper IV

Disentangling how the built environment relates to children's well-being: Participation in leisure activities as a mediating pathway among 8-year-olds based on the Norwegian Mother and Child Cohort Study

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Abstract

There is scarce research on the role of the built environment for children's subjective well-being. To increase our knowledge on this matter, we conducted a cross-sectional study comprising 23,043 children from the Norwegian Mother and Child Cohort Study. Information about children's leisure activities and their moods and feelings were linked to geospatial data on green space, facilities and population density to assess whether these built characteristics are related to subjective well-being and if participating in leisure activities is a mediator in such relations. Children having a park and more playgrounds/sports fields in the neighborhood, as well as those living in more densely populated areas, had more depressive moods and negative feelings. However, participating in leisure-time physical activity, organized activities and social activity with friends were mediators in these relations and contributed to counterbalancing some of the negative associations observed. The findings suggest that planners and policy makers should focus on ensuring children have neighborhood resources and venues that could support engagement in leisure activities that add positive experiences for their subjective well-being.

Keywords: Mediation; Green space; Facilities; Population density; Short Mood and Feelings Questionnaire; The Norwegian Mother and Child Cohort Study.

Introduction

High levels of well-being indicate that a child is experiencing positive emotions and feelings, functioning well and is able to realize his or her abilities and thrive (WHO, 2004). Enhancing the well-being of children can contribute to a sound childhood that fosters resilience and lays the foundation for good health throughout life. As such, the promotion of children's well-being is vital for sustainable development (Layard et al., 2014). Well-being covers both subjective and objective aspects of life. Subjective well-being relates to people's experiences, feelings, emotions and affective assessments of life, while objective well-being concerns the conditions assumed to be essential for well-being (Carlquist, 2015; Taylor, 2015; WHO, 2004), such as environments that afford opportunities to participate in activities (The Children's Society, 2012; United Nations, 1989).

Many children currently experience mental health problems (Norwegian Institute of Public Health, 2018; Patel et al., 2018). Going through psychological and emotional difficulties and feeling a lack of meaning in life can impair well-being. Thus, health-promoting efforts that can strengthen children's well-being, and which thereby also could contribute to counteract adverse mental health outcomes, are important (Norwegian Institute of Public Health, 2009; WHO, 2004). At the same time, we are witnessing urban population growth and an increase in centralized settlement patterns. These development trends exert pressure on our living environment and public health that may have consequences for health and well-being in the younger population (Statistics Norway, 2018; United Nations, 2018). Only recently, political leaders across Europe enacted to prioritize investment in population health and to design supportive environments that improve health and well-being at all ages (WHO, 2018). Evidence-based knowledge that addresses the environmental determinants of health and well-being is a prerequisite for such priorities.

A wealth of studies have examined the built environment determinants of participation in activities such as physical activity (PA), active travel and outdoor play in childhood (Christian et al., 2015; D'Haese et al., 2015; Ding et al., 2011; MacMillan et al., 2018; McGrath et al., 2015; Nordbø et al., 2019a). Yet, few empirical studies have addressed the potential built environment determinants of children's subjective well-being (Clark et al., 2007; Nordbø et al., 2019a). Some previous research suggested that neighborhoods with more green space are advantageous for health and well-being in childhood, and it has been linked to fewer behavioral problems (Amoly et al., 2014; Feng and Astell-Burt, 2017) and better self-perceived health (Kyttä et al., 2012). Additionally, longer distances to green spaces and poor aesthetic neighborhood conditions have been connected to more behavioral and mental health problems (Butler et al., 2012; Markevych et al., 2014; Singh and Ghandour, 2012), although inconsistencies in the evidence exist (Amoly et al., 2014; Huynh et al., 2013; McCracken et al., 2016). Apart from this, there is scant research that addresses other potential environmental determinants of children's well-being, such as population density and access to facilities (Nordbø et al., 2019a). Further, prior studies have mainly assumed and examined direct relations between the built environment and well-being (Twohig-Bennett and Jones, 2018).

Researchers have argued that associations between the environment and well-being are not only governed by direct effects but are also mediated through other key variables (Hartig et al., 2014; Kyttä et al., 2015; Lachowycz and Jones, 2013; Mouratidis, 2018). Frameworks and models, as presented in the references above, offer important information on *how* the built environment might relate to the well-being of children. Intrinsically, the built environment seems to support participation in activities that could yield positive experiences and bring about a sense of meaning in life, which may enhance children's well-being. However, this mediation mechanism is scarcely investigated. Beneficial associations between the built environment and participation in leisure-time PA, as well organized and social activities, have been reported among Norwegian children (Nordbø et al., 2019b). Involvement in these leisure activities has also been found to strengthen children's health and well-being (Badura et al., 2015; Breistøl et al., 2017; Janssen and LeBlanc, 2010; Mahoney et al., 2005; Thoits, 2011). Thus, the purpose of this study was to examine different pathways between some built environment determinants (i.e., population density, green space and facilities) and children's subjective well-being. Besides investigating direct relations, we assessed whether and how participating in different leisure activities operated as potential mediators in such relations among Norwegian 8-year-olds.

Methods

Study design and data sources

This study was designed as a cross-sectional data linkage study involving participants from the Norwegian Mother and Child Cohort Study (MoBa). MoBa is a prospective population-based pregnancy cohort conducted by the Norwegian Institute of Public Health (Magnus et al., 2016). Pregnant women from across Norway were recruited during week 17 of pregnancy between 1999 and 2008, and 41% of those invited consented to participate. The cohort includes 95,200 mothers and 114,500 children. We obtained version IX of the quality-assured data files released for research in November 2015. Questionnaire data reported by the mothers of children who turned 8-years old in 2011, 2012, 2013, 2014 and 2015 were linked to geospatial data about the built environment qualities surrounding the participants' addresses using geographical information systems (GIS).

Participants

Statistics Norway successfully linked GIS-derived variables to the residential addresses of 27,706 (86.3%) eligible 8-year-olds in the cohort. We excluded children with chronic or severe conditions (n = 613), such as rheumatoid arthritis and cancer. Children in post-separation families (n = 3,618) were also excluded because the GIS variables were computed around the mothers' addresses only. Additionally, we excluded children whose year of participation in the 8-year follow-up was unknown (n = 412). Upon removal of participants with missing data for outcomes, exposures, mediators and covariates (n = 2,024) the final analytical sample constituted 21,019 children.

MoBa questionnaire data

The survey used in MoBa provided information about the child's leisure activities, friends and general health, as well as the demographic information of the mother. We obtained outcome variables, mediators and covariates from this material.

Well-being indicator

Children's *moods and feelings* were assessed through the Norwegian version of the Short Mood and Feelings Questionnaire (SMFQ) (Angold et al., 1995). The SMFQ is a widely used tool for measuring mood, feelings and depressive symptoms in early childhood. The SMFQ consists of 13 items derived from a longer 30-item questionnaire. Each item was rated on a three-point Likert scale. Values were assigned to statements such as "feeling miserable/unhappy" and "feeling lonely" based on the following responses: "not true (0)," "sometimes true (1)" and "true (2)," referring to the past two weeks. The internal reliability of the SMFQ is previously reported as 0.85 (Angold et al., 1995). In this sample of 8-year-olds from MoBa, we found a Cronbach's alpha of 0.77. Based on the individual item scores, we computed a total score ranging from 0 to 26 in which higher values indicated more depressed moods and feelings (Angold et al., 2002; Messer et al., 1995). If a child had only four or less items missing, we replaced the missing values with the mean of the remaining items to obtain a total score (Angold et al., 1995). Otherwise, we did not compute the total score, and the child was subsequently removed from further analysis. We treated the total score as a continuous variable in the statistical analyses.

Potential mediators

To measure *leisure-time PA during the summer and winter,* we used two questions to elicit how much time the child spent on PA outside school hours during the summer and winter. The response alternatives were "< 1," "1-2," "3-4," "5-7," "8-10" and "≥ 11" h/week. A binary coding of "≥5 h/week" opposed to "4≤ h/week" was employed. This threshold complies with the national recommendation of 60 min/day (7 h/week) of PA (The Norwegian Directorate of Health, 2014), as the remaining hours of PA would be expected to occur at school, during either recess or physical education classes.

To measure *participation in organized activities,* one question that addressed how many days/week the child participated in any kind of organized leisure activity (e.g., sports, music or theater) were used. The response categories were “never/seldom,” “once a week,” “2-3,” “4-5” and “6-7 days/week.” We recoded the answers into a dichotomous variable: “2 days or more/week” in contrast to “once weekly or less” based on recent statistics showing that children in Norway on average take part in 1.7 different organized activities (Ipsos MMI, 2018).

We measured *informal social activity with friends/peers* with a question that elicited how many days/week the child spent time with friends/peers, excluding the periods during school hours and organized activities. Since nearly 60% of Norwegian children are together with their friends at least twice a week (Kolle et al., 2012), this variable was dichotomized into “2 days or more/week” opposed to “once weekly or less.”

Procedures for assessing built environment exposures

We downloaded geographical data from 2016 up until January 2017 from the Norwegian Mapping Authority and utilized GIS (ArcGIS 10.3 and QGIS 2.14) to derive environmental exposures. Built environment characteristics (see below for details) were calculated within 800- and 5,000-m circular buffers surrounding the participants’ geo-referenced home addresses. The smaller buffer represented the neighborhood area, while the larger buffer represented the local community. The radii were chosen based on existing research (Mitchell et al., 2016; Nordbø et al., 2018; Villanueva et al., 2012) while simultaneously taking into account the Norwegian context known for its low centrality in many areas (Høydahl, 2017). Statistics Norway performed the linkage of exposure data to each child in MoBa.

We operationalized *population density* as the total number of residents per square kilometers within the buffer zone. Due to high computational burden, we calculated this measure within the 800-m radius only. We divided the variable into four categories: ≤200 residents (reference), 201-799 (low), 800-1,649 (moderate) and ≥1,650 (high). The quartiles were derived statistically while also taking into account Statistics Norway’s definition of densely populated areas, which states that such areas are characterized by settlements >200 inhabitants where the distance between the houses does not exceed 50-m (Statistics Norway, 1999).

We calculated the *total number of facilities/amenities*, including schools, libraries, churches, cinemas, indoor pools, shopping malls and community and health care centers within both radii. We also computed the *total number of playgrounds/sports fields*. Both variables were divided into quartiles. Additionally, we calculated *access to school* within the 800- and,5000-m buffer zones. We used a binary coding that indicated “presence of school” (yes/no).

We calculated the *total area (square kilometers) of green spaces*, including forests, marshland, parks and golf courses. This measure was calculated within the 800-m buffer zone only since the computational burden was too high. We converted the area of green space into the proportion of the total area within the radius and then split the variable into quartiles. We also calculated a separate measure of *access to a park* within 800- and 5,000-m of the home addresses. Parks were defined according to the Norwegian Mapping Authority as built up and maintained green areas larger than 2,000 m^2 and wider than 30 meter, with lawns, plants, seating, water features, etc. We created a dichotomous variable that indicated "presence of park" (yes/no).

Confounders

Confounders were identified *a priori* based on the counterfactual theory and approach to mediation (Valeri and Vanderweele, 2013; VanderWeele, 2016). We created a directed acyclic graph (see Appendix A, Figure S1) and used previously published studies to inform this process. Based on the confounding assumptions articulated by VanderWeele (2016), we included a set of covariates for which adjustment was needed to control for the confounding of the (1) exposure-outcome, (2) mediator-outcome and (3) exposure-mediator pathways. The following individual-level covariates were adjusted for in the analyses: child's gender, after-school care, hours spent watching TV, hours spent on other screen-based activities and mother's age and level of education. To account for urban and rural differences, we treated population density as an area-level confounder in addition to considering it as an exposure variable.

Analytical strategy and statistical analysis

Statistical analyses were performed using SPSS Statistics 25 and R version 3.5.2. The level of statistical significance was set to 0.05. We conducted preliminary analyses to examine mean, median, range, standard deviations and frequencies and to explore the interrelations between the exposures, potential mediators and the outcome. Figure 1 depicts the conceptual mediation model that formed the basis for the regression modelling approach. In the initial analyses, we examined pathways A, B and C in Figure 1. We modelled the relationships between each built environment exposure and mediator (Path A) using logistic regression. A series of general linear models were fitted to examine (1) the relations between each mediator and children's moods and feelings (Path B) and (2) to estimate the total effect of each built characteristic on the well-being indicator (Path C). We included and adjusted for potential confounders in all models. The initial analyses revealed regression coefficients on Path B with an opposite sign to that of paths A and C, which presumably indicated a presence of inconsistent mediation (negative direct and positive indirect relations) and suppression (MacKinnon et al., 2007; MacKinnon et al., 2000). Based on our initial discoveries, we exploited the steps recommended by Shrout and Bolger (2002) to avoid a type II error for the mediation analyses. Thus, as a prerequisite for specifying the models, the following two conditions had to be met for a variable to be considered a mediator: (1) significant exposure-mediator relations and (2) significant mediator-outcome relations.

We utilized the counterfactual approach to mediation analysis formulated by Pearl (2001) and Robins and Greenland (1992) as the statistical framework for our analyses. Based on several recent extensions of this approach (Imai et al., 2010; Valeri and Vanderweele, 2013; VanderWeele and Vansteelandt, 2009), we estimated the total, direct and indirect associations in models with categorical built environment exposures and binary activity mediators. We employed methods and formulas provided within the mediation package in R developed by Tingley et al. (2014). The direct and indirect associations were estimated from fitting (1) a general linear model for children's moods and feelings (Y), conditional on each built environment determinant (X), the potential mediator (M) and the set of confounders, and (2) a logistic regression model for the potential mediator (M), conditional on the particular built environment determinant (X) and the set of confounders. We assumed that the set of covariates included in the models was sufficient to control for confounding on all paths, which enabled us to identify the controlled direct and indirect associations. In total, 15 separate mediation models were specified. We computed the direct and indirect associations for each level of a built characteristic using the reference group as the contrast. Robust standard errors were estimated to adjust for heteroscedasticity. We reported standardized regression coefficients (β) with corresponding 95% confidence intervals (CI) obtained through quasi-Bayesian Monte Carlo simulations based on normal approximation with 1,000 resamples (Imai et al., 2010).

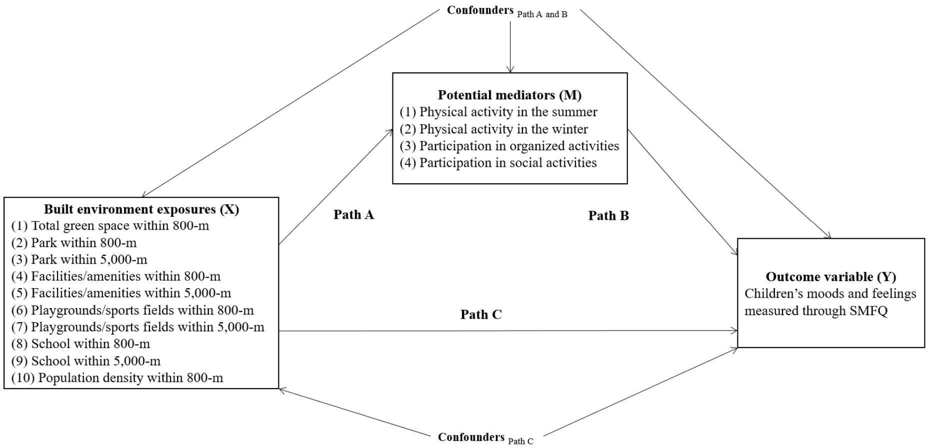

Figure 1. A conceptual mediation model showing the direct relationship on Path C and the indirect relationship through Path A and Path B, including the set of confounders on all paths.

Ethics

The establishment and data collection in MoBa were previously based on a license from the Norwegian Data Protection Authority (ref. 01/4325) and approval from the Regional Committee for Medical Research Ethics (ref. S-97045, S-95113), and are now based on regulations related to the Norwegian Health Registry Act. Written informed consent was obtained from the mothers at the time of enrollment in the cohort. We obtained additional approval for the use of data and the linking of GIS variables in this present study from the Norwegian Center for Research Data (ref. 48426/3/AMS, 48426/6/AMS/LR).

Results

General characteristics

Descriptive statistics of the participants and the exposure measures are provided in Table 1 and 2, respectively. Among the 23,043 Norwegian 8-year-olds, there were slightly more boys (51.4%) than girls. Just above 60% of the mothers were aged 30 or older, and nearly 40% had completed more than four years of university education. The mean score for the SMFQ was low (mean=1.71, SD=2.28), indicating that the children experienced few depressive and emotional symptoms. The girls experienced significantly fewer negative moods and feelings compared to the boys (Table 1).

Table 1. Individual-level characteristics for the total sample of 8-year-olds from the MoBa.

Individual level characteristics	Total (n=23 043)	Boys (n=11 826)	Girls (n=11 176)	P-value[a]
Well-being indicator				
Mood and feelings (SMFQ)				0.001
Mean (SD)	1.71 (2.28)	1.76 (2.36)	1.66 (2.20)	
Missing, n (%)	82 (0.4)	41 (0.3)	40 (0.4)	
Potential mediators, n (%)				
Hours of leisure-time PA (summer)				<0.001
≤ 4 h/week	8 758 (38.0)	3 658 (30.9)	5 086 (45.5)	
≥ 5 h/week	14 085 (61.1)	8 071 (68.3)	5 987 (53.6)	
Missing	200 (0.9)	97 (0.8)	103 (0.9)	
Hours of leisure-time PA (winter)				<0.001
≤ 4 h/week	11 375 (49.4)	5 110 (43.2)	6 247 (55.9)	
≥ 5 h/week	11 457 (49.7)	6 597 (55.8)	4 837 (43.3)	
Missing	211 (0.9)	119 (1.0)	92 (0.8)	
Participation in organized activities				0.003
Once a week or less	6 562 (28.5)	3 467 (29.3)	3 078 (27.6)	
2 days or more/week	16 430 (71.3)	8 333 (70.5)	8 073 (72.2)	
Missing	51 (0.2)	26 (0.2)	25 (0.2)	
Informal social activity with friends/peers				0.007
Once a week or less	3 627 (15.7)	1 934 (16.4)	1 684 (15.1)	
2 days or more/week	19 084 (82.8)	9 719 (82.2)	9 333 (83.5)	
Missing	332 (1.5)	173 (1.4)	159 (1.4)	
Covariates, n (%)				
Hours spent watching TV				<0.001
An hour or less/day	11 076 (48.1)	5 826 (49.3)	5 224 (46.7)	
> 1 hour/day	11 908 (51.7)	5 967 (50.5)	5 927 (53.0)	
Missing	59 (0.2)	33 (0.2)	25 (0.2)	
Hours spent on other screen-based activities				<0.001
An hour or less/day	17 027 (73.9)	7 831 (66.2)	9 164 (82.0)	
> 1 hour/day	5 835 (25.3)	3 918 (33.1)	1 909 (17.1)	
Missing	181 (0.8)	77 (0.7)	103 (0.9)	
After school care				0.516
No	6 096 (26.4)	3 162 (26.7)	2 918 (26.1)	
Yes	16 503 (71.6)	8 449 (71.5)	8 026 (71.8)	
Missing	444 (2.0)	214 (1.8)	230 (2.1)	
Maternal age (years) at recruitment				0.063
≤ 29	8 967 (38.9)	4 679 (39.6)	4 288 (38.4)	
≥ 30	14 035 (60.9)	7 147 (60.4)	6 888 (61.6)	
Missing	41 (0.2)	0 (0.0)	0 (0.0)	
Maternal level of education				0.731
High school or less	4 624 (20.1)	2 392 (20.2)	2 229 (19.9)	
University ≤ 4 years	8 904 (38.6)	4 603 (38.9)	4 286 (38.4)	
University > 4 years	8 951 (38.8)	4 576 (38.7)	4 355 (39.0)	
Missing	564 (2.5)	255 (2.2)	306 (2.7)	

Note: PA, physical activity.

[a]Results from independent samples T-test and chi-square statistics comparing boys and girls.

Table 2. Distribution of the built environment determinants for the total sample of 8-year-olds from the MoBa.

Built environment determinant	N (%) Total (n=23 043)	Boys (n=11 826)	Girls (n=11 176)	P-value[a]
Total green and open spaces				0.187
≤ 13.0 % (ref.)	5 593 (24.3)	2 866 (24.2)	2 717 (24.3)	
13.1 – 29.9 %	5 664 (24.6)	2 846 (24.1)	2 811 (25.2)	
30 – 49.9 %	5 983 (26.0)	3 085 (26.1)	2 887 (25.8)	
≥ 50.0 %	5 803 (25.2)	3 029 (25.6)	2 761 (24.7)	
Missing	0 (0.0)	0 (0.0)	0 (0.0)	
Park within 800 m				0.671
No	19 279 (83.7)	9 882 (83.6)	9 362 (83.8)	
Yes	3 764 (16.3)	1 944 (16.4)	1 814 (16.2)	
Missing	0 (0.0)	0 (0.0)	0 (0.0)	
Park within 5 000 m				0.517
No	8 493 (36.9)	4 384 (37.1)	4 097 (36.7)	
Yes	14 550 (63.1)	7 442 (62.9)	7 079 (63.3)	
Missing	0 (0.0)	0 (0.0)	0 (0.0)	
Number of facilities/amenities 800 m				0.325
0 (ref.)	10 837 (47.0)	5 600 (47.4)	5 220 (46.7)	
1	4 687 (20.3)	2 429 (20.5)	2 253 (20.2)	
2-3	4 542 (19.7)	2 311 (19.5)	2 219 (19.9)	
≥ 4	2 977 (12.9)	1 486 (12.6)	1 484 (13.3)	
Missing	0 (0.0)	0 (0.0)	0 (0.0)	
Number of facilities/amenities 5 000 m				0.689
≤ 5 (ref.)	6 007 (26.1)	3 096 (26.2)	2 901 (26.0)	
6-14	5 512 (23.9)	2 856 (24.2)	2 647 (23.7)	
15-29	5 257 (22.8)	2 665 (22.5)	2 582 (23.0)	
≥ 30	6 267 (27.2)	3 209 (27.1)	3 046 (27.3)	
Missing	0 (0.0)	0 (0.0)	0 (0.0)	
Number of playgrounds/sports fields 800 m				0.355
≤ 1 (ref.)	3 666 (15.9)	1 928 (16.3)	1 733 (15.5)	
2-5	4 002 (17.4)	2 058 (17.4)	1 935 (17.3)	
6-10	3 748 (16.3)	1 900 (16.1)	1 846 (16.5)	
≥ 11	11 627 (50.5)	5 940 (50.2)	5 662 (50.7)	
Missing	0 (0.0)	0 (0.0)	0 (0.0)	
Number of playgrounds/sports fields 5 000 m				0.176
≤ 35 (ref.)	5 845 (25.4)	3 031 (25.6)	2 805 (25.1)	
36-119	5 654 (24.5)	2 839 (24.0)	2 806 (25.1)	
120-419	5 690 (24.7)	2 965 (25.1)	2 716 (24.3)	
≥ 420	5 854 (25.4)	2 991 (25.3)	2 846 (25.5)	
Missing	0 (0.0)	0 (0.0)	0 (0.0)	
School within 800 m				
No	16 540 (71.8)	8 540 (72.2)	7 974 (71.3)	0.145
Yes	6 503 (28.2)	3 286 (27.8)	3 202 (28.7)	
Missing	0 (0.0)	0 (0.0)	0 (0.0)	
School within 5 000 m				0.363
No	4 941 (21.4)	2 565 (21.7)	2 369 (21.2)	
Yes	18 102 (78.6)	9 261 (78.3)	8 807 (78.8)	
Missing	0 (0.0)	0 (0.0)	0 (0.0)	
Population density				0.072
≤ 200 (ref.)	4 747 (20.6)	2 515 (21.3)	2 227 (19.9)	
201-799	6 679 (29.0)	3 397 (28.7)	3 271 (29.3)	
800-1 649	5 832 (25.3)	3 004 (25.4)	2 817 (25.2)	
≥ 1 650	5 649 (24.5)	2 853 (24.1)	2 783 (24.9)	
Missing	136 (0.6)	58 (0.5)	78 (0.7)	

[a]Results from chi-square statistics comparing boys and girls.

Results from the pathway regression analyses

Tables 3, 4 and 5 present the estimates for each of the pathways depicted in Figure 1. The regression coefficients on Path A showed that the all the built environment characteristics were positively related to leisure-time PA in both seasons, organized activities and social activity with friends. Further, greater participation in all leisure activities was significantly associated with better moods and feelings (Path B) (Tables 3, 4 and 5), of which the largest estimates were observed for social activity with friends. Children who spent time with their friends $\geq$ 2 days/week had significantly less depressive and emotional symptoms compared to children who were together with their friends once weekly or less (β = -0.55, 95% CI = -0.47, -0.64). The adjusted total associations (Path C) showed that several built environment characteristics increased the level of depressive and emotional symptoms among the Norwegian 8-year-olds. Such adverse significant associations were observed for parks (800-m), playgrounds/sports fields (800- and 5,000-m) and population density (Tables 3, 4 and 5). A few exceptions were total green space (800-m) and parks (5,000-m), which reduced the level of negative symptoms, although not significantly (Tables 3 and 5).

Mediation analyses

The direct and indirect relations between the built environment and children's well-being through each possible mediator are shown in Tables 3, 4 and 5. The pattern of the regression coefficients in the mediation analyses revealed inconsistent mediation in several models. Inconsistent mediation pertained to relations between the SMFQ and the determinants park (800-m), playgrounds/sports fields (800- and 5,000-m) and population density (Tables 3, 4 and 5: models 1, 5, 6, 9, 12, 13 and 15). In these models, we found negative direct associations showing that the built environment characteristics were related to more depressive moods and feelings, whereas indirect associations through each potential mediator were inversed by unveiling fewer depressive moods and feelings.

Inconsistent mediation was indicated by greater direct associations (β= 0.165, 95% CI= 0.07, 0.26) than overall associations (β= 0.162, 95% CI= 0.07, 0.26) and by inverse indirect relationships (β= -0.003, 95% CI= -0.006, -0.001). Children with a park within 800-m of home participated more in leisure-time PA in the summer. This was in turn associated with better moods and feelings, even though the overall association between having a park within 800-m and the well-being indicator remained negative (Table 3: model 1). Similarly, we identified indirect positive associations between living in more densely populated areas and children's moods and feelings through more frequent involvement in organized and social activities.

However, the significant overall negative association between population density and children's subjective well-being persisted (Tables 4 and 5: models 9 and 15).

Positive indirect relations were greatest through participation in social activities, which mediated the associations between the SMFQ and population density and playgrounds/sports fields within 800- and 5,000-m (Table 5). The positive indirect association through participation in social activities with friends $\geq$ 2 days/week among children with 2-5 playgrounds/sports fields (β = -0.028, 95% CI = -0.035, -0.02) counteracted the negative direct association of having more playgrounds/sports fields within the neighborhood (β = 0.055, 95% CI = 0.026, 0.08). Thus, the overall associations between more playgrounds/sports fields within the neighborhood and these children's moods and feelings were not significantly different from the moods and feelings of children having $\leq$ 1 playground/sports field in their neighborhood ($p > 0.05$).

Total green space (800-m) and park, facilities and school (5,000-m) were only indirectly associated with the moods and feelings of the Norwegian 8-year-olds. We found significant indirect relations between these built characteristics and children's moods and feelings via participation in leisure-time PA in the winter, organized activities and social activity (Tables 3, 4 and 5: models 2, 4, 10, 11 and 14). Neither any total nor any direct or indirect relations were found for facilities and schools within 800-m of the home addresses and the children's subjective well-being (Table 4: models 3 and 7).

Table 3. Pathway, direct and indirect estimates for participating in leisure-time PA as a mediator in the relations between the built environment and moods and feelings (SMFQ) among 21 019 Norwegian 8-year-olds[a].

	Built environment exposures	Path A[b]		Path B[c]		Path C[d] (total effect)		Direct effect[e]		Indirect effect[f]	
		β	95% CI	β	95% CI	β	95% CI	β	95% CI	β	95% CI
Model 1		PA in the summer		Mood and feelings		Mood and feelings		Mood and feelings		Mood and feelings	
	Park within 800-m										
	No (Ref.)	Ref.		-0.12***	-0.05, -0.18	Ref.		Ref.		Ref.	
	Yes	0.12***	0.08, 0.26			0.162***	0.07, 0.26	0.165***	0.07, 0.26	-0.003*	-0.006, -0.001
Model 2		PA in the winter		Mood and feelings		Mood and feelings		Mood and feelings		Mood and feelings	
	Total green space										
	≤ 13.0 % (Ref.)	Ref.		-0.22***	-0.15, -0.28	Ref.		Ref.		Ref.	
	13.1 – 29.9 %	0.08**	0.03, 0.13			-0.004	-0.03, 0.02	-0.004	-0.03, 0.03	-0.003*	-0.006, -0.001
	30.0 – 49.9 %	0.08**	0.03, 0.13			-0.007	-0.07, 0.05	-0.001	-0.06, 0.06	-0.006**	-0.010, -0.001
	≥ 50.0 %	0.12***	0.07, 0.17			-0.013	-0.10, 0.07	-0.004	-0.09, 0.08	-0.009**	-0.015, -0.001

Abbreviations: NE, not estimated due to non-significance on either Path A or Path B.
[a]Estimates are adjusted for child's gender, mother's age and level of education, hours spent on watching TV, hours spent on other screen-based activities, after-school care and population density.
[b]Associations between the built environment exposure and the potential mediators.
[c]Associations between the potential mediators and mood and feelings.
[d]Associations between the built environment exposure and mood and feelings.
[e]Associations between the built environment exposure and mood and feelings, adjusted for the potential mediator investigated.
[f]Associations between the built environment exposure and mood and feelings, through the potential mediator investigated.
*p<0.05, **p<0.01, ***p<0.001

Table 4. Pathway, direct and indirect estimates for participating organized activities as a mediator in the relations between the built environment and mood and feelings (SMFQ) among 21 019 Norwegian 8-year-olds[a].

	Built environment exposure	Path A[b]		Path B[c]		Path C[d] (total effect)		Direct effect[e]		Indirect effect[f]	
		β	95% CI	β	95% CI	β	95% CI	β	95% CI	β	95% CI
		Organized activities		Mood and feelings		Mood and feelings		Mood and feelings		Mood and feelings	
Model 3	Facilities within 800-m										
	0 (Ref.)	Ref.		-0.34***	-0.28, -0.41	Ref.		Ref.		Ref.	
	1	0.08*	0.03, 0.13			0.010	-0.030, 0.05	0.011	-0.025, 0.05	-0.001	-0.005, 0.001
	2-3	0.04	-0.01, 0.10			0.020	-0.046, 0.09	NE		NE	
	≥ 4	0.03	-0.04, 0.09			0.030	-0.068, 0.14	NE		NE	
Model 4	Facilities within 5 000-m†										
	≤ 5 (Ref.)	Ref.		-0.34***	-0.28, -0.41	Ref.		Ref.		Ref.	
	6-14	-0.004	-0.05, 0.05			0.016	-0.016, 0.04	NE		NE	
	15-29	0.042	-0.01, 0.09			0.032	-0.024, 0.09	NE		NE	
	≥ 30	0.077**	0.02, 0.13			0.048	-0.039, 0.14	0.058	-0.030, 0.14	-0.01**	-0.016, -0.001
Model 5	Playgrounds/sports fields within 800-m†										
	≤ 1 (Ref.)	Ref.		-0.34***	-0.28, -0.41	Ref.		Ref.		Ref.	
	2-5	0.09**	0.02, 0.15			0.031*	0.005, 0.06	0.037**	0.009, 0.07	-0.005**	-0.009, -0.001
	6-10	0.09**	0.03, 0.16			0.063*	0.011, 0.12	0.073*	0.021, 0.13	-0.010***	-0.016, -0.01
	≥ 11	0.14***	0.09, 0.20			0.095*	0.010, 0.18	0.110*	0.025, 0.20	-0.015***	-0.020, -0.01
Model 6	Playgrounds/sports fields within 5 000-m†										
	≤ 35 (Ref.)	Ref.		-0.34***	-0.28, -0.41			Ref.		Ref.	
	36-119	-0.04	-0.09, 0.01			0.041**	0.013, 0.07	NE		NE	
	120-419	0.05	-0.004, 0.10			0.090***	0.031, 0.14	NE		NE	
	≥ 420	0.08*	0.02, 0.13			0.122*	0.031, 0.21	0.133**	0.041, 0.22	-0.011**	-0.018, -0.001
Model 7	School within 800-m										
	No (ref.)	Ref.		-0.34***	-0.28, -0.41			Ref.		Ref.	
	Yes	0.06	-0.001, 0.14			0.017	-0.055, 0.09	NE		NE	
Model 8	School within 5 000-m										
	No (ref.)	Ref.		-0.34***	-0.28, -0.41						
	Yes	0.09*	0.012, 0.18			0.052	-0.034, 0.14	0.059	-0.03, 0.14	-0.007	-0.014, -0.001
Model 9	Population density within 800-m†										
	≤ 200 (Ref.)	Ref.		-0.34***	-0.28, -0.41	Ref.		Ref.		Ref.	
	210-799	0.08**	0.03, 0.13			0.048**	0.015, 0.08	0.052**	0.020, 0.08	-0.004*	-0.009, -0.001
	800-1649	0.14***	0.08, 0.19			0.093**	0.029, 0.15	0.102**	0.039, 0.16	-0.009***	-0.015, -0.001
	≥ 1650	0.11***	0.05, 0.16			0.143**	0.057, 0.23	0.156**	0.070, 0.24	-0.013***	-0.020, -0.01

Abbreviations: NE, not estimated due to non-significance on either Path A or Path B.

[a] Estimates are adjusted for child's gender, mother's age and level of education, hours spent on watching TV, hours spent on other screen-based activities, after-school care and population density, with a few exceptions due to multicollinearity between the exposure of interest and population density. The models in which population density have been omitted are indicated with †.

[b] Associations between the built environment exposure and the potential mediators.

[c] Associations between the potential mediators and mood and feelings.

[d] Associations between the built environment exposure and mood and feelings.

[e] Associations between the built environment exposure and mood and feelings, adjusted for the potential mediator investigated.

[f] Associations between the built environment exposure and mood and feelings, through the potential mediator investigated.

*p<0.05, **p<0.01, ***p<0.001

Table 5. Pathway, direct and indirect estimates for participating social activities with friends as a mediator in the relations between the built environment and mood and feelings (SMFQ) among 21 019 Norwegian 8-year-olds[a].

	Built environment exposures	Path A[b]		Path B[c]		Path C[d] (total effect)		Direct effect[e]		Indirect effect[f]	
		β	95% CI	β	95% CI	β	95% CI	β	95% CI	β	95% CI
		Social activities		Mood and feelings		Mood and feelings		Mood and feelings		Mood and feelings	
Model 10	Park within 5 000-m										
	No (Ref.)	Ref.		-0.55***	-0.46, -0.63	Ref.		Ref.		Ref.	
	Yes	0.22***	0.12, 0.31			-0.030	-0.111, 0.05	-0.014	-0.09, 0.06	-0.016***	-0.024, -0.01
Model 11	Facilities within 5 000-m†										
	≤ 5 (Ref.)	Ref.		-0.55***	-0.46, -0.63	Ref.		Ref.		Ref.	
	6-14	0.19***	0.13, 0.25			0.015	-0.014, 0.04	0.026	-0.003, 0.05	-0.011***	-0.017, -0.01
	15-29	0.26***	0.20, 0.32			0.032	-0.026, 0.09	0.052	-0.004, 0.11	-0.021***	-0.029, -0.01
	≥ 30	0.23***	0.17, 0.29			0.047	-0.035, 0.13	0.077	-0.009, 0.16	-0.030***	-0.041, -0.02
Model 12	Playgrounds/sports fields within 800-m†										
	≤ 1 (Ref.)	Ref.		-0.55***	-0.46, -0.63	Ref.		Ref.		Ref.	
	2-5	0.59***	0.52, 0.66			0.027	-0.002, 0.05	0.055***	0.026, 0.08	-0.028***	-0.035, -0.02
	6-10	0.61***	0.54, 0.68			0.057*	0.002, 0.11	0.108***	0.053, 0.16	-0.051***	-0.064, -0.04
	≥ 11	0.62***	0.56, 0.67			0.092*	0.013, 0.17	0.164***	0.082, 0.24	-0.072***	-0.086, -0.06
Model 13	Playgrounds/sports fields within 5 000-m†										
	≤ 35 (Ref.)	Ref.		-0.55***	-0.46, -0.63	Ref.		Ref.		Ref.	
	36-119	0.32***	0.26, 0.38			0.040**	0.012, 0.07	0.055***	0.027, 0.08	-0.015***	-0.021, -0.01
	120-419	0.35***	0.29, 0.40			0.081**	0.023, 0.14	0.110***	0.053, 0.17	-0.029***	-0.037, -0.02
	≥ 420	0.32***	0.26, 0.38			0.123**	0.040, 0.20	0.164***	0.078, 0.25	-0.041***	-0.053, -0.03
Model 14	School within 5 000-m										
	No (ref.)	Ref.		-0.55***	-0.46, -0.63	Ref.		Ref.		Ref.	
	Yes	0.29***	0.19, 0.39			0.052	-0.033, 0.13	0.074	-0.009, 0.15	-0.022***	-0.033, -0.01
Model 15	Population density within 800-m†										
	≤ 200 (Ref.)	Ref.		-0.55***	-0.46, -0.63			Ref.		Ref.	
	210-799	0.53***	0.47, 0.59			0.045**	0.016, 0.07	0.064**	0.034, 0.09	-0.019***	-0.026, -0.01
	800-1649	0.53***	0.47, 0.59			0.093***	0.034, 0.15	0.128***	0.071, 0.19	-0.035***	-0.046, -0.03
	≥ 1650	0.42***	0.36, 0.48			0.141**	0.051, 0.23	0.191***	0.100, 0.28	-0.050***	-0.064, -0.04

Abbreviations: NE, not estimated due to non-significance on either Path A or Path B.
[a] Estimates are adjusted for child's gender, mother's age and level of education, hours spent on watching TV, hours spent on other screen-based activities, after-school care and population density, with a few exceptions due to multicollinearity between the exposure of interest and population density. The models in which population density have been omitted are indicated with †.
[b] Associations between the built environment exposure and the potential mediators.
[c] Associations between the potential mediators and mood and feelings.
[d] Associations between the built environment exposure and mood and feelings.
[e] Associations between the built environment exposure and mood and feelings, adjusted for the potential mediator investigated.
[f] Associations between the built environment exposure and mood and feelings, through the potential mediator investigated.
*p<0.05, **p<0.01, ***p<0.001

Discussion

This study investigated the direct and mediating pathways between certain built environment characteristics and the subjective well-being of Norwegian 8-year-olds. Unexpectedly, we found that having a park and more playgrounds/sports fields in the neighborhood were related to more depressive moods and feelings when analyzing direct associations. Also living in more densely populated areas was adversely related to children's subjective well-being. However, participating in leisure-time PA, organized activities and social activity with friends operated as mediators and diluted some of the negative associations observed between these built characteristics and the 8-year-olds' well-being. Additionally, positive indirect associations were revealed between total green space in the neighborhood area, as well as access to a park, more facilities within 5,000-m of the home and children's moods and feelings through greater involvement in organized and social activities.

There seems to be limited evidence on whether and how facilities and population density relate to children's subjective well-being (Clark et al., 2007; Nordbø et al., 2019a). As such, we contribute to addressing this research gap by revealing that children who lived in more densely populated areas were more likely to report poorer moods and feelings than those who lived in low-density neighborhoods. This finding mirrors previous results among adults showing that less densely populated areas promoted better quality of life (Cramer et al., 2004), whereas high-density areas were related to more psychological distress (Clark et al., 2007). Research across the European Union has also shown that residents of rural settlements have higher life satisfaction than dwellers in more urban areas (Sørensen, 2014).

Studies have repeatedly shown that neighborhood green space is beneficial for well-being, and it has been linked to less behavioral problems in childhood (Amoly et al., 2014; Feng and Astell-Burt, 2017). In addition, outdoor life in green space has a strong position in Norwegians' everyday life (Calogiuri et al., 2016; Dervo et al., 2014), which led us to expect a positive relationship between access to green space and subjective well-being among children in this present study. Contrary to this, we found that having a park within the neighborhood was negative for the moods and feelings of Norwegian 8-year-olds. Our findings concur with a recent review reporting no clear evidence of enhanced emotional well-being with increased exposure to green space among children (Tillmann et al., 2018). Also Duncan et al. (2013) reported that the built environment minimally influenced depressive symptoms in youths, but in some ethnic groups, a higher density of parks within 800-m of the home increased levels of depressive moods and feelings. The children in our sample were only 8-years old. At this age, children often begin to explore new territory, such as the neighborhood surroundings, more independently (Ames and Haber, 2012). We speculate that this might provoke overwhelming experiences and unpredictable situations that could potentially arouse stress in younger children. Nevertheless, we focused on the positive factors that may contribute to nurturing well-being and any presumed negative stress-related pathways were not considered in this study. Further, unmeasured area-level influences, such as low neighborhood safety and poor aesthetic conditions (e.g., presence of garbage, litter and vandalism), which have been linked to more behavioral and mental health problems among children (Butler et al., 2012; Singh and Ghandour, 2012), may have confounded our results. This could explain the negative associations observed between certain built environment characteristics and children's emotional state.

Studies in adults suggest that neighborhood physical features in themselves do not promote health, but rather health is strengthened through active engagement with available neighborhood resources (Maass et al., 2017). This indicates why it is important to make efforts to unveil how the built environment relates to children's well-being. Investigating mediating pathways, as we did in the present study, is essential in that respect. Importantly, we discovered that the built environment characteristics were positively related to participation in well-being enhancing leisure activities among the Norwegian 8-year-olds. To some extent, the indirect pathways counteracted the adverse associations that were identified between the built environment (i.e., access to a park, more playgrounds/sport fields and higher population density) and children's moods and feelings. No overall associations were observed between total green space (800-m), facilities, parks or schools (5,000-m) and moods and feelings. However, all these characteristics were indirectly linked to less depressive moods and feelings by supporting participation in organized and social activities among the 8-year-olds. The above findings reinforce the notion that providing venues that can facilitate engagement in leisure activities could be vital because participating in such activities potentially plays a health-promoting role when children are faced with the neighborhood's built environment.

The present study provides interesting findings on the built environment determinants of younger children's well-being. We found statistically significant total, direct and indirect relations between several built environment characteristics and children's well-being; however, the magnitude of the estimated effect measures (i.e., changes in the total moods and feelings score) were very small. One explanation for this might be that the children in our sample reported few depressive moods and feelings and seemed very happy in general. As a human being, it is common to experience negative moods and feelings from time to time, and 24% of Norwegian sixth graders have reported feeling depressed at least once every month for the past six months (Samdal et al., 2016). However, this does not seem to have any far-reaching consequences, and national statistics indicate that children in Norway are healthy (Norwegian Institute of Public Health, 2018). Thus, the small differences observed across the exposure categories may have less political value and practical use. Lastly, many determinants act together through a dynamic interplay to influence the health and well-being of younger children (Bronfenbrenner, 1979; Dahlgren and Whitehead, 1991). Of all the modifiable determinants, parental income, employment and health, schooling and a child's own health status have been identified as strong determinants of emotional well-being in childhood (Helliwell et al., 2017). Equally, there is strong evidence that income inequality and access to education are the strongest determinants of well-being among adolescents (Viner et al., 2012). These other determinants should be accounted for as an explanation for the relatively marginal estimated effect measures. Sellström and Bremberg (2006) have tried to clarify the importance of neighborhood contextual factors for health and well-being in childhood and adolescence. They showed that individual, social and environmental determinants together explained 75-90% of the variation in certain outcomes, of which the neighborhood contextual factors contributed to explaining up to 10%, after controlling for other characteristics. Likely, the role of the built environment alone and through promoting participation in leisure activities simply represents a small fraction of a complete picture. Thus, larger estimates for built environment determinants may not be expected in this group of more privileged children in Norway.

However, regardless of the small estimates, our results indicate that participating in leisure activities represents an intermediate resource for children in the pathway between the built environment and well-being. Such resources might play an even more important role in relations between the built environment and well-being of children in more disadvantaged groups. Whether the mechanisms vary by socioeconomic status and other characteristics of a child (e.g., personality traits) should be explored in future studies. Such studies may also benefit from examining more complex models than we did. Additionally, it would be essential to examine the mechanisms using a more place-based and context-sensitive strategy that could open up for considering more local factors than this large-scale study was able to. This may help clarify the relationship between the built environment and children's subjective well-being in detail.

Strengths and limitations

The study strengths include the large sample of children from across Norway and the utilization of GIS measures to assess the built environment around each child's residence. The latter eliminated the risk of single source bias. Despite ongoing debates on how to define the geographic areas and determinants of interest, we selected and operationalized the built environment based on previous methodological research considering GIS measures applied to children and adolescents (Nordbø et al., 2018). Additionally, we contribute to the evidence by applying a novel statistical method to estimate the direct and indirect relations in formal mediation analyses.

Limitations of this study relate to the completeness and accuracy of the geographic data from the Norwegian Mapping Authority. There is also uncertainty in the exposure data, as we utilized pre-defined buffer zones to delineate the geographic areas. Both these issues increased the likelihood of measurement errors. However, we made efforts to reduce the risk of error by excluding children living in post-separation families. The cross-sectional data impeded us from determining the temporality of the observed associations, and thus, we cannot infer causality. Further, the children took part in the 8-year follow-up between 2011 and 2015, while the GIS-derived exposures were calculated based on geographical data from 2016 to January 2017. The built environment might have changed since the children participated in the follow-up, but large infrastructural deviations between 2011 and 2016 is less likely (Duncan et al., 2011). Further, the risk of error was expected to be limited for children followed-up on in 2014 and 2015. We also made assumptions regarding which confounding variables to include in the models. If these assumptions were violated, unmeasured confounding could bias our results (VanderWeele, 2016). It is likely that bias resulted from unmeasured factors (e.g., parental preference for green space) that influence both where families with younger children decide to live as well as the mediators and well-being indicator examined herein. This is typically referred to as residential self-selection bias (Boone-Heinonen et al., 2010), and our estimates are vulnerable to such bias. Thus, the assumption of no unmeasured confounding may not hold. Additionally, children of older and higher-educated mothers were more likely to be included in the analyses. This increased the risk of selection bias even more. However, we identified and adjusted for important variables on all paths in the mediation analyses. Lastly, there are multiple mechanisms by which the built environment might influence children's well-being. Relations and mechanisms likely vary across cultures and between populations and population subgroups. These results specifically apply to a group of more privileged 8-year-olds in Norway, and our findings may not be widely generalizable to other groups. However, considering the broad scope of research that has revealed positive associations between the built environment and children's engagement in activities across the world (Christian et al., 2015; D'Haese et al., 2015; Ding et al., 2011; Nordbø et al., 2019a), it is reasonable to assume that the indirect mechanisms identified herein are applicable outside this study's context.

Conclusion and implications

This population-based study from Norway represents one of few initial efforts to examine whether and how the built environment relates to the well-being of children. While the estimated effect measures were small in magnitude, our findings make an important contribution to knowledge on the built environment as a determinant of children's subjective well-being. The built environment seemed to be simultaneously unfavorable and beneficial for children's well-being. Population density, green space and facilities, such as playgrounds/sports fields and school, were not resources for the well-being of Norwegian 8-year-olds in themselves. However, they appeared to be assets for well-being enhancing participation in leisure-time PA, organized activities and social activity with friends, which counterbalanced some of the negative associations observed. Additional research is needed to understand these relations deeply. However, these initial results should direct the attention of policy makers and planners toward safeguarding children have neighborhood resources and venues that could support engagement in a variety of leisure activities that add positive experiences for their subjective well-being.

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Declarations of interest

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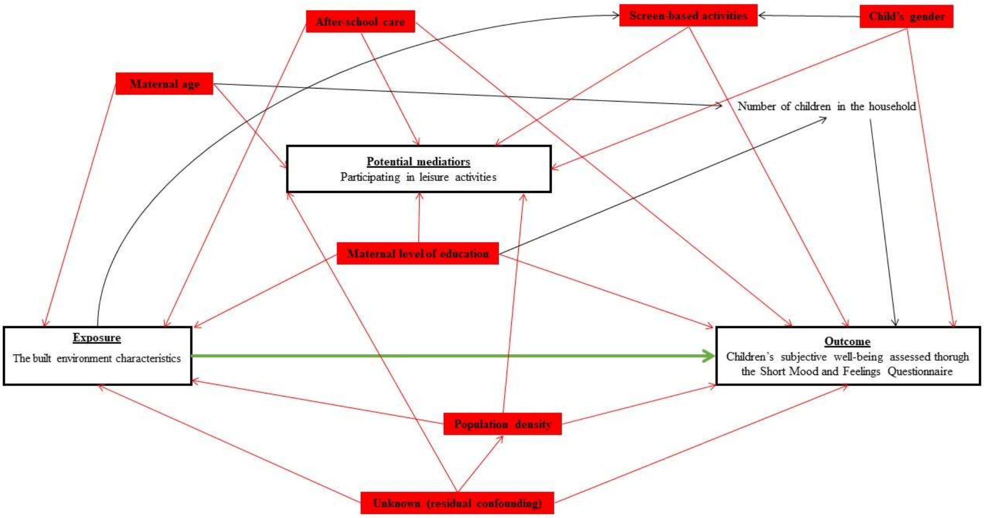
Appendix A



Note: The read arrows and boxes represent confounded paths and the related confounding variables. The black arrows are unconfounded paths. To estimate the total, direct and indirect associations between the built environment and children's subjective well-being minimal sufficient adjustment were identified to include the following confounders: child's gender, screen-based activities, after-school care, maternal age and level of education and population density.

Figure S1. Directed acyclic graph illustrating the links between the exposures, potential mediators, well-being indicator and all the covariates.

Appendices

Region:	Saksbehandler:	Telefon:	Vår dato:	Vår referanse:
REK sør-øst	Gjøril Bergva	22845529	18.03.2016	2016/84 REK sør-øst D
			Deres dato:	**Deres referanse:**
			12.01.2016	

Vår referanse må oppgis ved alle henvendelser

Geir Aamodt

Norges miljø og biovitenskapelige universitet

2016/84 Helsefremmende nærmiljø for barn

Vi viser til søknad om forhåndsgodkjenning av ovennevnte forskningsprosjekt. Søknaden ble behandlet av Regional komité for medisinsk og helsefaglig forskningsetikk (REK sør-øst D) i møtet 17.02.2016. Vurderingen er gjort med hjemmel i helseforskningsloven § 10, jf. forskningsetikkloven § 4.

Forskningsansvarlig: Norges miljø og biovitenskapelige universitet
Prosjektleder: Geir Aamodt

Prosjektleders prosjektbeskrivelse
Sammenhenger mellom nærmiljø, deltakelse i aktiviteter og velvære blant barn er ikke godt forstått. Hovedmålet med prosjektet er å undersøke hva som karakteriserer et helsefremmende nærmiljø for barn. De spesifikke forskningsmålene er (1) kartlegge barns favoritt- og negative steder og utforske deres arealbruk; (2) studere sammenhenger mellom velvære, deltakelse i aktivitet, avstand til favoritt- og negative steder samt nærmiljøets grøntegenskaper; og (3) teste en modell for mekanismer for hvordan barns nærmiljø og aktiviteter kan være helsefremmende. Prosjektet har et eksplorativt, observasjonelt design. Det skal gjennomføres en kartleggingsstudie og to epidemiologiske tverrsnittstudier. Data hentes fra Digital Barnetråkk og Den norske mor og barn-undersøkelsen (MoBa). Barnetråkk-data skal kobles til arealbrukskart og kommunedata, og analyser skal utføres ved hjelp av geografiske informasjonssystemer (GIS). MoBa-data skal geokodes og kobles til Barnetråkk-dataene.

Vurdering
Hovedmålet med prosjektet er å undersøke hva som karakteriserer et helsefremmende nærmiljø for barn. De spesifikke forskningsmålene er: (1) kartlegge barns favoritt- og negative steder og utforske deres arealbruk; (2) studere sammenhenger mellom velvære, deltakelse i aktivitet, avstand til favoritt- og negative steder samt nærmiljøets grøntegenskaper; og (3) teste en modell for mekanismer for hvordan barns nærmiljø og aktiviteter kan være helsefremmende.

Komiteen vurderer at prosjektet, slik det er presentert i søknad og protokoll, ikke vil gi ny kunnskap om helse og sykdom som sådan. Prosjektet faller derfor utenfor REKs mandat etter helseforskningsloven, som forutsetter at formålet med prosjektet er å skaffe til veie "ny kunnskap om helse og sykdom", se lovens § 2 og § 4 bokstav a).

Det kreves ikke godkjenning fra REK for å gjennomføre prosjektet. Det er institusjonens ansvar å sørge for at prosjektet gjennomføres på en forsvarlig måte med hensyn til for eksempel regler for taushetsplikt og personvern samt innhenting av stedlige godkjenninger.

Vedtak
Prosjektet faller utenfor helseforskningslovens virkeområde, jf. § 2 og § 4 bokstav a). Det kreves ikke

godkjenning fra REK for å gjennomføre prosjektet.

Klageadgang
REKs vedtak kan påklages, jf. forvaltningslovens § 28 flg. Klagen sendes til REK sør-øst D. Klagefristen er tre uker fra du mottar dette brevet. Dersom vedtaket opprettholdes av REK sør-øst D, sendes klagen videre til Den nasjonale forskningsetiske komité for medisin og helsefag for endelig vurdering.

Vi ber om at alle henvendelser sendes inn med korrekt skjema via vår saksportal: http://helseforskning.etikkom.no. Dersom det ikke finnes passende skjema kan henvendelsen rettes på e-post til: post@helseforskning.etikkom.no.

Vennligst oppgi vårt referansenummer i korrespondansen.

Med vennlig hilsen

Finn Wisløff
Professor em. dr. med.
Leder

Gjøril Bergva
Rådgiver

Kopi til: inger-lise.saglie@nmbu.no
Norges miljø- og biovitenskapelige universitet ved øverste administrative ledelse: post@nmbu.no

Emma Charlott Andersson Nordbø
Institutt for landskapsplanlegging Norges miljø- og biovitenskapelige universitet

1430 ÅS

Vår dato: 17.08.2016	Vår ref: 48426 / 3 / AMS	Deres dato:	Deres ref:

TILBAKEMELDING PÅ MELDING OM BEHANDLING AV PERSONOPPLYSNINGER

Vi viser til melding om behandling av personopplysninger, mottatt 20.04.2016. Meldingen gjelder prosjektet:

48426	*Characteristics of a health promoting childhood environment*
Behandlingsansvarlig	*Norges miljø- og biovitenskapelige universitet, ved institusjonens øverste leder*
Daglig ansvarlig	*Emma Charlott Andersson Nordbø*

Personvernombudet har vurdert prosjektet, og finner at behandlingen av personopplysninger vil være regulert av § 7-27 i personopplysningsforskriften. Personvernombudet tilrår at prosjektet gjennomføres.

Personvernombudets tilråding forutsetter at prosjektet gjennomføres i tråd med opplysningene gitt i meldeskjemaet, korrespondanse med ombudet, ombudets kommentarer samt personopplysningsloven og helseregisterloven med forskrifter. Behandlingen av personopplysninger kan settes i gang.

Det gjøres oppmerksom på at det skal gis ny melding dersom behandlingen endres i forhold til de opplysninger som ligger til grunn for personvernombudets vurdering. Endringsmeldinger gis via et eget skjema, http://www.nsd.uib.no/personvern/meldeplikt/skjema.html. Det skal også gis melding etter tre år dersom prosjektet fortsatt pågår. Meldinger skal skje skriftlig til ombudet.

Personvernombudet har lagt ut opplysninger om prosjektet i en offentlig database, http://pvo.nsd.no/prosjekt.

Personvernombudet vil ved prosjektets avslutning, 31.08.2025, rette en henvendelse angående status for behandlingen av personopplysninger.

Vennlig hilsen

Kjersti Haugstvedt

Anne-Mette Somby

Kontaktperson: Anne-Mette Somby tlf: 55 58 24 10
Vedlegg: Prosjektvurdering

Dokumentet er elektronisk produsert og godkjent ved NSDs rutiner for elektronisk godkjenning.

Personvernombudet for forskning

Prosjektvurdering - Kommentar

Prosjektnr: 48426

FORMÅL
Hovedmålet med dette doktorgradsprosjektet er å undersøke hva som karakteriserer et helsefremmende nærmiljø for barn. De spesifikke forskningsmålene er (1) å kartlegge fysiske miljøegenskaper for steder i nærmiljøet som barn benytter til aktivitetsformål (2) studere sammenhenger mellom velvære, deltakelse i aktivitet og bestemte fysiske miljøegenskaper i barnas nærmiljø, og (3) teste en modell for mekanismer for hvordan ulike fysiske miljøegenskaper kan være helsefremmende ved å påvirke deltakelse i aktivitet og velvære.

UTVALG
Dette prosjektet har to ulike utvalg. Forskningsmål 1 inkluderer et utvalg av 5. og 6. klassinger fra skoler i 32 ulike kommuner i Norge, som deltar i digital Barnetråkk. Det skal ikke innhentes noen personopplysninger om disse elevene. I og med at det ikke innhentes personopplysninger vurderer vi at denne delen av datamaterialet ikke omfattes av melde- eller konsesjonsplikten,

For å besvare forskningsmål 2 og 3 tar prosjektet utgangspunkt i et utvalg barn fra Den norske mor og barn-undersøkelsen (MoBa). Opplysningene fra MoBa leveres avidentifisert til prosjektet. Denne delen kan unntas fra konsesjonsplikten jf. personopplysningsforskriften § 7-27.

KOPLING TIL GIS
Datamaterialet i MoBa skal koples til geokoder og til sosioøkonomisk og demografiske data fra Statistisk sentralbyrå (SSB). SSB gjennomfører koplingen. I forbindelse med saksbehandlingen har personvernombudet vært i kontakt med Folkehelseinstituttet for å avklare kopling mot geokoder. Tilbakemeldingen fra Kristine Vejrup mottatt 01.07.16 bekrefter at en slik kopling er mulig innenfor rammene av samtykket som er gitt i MoBa, og at dette er gjort tidligere. Personvernombudet har derfor lagt til grunn at koplingene mellom data fra MoBa til geokoder og andre data i SSB ikke er i strid med interne bestemmelser i Folkehelseinstituttet eller konsesjonsvilkår for MoBa.

VURDERING AV HJEMMELSGRUNNLAG
Det ligger til grunn for vår vurdering at opplysningene er avidentifiserte (anonyme for forsker) og at det ikke inngår bakgrunnsopplysninger som kan identifisere enkeltpersoner. Vi har forstått det slik at geokodene ikke vil gi opplysninger om den registrertes tilknytning til kommune eller fylke, og at andre bakgrunnsvariabler skal kategoriseres slik at bakveisidentifikasjon ikke er mulig. Koblingsnøkkel er kun tilgjengelig for SSB.

PROSJEKTSLUTT
Forventet prosjektslutt er 31.08.2025. Ifølge prosjektmeldingen skal innsamlede opplysninger da slettes.

Geir Aamodt
Institutt for landskapsplanlegging
Norges miljø- og biovitenskapelige universitet
1430 Ås

Vår dato: 13.10.2016 Vår ref: 48426/6/AMS/LR Deres dato: Deres ref:

FORSKNINGSPROSJEKT UNNTATT KONSESJONSPLIKT - § 7-27

Vi har mottatt meldeskjema for prosjektet;

Nummer	*48426*
Behandlingsansvarlig	*Norges miljø- og biovitenskapelige universitet, ved institusjonens øverste leder*
Daglig ansvarlig	*Geir Aamodt*
Stipendiat	*Emma Charlott Andersson Norbø*

Personvernombudet har vurdert meldingen og finner at prosjektet kan unntas konsesjonsplikt jf. personopplysningsforskriften § 7-27. Vi viser til vår tilrådning datert 17.08.2016.

Vi mottok en e-post fra prosjektmedarbeider Emma Charlott Nordbø 15.09.2016 med kopi av svar fra SSB sendt samme dag. Vi forstår av SSB sin e-post at søknaden må presiseres og endres på noen punkter:

1. Daglig ansvarlig må endres fra Emma Charlott Andersson Norbø til Geir Aamodt. Denne endringen er bekreftet i egen e-post fra oss 21.09.2016.

2. SSB ber om at vi gjør en selvstendig vurdering av samtykket i MoBa:

   Personvernombudet har bare tilgang til deler av dokumentasjonen til MoBa. Folkehelseinstituttet er registereier og har allerede godkjent utlevering av datamaterialet til prosjektet, noe som er vektlagt i vår tilrådning. Selv om registereier har godkjent at utleveringen er lovlig må vi vurdere om mottaker har lov til å behandle opplysningene. Samtykket i MoBa nevner ikke koplingen mot koordinater eksplisitt, derfor er samtykket ikke gyldig i henhold til bestemmelsene i personopplysningsloven § 8 første ledd og 9 a). Vi må derfor vurdere om unntaksbestemmelsene i §§ 8 og 9 kommer til anvendelse.

   Prosjektets formål er beskrevet slik:
   Sammenhenger mellom nærmiljø, deltakelse i aktivitet og velvære blant barn er komplekse og ikke gått forstått. Hovedmålet med dette doktorgradsprosjektet er å undersøke hva som karakteriserer et helsefremmende nærmiljø for barn. De spesifikke forskningsmålene er (1) å kartlegge fysiske

miljøegenskaper for steder i nærmiljøet som barn benytter til aktivitetsformål (2) studere sammenhenger mellom velvære, deltakelse i aktivitet og bestemte fysiske miljøegenskaper i barnas nærmiljø, og (3) teste en modell for mekanismer for hvordan ulike fysiske miljøegenskaper kan være helsefremmende ved å påvirke deltakelse i aktivitet og velvære.

Prosjektet er en del av en doktorgradsstudie som skal undersøke hva som er helsefremmende nærmiljø for barn. Vi mener at prosjektet som helhet, og denne delstudien, har stor samfunnsnytte. Dette taler for at unntaksbestemmelsen kan anvendes. Samfunnsytten må likevel veies mot en eventuell personvernulempe. I dette delprosjektet er personvernulempen liten så fremt opplysningene som leveres til forsker i liten grad kan identifisere enkeltpersoner i datamaterialet. Vi mener derfor at samfunnsnytten klart overstiger personvernulempen for kopling til GIS og behandling av indirekte personidentifiserende opplysninger.

Vi har i dialog med daglig ansvarlig avklart at det er mulig å informere om prosjektet på nettsidene til Folkehelseinstituttet. Vi forutsetter at det gis konkret informasjon om prosjektet. Det må gis eksplisitt informasjon om at opplysningene i MoBa koples mot GIS på nettsidene til Folkehelseinstituttet.

3. SSB ber om at vi presiserer hvorvidt opplysningene som prosjektet søker om er anonyme eller indirekte personidentifiserende.

   Personvernombudet har i dialog med daglig ansvarlig og prosjektmedarbeider forstått at datamaterialet i liten grad vil kunne bidra til indirekte identifisering. Det er likevel ikke utenkelig at det kan forekomme, og datamaterialet vil derfor kunne karakteriseres som indirekte personidentifiserende. Vi mener likevel at behandlingsgrunnlaget i personopplysningsforskriften kommer til anvendelse fordi det er avidentifisert på en sikker måte ved at det kun er SSB som har koblingsnøkkel.

Dersom det er spørsmål kan dere kontakte saksbehandler Anne-Mette Somby tlf.: 55 58 24 10

Vennlig hilsen

Anne-Mette Somby

Anne-Mette Somby

Statistisk sentralbyrå
Statistics Norway

SSB-ref: 16/1678

Taushetserklæring

Jeg forstår

- at jeg i arbeidet med *«Helsefremmende nærmiljø for barn»* vil kunne få kjennskap til opplysninger som av hensyn til offentlige, enkeltpersoners, institusjoners eller bedrifters interesser, ikke må bli kjent for uvedkommende
- at statistikklovens bestemmelse om taushetsplikt § 2-4 gjelder for de opplysninger jeg får tilgang til utlevert fra Statistisk sentralbyrå

Jeg forplikter meg til

- å vise aktsomhet i behandlingen av alle opplysninger som er utlevert fra Statistisk sentralbyrå og arbeide i samsvar med retningslinjer og instrukser gitt av Statistisk sentralbyrå og Datatilsynet.
- ikke å gi opplysninger videre til noen personer i eller utenfor Norges miljø- og biovitenskapelige universitet.

Jeg er klar over

- at brudd på taushetsplikten og misbruk av informasjon jeg får kunnskap om, for meg selv eller andre, kan medføre straffansvar
- at taushetsplikten også gjelder etter at mitt arbeid tilknyttet Norges miljø- og biovitenskapelige universitet er avsluttet.

Jeg er gjort kjent med og har forstått

- Statistikkloven § 2-4. Taushetsplikt.

  (1) De som utfører arbeid eller tjeneste for et organ som forbereder eller utarbeider offisiell statistikk, plikter å hindre at uvedkommende får adgang eller kjennskap til det de under forberedelsen eller utarbeidelsen av en statistikk får vite om personlige forhold, drifts- eller forretningsforhold, eller tekniske innretninger og fremgangsmåter. Taushetsplikten gjelder bare de opplysninger som er hentet inn med sikte på utarbeidelse av offisiell statistikk.

  (2) Taushetsplikten gjelder også etter at vedkommende har avsluttet arbeidet eller tjenesten. Vedkommende kan heller ikke utnytte opplysninger som nevnt i denne paragraf i egen virksomhet eller i arbeid eller tjeneste for andre.

  (3) Forvaltningsloven § 13 til § 13e kommer ikke til anvendelse.

- Straffeloven § 121

  Den som forsettlig eller grovt uaktsomt krenker taushetsplikt som i henhold til lovbestemmelse eller gyldig instruks følger av hans tjeneste eller arbeid for statlig eller kommunalt organ, straffes med bøter eller med fengsel inntil 6 måneder.

  Begår han taushetsbrudd i den hensikt å tilvende seg eller andre en uberettiget vinning eller utnytter han i slik hensikt på annen måte opplysninger som er belagt med taushetsplikt, kan fengsel inntil 3 år anvendes.

  Denne bestemmelse rammer også taushetsbrudd m.m. etter at vedkommende har avsluttet tjenesten eller arbeidet.

Denne taushetserklæring er undertegnet i to eksemplarer, hvorav underskriver og SSB beholder hver sitt eksemplar.

Ås, 13/2-2017 — Emma Charlott A. Nordbø

Sted/dato — Signatur

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