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Children's access to urban greenspace: a survey of factors and measures

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ABSTRACT

Access to greenspace impacts children's physical, social, and mental health. Numerous factors affect children's access to urban greenspaces, often distinct from those affecting the general population, including parental restrictions, limited routine activity-space, and particular preferences. Most accessibility measures, however, employ the same principles for children and the general population, and a comprehensive exploration of factors and corresponding measures remains lacking. We conduct a scoping review and workshops with researchers and practitioners to identify factors affecting children's access to greenspace, synthesize them into a conceptual model, and assess how existing accessibility measures address these factors. We focus on children aged 6–11 years old. Our analysis indicates children's access involves a trade-off between reachability, determined by the route connecting the child's starting setting to greenspace, and attractiveness, determined by how the greenspaces adhere to the child's, and their companions', preferences and motivations for visiting. Safety perceptions are important throughout. Existing accessibility measures predominantly emphasize reachability, neglecting personal characteristics and motivations. Based on our findings, we propose future directions for developing child-centered accessibility metrics. Our overview of metrics can facilitate decision-making in the selection of suitable measures, while our conceptual model can foster shared understanding of factors affecting children's access to urban greenspace.

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Children; urban greenspace; accessibility; measurement; conceptual model

Introduction

Greenspaces play a vital role in healthy living environments. Spending time in greenspace can improve children's attention, reduce stress, and combat childhood obesity (McCurdy *et al.* 2010), and improve mental health (Almanza *et al.* 2012, Perez-Del-Pulgar *et al.* 2021). Greenspaces provide opportunities for children to engage in physical activity and socialize with their peers (Talal and Santelmann 2021). Additionally, traversing greenspace on a daily basis has been associated with school children's cognitive development (Dadvand *et al.* 2015).

Access is a primary driver of using greenspace (Talal and Santelmann 2021, Zhang *et al.* 2021). However, ensuring children's access to greenspaces is not trivial, and literature indicates the factors at play are not the same as factors affecting access by adults. Instead, children's routine activity-space is strongly bound to locations near their home, school, and homes of friends and family (Chambers *et al.* 2017, Hand *et al.* 2018, Qiu and Zhu 2021). Additionally, parents or other caretakers may impose rules on children, determining where children are allowed to go, given physical and social safety concerns relating, for instance, to traffic danger (Carver *et al.* 2008, Amiour *et al.* 2022, Truong *et al.* 2022) or incidents involving strangers (Veitch *et al.* 2006, Carver *et al.* 2008, Qiu and Zhu 2021, Truong *et al.* 2022). As a result, children often remain dependent on adults to accompany them on outdoor trips, including visits to greenspace (Veitch *et al.* 2006, 2007, Truong *et al.* 2023). Furthermore, children have their own fears and preferences when visiting greenspaces, such as fear of injury (Finney and Atkinson 2020), value of nature for play (Veitch *et al.* 2007, Sundevall and Jansson 2020), the wish to interact with peers (Sundevall and Jansson 2020) without parental supervision (Finney and Atkinson 2020, Qiu and Zhu 2021), or the wish for diverse and challenging play opportunities (Finney and Atkinson 2020, Qiu and Zhu 2021).

Methods for measuring children's access to urban greenspace can help in understanding the links between greenspace and children's health and well-being (Nieuwenhuijsen *et al.* 2017, Larkin and Hystad 2019), yet two issues remain. First, existing accessibility metrics often employ the same principles for both children and the general population, ignoring factors such as parental restrictions and children's preferences, which are important determinants of children's access to greenspace. Instead, these metrics predominantly capture the mere presence of

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greenspace in a given environment (Flouri *et al.* 2014, Engemann *et al.* 2021, Winnicki *et al.* 2022) or the distance to the nearest greenspace (Markevych *et al.* 2014). Second, the lack of a comprehensive assessment of factors influencing children's access to urban greenspace highlights the limitations of the existing metrics. During an exploratory literature review, we identified one conceptual framework on *planning* greenspaces for and with children (Vidal and Castro Seixas 2022). While this framework regards accessibility as important, and may serve well in urban planning processes, it does not unpack in further detail what it entails for a greenspace to be accessible to children, nor did we identify any other reviews, frameworks, or models that do so. Yet, a comprehensive overview of what determines children's access could provide valuable insight into what factors remain unaccounted for by accessibility measures, support the design of measures that better account for these factors, and help communicate the coverage and limitations of measures available to date.

In this study, we introduce a conceptual model of what factors affect children's access to urban greenspace and present an overview of how these are, or are not, accounted for in accessibility measures implemented in literature. Doing so allows us to identify promising lines for future work on designing measures for children's access to urban greenspace. We collect data from two sources: a scoping review of scientific and policy-making literature identifying factors affecting children's access to urban greenspace, or implementing measures thereof, and generative workshops with researchers and practitioners as participants to elicit their ideas and needs for measures. We then analyze all data and synthesize our findings into two contributions: (1) a conceptual model of factors affecting children's access to greenspace, and (2) an overview of accessibility measures implemented in literature, positioned in relation to these factors and participants' needs. We scope to access by children in so-called middle childhood (Cohen Hubal *et al.* 2014), i.e. roughly 6- to 11-years old, a phase in which children start to gain *some* freedom from adults (Bell *et al.* 2003), depending on the cultural and geographic context. By positioning existing measures into our conceptual model of factors, we provide insight into promising lines for future development of accessibility measures that account for factors previously uncovered.

In the remainder of this paper, we define key terms and set our scope and detail our approach. Then, we present our two contributions: a conceptual model of factors affecting children's access to urban greenspace, and an overview of how measures implemented in literature account for them. Lastly, we interpret our results and their implications, before concluding with our key findings.

Definitions and scope

Before delving into how we conduct our data collection and analysis, we define key terminology and set the scope of our study.

The definition of *greenspace* varies per discipline and study. Generally, two types of definitions can be distinguished, referring to either an overarching concept of nature (and thus an antonym to urbanization) or to urban vegetation, in interaction with humans (Taylor and Hochuli 2017). We focus on the latter, specifically, urban vegetation open for activities by the general public. The World Health Organization (WHO) defines *urban greenspace* as 'urban space covered by vegetation of any kind' (World Health Organization Regional Office for Europe 2017). We adapt this definition to '*public* urban space *characterized* by vegetation of any kind', including 'smaller green space features (such as street trees and roadside vegetation), and larger green spaces that provide various social and recreational functions (such as parks, playgrounds or greenways)'. Contrary to the WHO definition, however, we exclude 'green spaces not available for public access or recreational use (such as green roofs and facades, or green space on private grounds)'.

Accessibility can be defined as 'the ease of reaching a destination' (Handy and Niemeier 1997), affected by the amount, variety and spatial distribution of potential destinations, the magnitude, quality, and character of activities that can be performed in them, and the travel costs and modality associated to getting there. A multitude of *measures* have been designed to quantify access to greenspace (Zhang *et al.* 2011, Nieuwenhuijsen *et al.* 2017, Wang *et al.* 2021, Liu *et al.* 2023), including measures of straight-line or network distance, or temporal or monetary costs of getting to a greenspace, potentially differentiating between greenspace class, size, and presence of desirable facilities.

Throughout this paper, we focus on *generalizable accessibility measures* quantifying access to greenspace in entire cities, building upon principles that can transcend to other geographical contexts. This means we exclude studies relying on the participation of local populations (e.g. by conducting questionnaires or tracking GPS coordinates) or in-situ field work (e.g. observations or audits). Instead, we scope to approaches that use geographical data, such as land use and land cover data, street networks, satellite imagery, and population data, to model access within a city. Such generalizable measures can serve to study not only if greenspace is needed, but also how much, where, when and of what type (Nieuwenhuijsen *et al.* 2017), to perform large-scale epidemiological studies (Larkin and Hystad 2019), or to assess how equitable access to greenspace is distributed over cities (Iraegui *et al.* 2020, Baró *et al.* 2021).

We scope further down to generalizable accessibility measures *tailored to the children's age group*: We solely consider measures that adapt their design to, or motivate their design choices with respect to, the children's age group. We exclude measures applying the same principles to the children's group as to any other population group without explicitly motivating why the same principles hold for children as well. For instance, we exclude measures quantifying access as the presence of greenspace within a given distance, without explaining why the chosen distance suits for access by children, while we do include measures that apply similar principles, but explicitly motivate their proximity threshold as the distance *that can be traversed by children*, or that motivate chosen greenspaces as *suitable for children* because playing equipment is present.

Lastly, we scope to access by children in so-called *middle childhood* (Cohen Hubal *et al.* 2014), i.e. roughly 6- to 11-years old. In this age group, depending on parental concerns and the cultural and geographical context, children may start to gain their first independence from adults (Bell *et al.* 2003). This choice has further been determined by the European research project this study is part of: Equal-Life (Van Kamp *et al.* 2022).

Methods

In this section, we describe how we collect data, compose a conceptual model of factors, and create an overview of measures in relation to these factors. Figure 1 illustrates our workflow. We follow the conceptual framework analysis methodology by Jabareen (2009) to build our conceptual model. Informed by an initial exploratory literature review, we collect two types of data: first, literature from academia and policy-making practice (Identifying relevant literature), and second, ideas and needs for measures from researchers and practitioners articulated during two workshops (Two generative workshops). Combining knowledge described in literature with knowledge stemming from researchers and practitioners allows us to gain a more holistic understanding of our topic. Using thematic analysis (Clarke and Braun 2013) and visual mapping techniques, we iteratively compose our conceptual model, before applying deductive coding to position measures in relation to the identified factors (Synthesizing findings into a model, and positioning measures against it).

Identifying relevant literature

We perform a scoping review to identify relevant literature from academia and policy-making practice. We structure our review in four phases, following an adaptation of the PRISMA statement (Moher *et al.* 2009) (Figure 2).

Academic literature

We use *Scopus* to identify academic literature: a multidisciplinary database integrating content from various specialized databases (Pranckute 2021). We filter for journal articles and conference papers in English, published no later than October 2023 (i.e. until we conducted our analysis) mentioning in their title, abstract, or keywords 'urban', 'greenspace', 'access', and 'child', or synonyms thereof, as defined based on the authors' best judgment, using in the following Scopus search query:

```
TITLE-ABS-KEY (
(urban* OR "city" OR "cities" OR metropol*) AND
("greenspace" OR "green space") AND
(access* OR reach*) AND
(child* OR "youth" OR "young people" OR "young
person")) AND
(LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO
(DOCTYPE, "cp")) AND
(LIMIT-TO (LANGUAGE, "English"))
```

We then assess the identified literature on eligibility. In line with definitions and scope set in section *Definitions and scope*, we use the following exclusion criteria: (a) the *greenspace* criterion, excluding studies that do not focus at least partly on public urban greenspace (but instead, e.g. hospital gardens, or nature reserves far from cities);

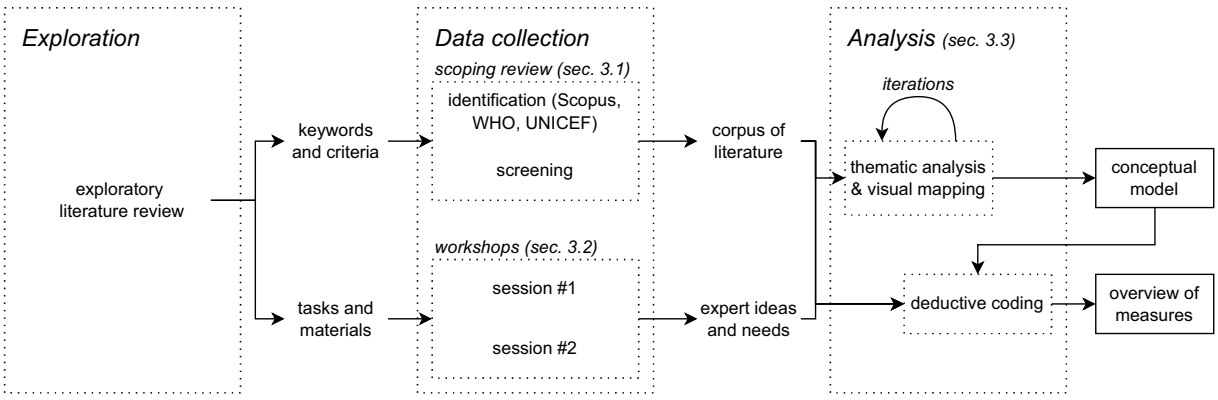

Figure 1. Research workflow: exploratory literature informing review keywords and criteria, and workshop tasks and materials; data collection through scoping review and two workshops; iterative thematic analysis and visual mapping resulting in a conceptual model of factors; and deductive coding resulting in an overview of measures positioned in relation to these factors.

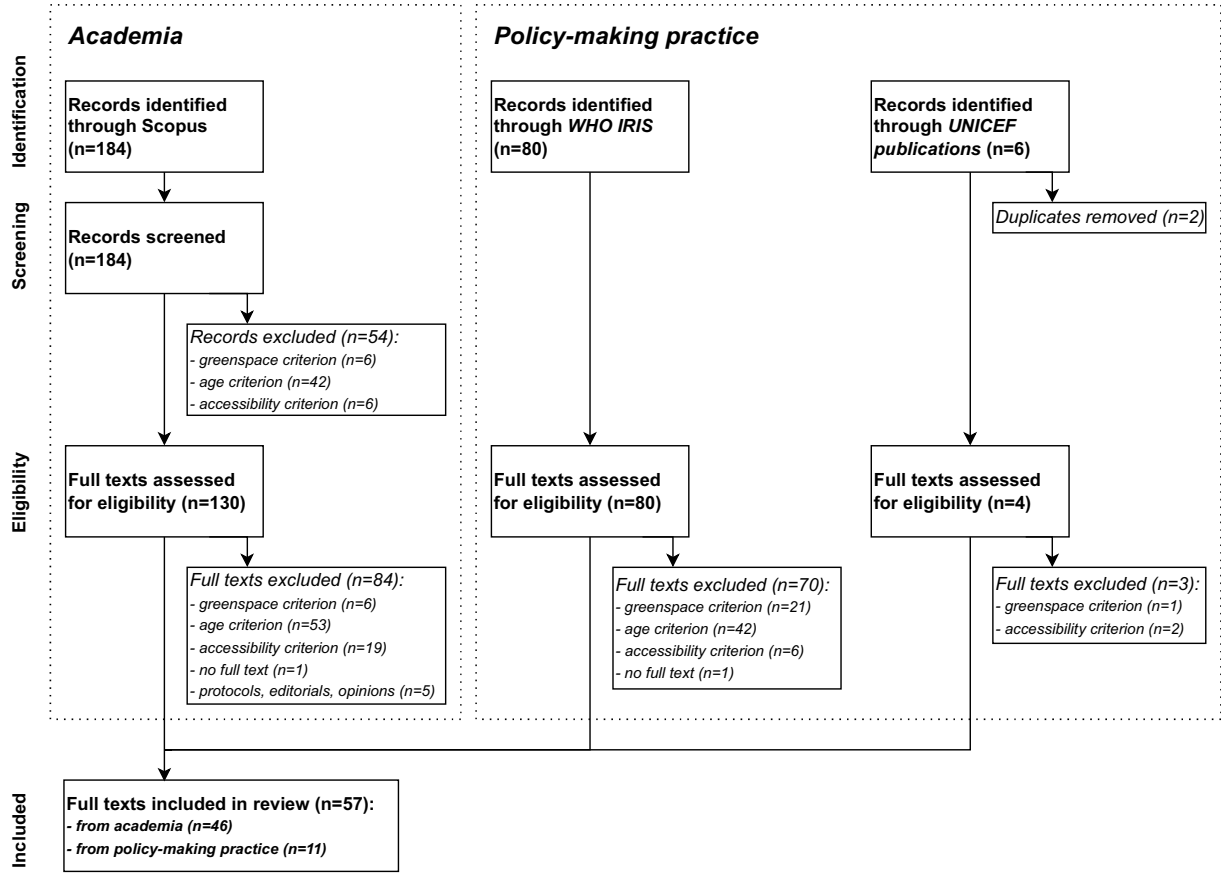

Figure 2. Information flow throughout the phases of the scoping review.

(b) the *age* criterion, excluding studies that do not focus at least partly on children between 6- and 11-years old; and (c) the *accessibility* criterion, excluding studies that do not study the concept of greenspace accessibility (but instead, e.g. 'bioaccessibility' in soil, or having 'far-reaching' implications). We also exclude study protocols, editorials, and opinion statements, and entries to which we cannot obtain the full text. The first and last author formulate the query parameters and exclusion criteria together. The first author performs the screening, while iteratively consulting with the last author to discuss considerations made and to decide on particular cases. After excluding literature that does not meet our criteria, 46 academic full texts remain (Figure 2).

Policy-making literature

We also collect policy-making literature from two organizations operating world-wide to improve, among others, children's health and well-being: the *World Health Organization* (WHO) and the *United Nations Children's Fund* (UNICEF). We query the WHO *Institutional Repository for Information Sharing* (IRIS) for English publications mentioning our keywords 'urban' and 'greenspace', or their synonyms, as of October 2023, resulting in 80 technical documents, governing documents, periodical articles, and other publications. We query the topic-based *UNICEF publications* search engine, focusing on the topics 'urbanization', 'environment', 'sustainable development goals', 'data and reports', and 'health' and search for publications mentioning 'greenspace' or its synonyms. After excluding documents that do not meet our criteria, 11 policy-making full texts remain (Figure 2).

Two generative workshops

Following Jabareen (2009), we also collect data from researchers and practitioners, complementing knowledge described in literature with knowledge on what practitioners deem meaningful to measure. The workshop activities have been reviewed and approved by the Human Research Ethics Committee at the authors' institute: Delft University of Technology.

Participants

We recruit a total of 27 participants. For the first workshop, we recruit researchers and practitioners ($n = 17$) on children's health and well-being through a stakeholder network of the European Horizon 2020 research project this study is part of: Equal-Life (Van Kamp *et al.* 2022). For the second workshop, we recruit practitioners ($n = 10$) working on green urban development for children at regional authorities in the region of The Hague, the Netherlands. We obtain informed consent from all participants.

Table 1. Workshop structure in three rounds: (1) introduction of topic and participants, (2) sharing ideas and needs for measures, supported and inspired by a form and card deck, and (3) pitching ideas and plenary discussion.

Round	Tasks and materials
1. Introduction	We introduce the topic and the research context and ask participants to introduce themselves and how they work on children's access to urban greenspace.
2. Ideas & needs	We ask participants to generate and share ideas for meaningful ways to measure children's access to urban greenspace, individually or in small groups, without briefing them on existing measures beforehand. We encourage free thinking and creativity, and ask participants suggest whatever could support them in their work, and not to constrain themselves to what they perceive is feasible to implement. For support and inspiration, we provide participants with: • A form with guiding questions: what would they like to measure, why, on what scale, using what information? We also invite them to illustrate their idea in any way suitable (e.g. a schematic map, diagram, or drawing). • A card deck in which we introduce various potentially relevant information types, informed by the exploratory literature review: green- and bluespace data (e.g. from imagery, land use and land cover data (Li *et al.* 2015, Markevych *et al.* 2017, Nieuwenhuijsen *et al.* 2017)), locations where children perform activities (e.g. homes, schools (Chambers *et al.* 2017, Nieuwenhuijsen *et al.* 2017)), (slow) traffic infrastructure (e.g. sidewalks, main roads (Qiu and Zhu 2021, Amiour *et al.* 2022, Truong *et al.* 2022)), people's judgment of greenspace (e.g. through questionnaires, audits, and children's participation (Nieuwenhuijsen *et al.* 2017, Markevych *et al.* 2017, Zijlema *et al.* 2017, Abma and Schrijver 2020, Finney and Atkinson 2020)), and a joker card to remind participants to bring up any other potentially relevant information type.
3. Discussion	We ask participants to pitch their ideas to each other, opening the floor for a broader discussion on what they deem relevant to measure, why that, and what such a measure could look like.

Procedure

Both workshops follow the same three-round structure: introduction of the topic and participants, sharing ideas and needs for measures, and a plenary discussion. Table 1 details the tasks and materials we gave participants in each round, including filling a form and pitching ideas, and Figure 3 shows an impression of the workshop setup. Both workshops took place in September 2023, the first in English and the second in Dutch. The English workshop materials are included in Appendix A.

Synthesizing findings into a model, and positioning measures against it

We analyze our data to make two contributions: (1) a visual conceptual model of factors affecting children's access to urban greenspaces and (2) an overview of how measures implemented in literature and proposed by participants relate to these factors, and which factors remain unaccounted for.

Conceptual model

By means of reflexive thematic analysis (Clarke and Braun 2013) on the identified literature and data gathered during the workshops, i.e. transcripts and forms, we identify themes covering factors that affect children's access to urban greenspace. To each theme, we formulate a key question based on which we report our results. Using visual mapping techniques, we then synthesize the identified clusters and factors into a visual conceptual model. We iterate on this process several times until we finalize our conceptual model.

Overview of measures

We then delve further into how children's access to urban greenspace is measured. From our corpus of literature, we identify implementations of generalizable accessibility measures that are tailored to the children's age group, as defined in section *Definitions and scope*. We apply deductive coding, using the factors from the conceptual model as codes, on the identified measures from literature, and the needs for measures collected during the workshops, to identify (1) which factors participants deem meaningful to measure, and why; and (2) which factors are accounted for by generalizable accessibility measures in literature to date, and how.

The first author performs the coding and identifies the initial themes while iteratively consulting and refining with the last author. We document our analysis in Microsoft Excel and Atlas TI. The

Figure 3. Three participants filling the forms during the first workshop, with the card deck lying on the left.

authors acknowledge their perspectives are grounded in the European geographical context and their background in spatial and urban analysis. Workshop transcripts are analyzed in their original language. We report evidence stemming from the workshops in 'quotes' (Pn.m) with *n* depicting the workshop, and *m* the participant. Quotes from the second workshop are translated into English for reporting purposes.

Factors affecting children's access to urban greenspace: a conceptual model

Based on our corpus of literature ($n = 57$) and workshops ($n = 2$), we build a conceptual model of factors affecting children's access to urban greenspace, presented in Figure 4: Within an encompassing ellipsoid, depicting the context, we present five clusters of factors, each relating to a key question: *(With) whom* does the child access? *From where*? *How*? *To where*? And *why*? Arrows depict key relationships, and overarching factors are placed in the center. In the following subsections, we explain and exemplify our model, emphasizing terms from Figure 4 in *italics*.

(With) whom? The child, and their household and network

Not every *child* is the same. Opportunities to access greenspace depend on a child's *age*, affecting their preferred activities (Bell *et al.* 2003, Jansson *et al.* 2014). *Character* plays a role too, as every child is different (UNICEF 2018, Vidal and Castro Seixas 2022). On *gender*, results are mixed. Some studies observe behavioral differences between boys and girls (World Health Organization Regional Office for Europe 2017, Raney *et al.* 2023) or report less experience with nature among girls (Sugiyama *et al.* 2021), while others find no differences (Rupprecht *et al.* 2016). For children living with certain *conditions*, these play a major role (UNICEF 2018, Sefcik *et al.* 2019, Bozkurt 2021, Vidal and Castro Seixas 2022), for example autism spectrum condition (Refshauge *et al.* 2012, McAllister *et al.* 2022). Throughout, the level of *independence* granted to the child by adults is key, primarily in terms of autonomy. Some children are allowed and able to access greenspaces without adult supervision 'so they can just do it by themselves' (P1.16), or with peers (Bell *et al.* 2003, Christian *et al.* 2015, Hand *et al.* 2018, Freeman *et al.* 2021, Osborne 2022), while others are accompanied by adults (Bell *et al.* 2003, Refshauge *et al.* 2012, Lestan *et al.* 2014, Willemse 2017, Huang *et al.* 2020, Sonti *et al.* 2020, Freeman *et al.* 2021, Talal and Santelmann 2021, Osborne 2022).

These adults are often members of the *household*, typically *family* (e.g., (grand)parents), or *guardians* (UNICEF 2018, Freeman *et al.* 2021, Osborne 2022), setting *restrictions* on the child's independence, defining which routes they can take, or what greenspace they can go to. Restrictions may conflict with children's wish for freedom and challenge (Vilalta 1997, Bell *et al.* 2003, Rupprecht *et al.* 2016, World Health Organization Regional Office for Europe 2016,

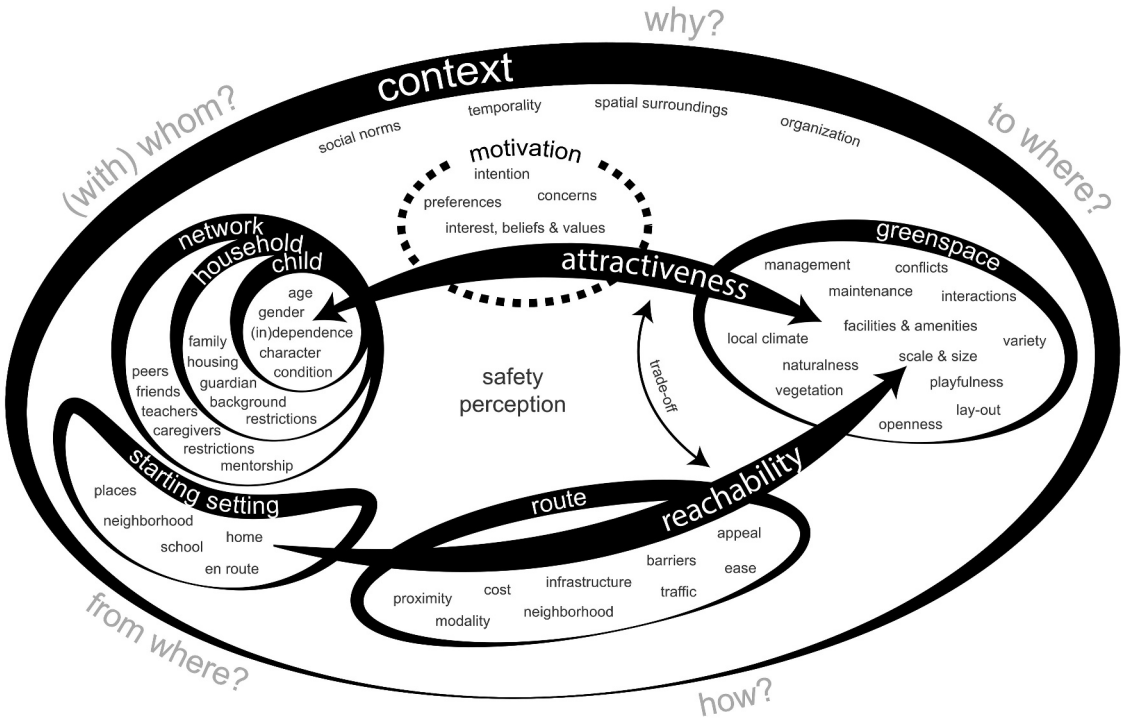

Figure 4. Conceptual model of factors affecting children's access to urban greenspace, organized into five clusters, with overarching factors and key relations depicted in the middle. Key question to each cluster stated outside the encompassing ellipsoid: access with and by Whom? From Where? How? To Where? And Why?

UNICEF 2018). Restrictions can be imposed by parents (Bell *et al.* 2003, Refshauge *et al.* 2012, Christian *et al.* 2015, Rupprecht *et al.* 2016, Hand *et al.* 2018, Pedrosa *et al.* 2021), teachers (Jansson *et al.* 2014), greenspace managers (McAllister 2008), or other adults: 'what other people find what is and isn't allowed' (P2.8). The *housing* situation may also affect access. A garden may serve as play space and catalyst for visiting public greenspaces (Refshauge *et al.* 2012, Osborne 2022), while for other people 'the park is your garden' (P1.13). Children living in gated communities visit greenspace more frequently (Bozkurt 2021). On the socio-economic *background* of the household, results are mixed (World Health Organization Regional Office for Europe 2019). Family finance may affect type and location of housing, and access to transport means (Willemse 2017, UNICEF 2018, Sefcik *et al.* 2019), while migration status (Hordyk *et al.* 2015) or ethnicity (Huang *et al.* 2020, Talal and Santelmann 2021) can play a role too. Furthermore, spatial inequalities in provision, quality and funding of greenspaces may correlate with demographics (McAllister 2008, Willemse 2017, UNICEF 2018, Sefcik *et al.* 2019, Huang *et al.* 2020): 'in [neighborhood A] you obviously have more greenery for children anyway than in [neighborhood B]' (P2.10).

A wider social and support *network* around the child may also be involved, including *peers* and *friends*. With other children nearby, adults grant children more freedom and autonomy (Hand *et al.* 2018, Osborne 2022), and children enjoy themselves: 'often it is not at all the greenery itself, but simply that your friends are there' (P2.2). Adults from the network can accompany children too, for example *teachers* or *caregivers*, or may set *restrictions*, similarly to adults within the household. Sometimes, the social network provides *mentorship*: community workers or others providing information or practical support for accessing greenspace (Hordyk *et al.* 2015).

From where? The starting setting

Children may access greenspace from various *starting settings*. Most typical are the *home* (Bell *et al.* 2003, Gardsjord *et al.* 2013, World Health Organization Regional Office for Europe 2019, Bozkurt 2021, Talal and Santelmann 2021) and *school* (Bell *et al.* 2003, McAllister 2008, Refshauge *et al.* 2012, World Health Organization Regional Office for Europe 2012, Talal and Santelmann 2021, Walker *et al.* 2021, Vidal and Castro Seixas 2022), either during school hours (World Health Organization Regional Office for Europe 2017, UNICEF 2018, Walker *et al.* 2021, Osborne 2022), depending on the school's budget and schedule, and teacher's confidence or concerns (Walker *et al.* 2021), or after school with school mates or adults picking children up from school: 'perhaps they can go before or after school and make use of those spaces because they've been brought there during their school day to learn how to use and interact in that space and may feel welcome' (P2.15). The *neighborhood* around the starting setting matters too, e.g. neighborhood greenness, deprivation, safety, or crowdedness (Hand *et al.* 2018).

Another possible starting setting is while being *en route* between home and school: 'greenery is also important in the every-day life of children so simply on your route for example to school' (P2.5) (Christian *et al.* 2015, Rupprecht *et al.* 2016, World Health Organization Regional Office for Europe 2022). Lastly, other *places* where children perform routine (extra-curricular) activities can serve as starting settings (UNICEF 2018, Huang *et al.* 2020, Vidal and Castro Seixas 2022), particularly when houses are mixed with other places: 'the physical network of those children, school, sports club, the stores where you go to' (P2.2).

To where? Characterizing child-friendly greenspace

Children's access also depends on *greenspace* characteristics and quality (Huang *et al.* 2020, Bozkurt 2021). Good quality *vegetation* makes a greenspace suitable for children, sparse vegetation is often preferred (Jansson *et al.* 2014, Freeman *et al.* 2021), and *openness* is valued, allowing good visibility and space to be active (Bell *et al.* 2003, Jansson *et al.* 2014, Lestan *et al.* 2014). On greenspace *scale and size*, evidence is mixed. Some studies stress large area does not imply satisfaction (Refshauge *et al.* 2012), while others find large-size greenspaces to promote accessibility (World Health Organization Regional Office for Europe 2016, Huang *et al.* 2020). Several studies highlight how small, local, or informal greenspaces are essential to complement larger ones: 'that is of course especially important for the children' (P2.10) (World Health Organization Regional Office for Europe 2012, Christian *et al.* 2015, Rupprecht *et al.* 2016, Freeman *et al.* 2021, Pedrosa *et al.* 2021, Osborne 2022). Regarding *lay-out*, people prefer open and landscaped greenspaces for children (Bell *et al.* 2003, Jansson *et al.* 2014, Lestan *et al.* 2014, Sonti *et al.* 2020, Talal and Santelmann 2021, Raney *et al.* 2023), compartmentalized in various inter-connected areas (UNICEF 2018, McAllister *et al.* 2022, Vidal and Castro Seixas 2022).

Opposed to landscaped greenspace, *naturalness* is valued less for children's activities (Talal and Santelmann 2021), especially when wild animals or poisonous planting (so-called 'ecosystem disservices' (Pedrosa *et al.* 2021)) are present (Rupprecht *et al.* 2016, Pedrosa *et al.* 2021, Cooper 2022), while some studies do report preference for less manicured and more wild greenspaces (Rupprecht *et al.* 2016,

Freeman *et al.* 2021). Children dedicate value to vegetation (World Health Organization Regional Office for Europe 2016, 2017, UNICEF 2018, Pedrosa *et al.* 2021), and biodiversity has 'value as well' (P1.1). The *local climate* may make a greenspace more suitable, e.g. with shade (Refshauge *et al.* 2012, Huang *et al.* 2020, Raney *et al.* 2023), and without environmental pollution: 'air pollution, water appropriateness, and so on' (P1.5). During the workshops, attractive soundscapes were mentioned: 'the idea of that a place is also characterized by the acoustics, if you have a spring water, it has an acoustic, traffic roads is another, acoustic birds in the park' (P1.3). Greenspace *playfulness* encompasses various aspects. Natural elements serving for play, such as trees for climbing or natural or hilly terrains promoting adventure and exploration (McAllister 2008, Jansson *et al.* 2014, Lestan *et al.* 2014, UNICEF 2018). Additionally, playgrounds may be linked 'to the greenery that is already there' (P2.8) (World Health Organization Regional Office for Europe 2012, Baró *et al.* 2021), and playful furniture and art may be present (UNICEF 2018), or recreational water for 'swimming in nature' (P1.5) (Talal and Santelmann 2021).

When accessing greenspace, *conflicts* with other users may occur, including older children or teenagers perceived as intimidating (Bell *et al.* 2003), dogs perceived intimidating, and their poo (Vilalta 1997), homeless people living there occasionally (Rupprecht *et al.* 2016), and people who intimidate, harass, beg, shout, or otherwise induce fear among children or their companions (Bell *et al.* 2003, Willemse 2017, UNICEF 2018). Yet, children do value *interactions* with peers (Talal and Santelmann 2021, Osborne 2022, Vidal and Castro Seixas 2022), other generations (UNICEF 2018, Talal and Santelmann 2021, Vidal and Castro Seixas 2022), or animals inhabiting the greenspace (Vidal and Castro Seixas 2022), and accompanying adults value interactions with each other (Refshauge *et al.* 2012). Perceived social safety further encourages access, promoted by good visibility and presence of people (Bell *et al.* 2003, McAllister 2008, Refshauge *et al.* 2012).

Facilities and amenities may further induce such interactions, and access in general (World Health Organization Regional Office for Europe 2017): e.g. safe play and sports equipment concentrated in one place (Vilalta 1997, Refshauge *et al.* 2012, UNICEF 2018, Huang *et al.* 2020, Sonti *et al.* 2020), seating for accompanying adults (UNICEF 2018), lighting to ensure visibility during dark hours (UNICEF 2018, Pedrosa *et al.* 2021, Purwohandoyo *et al.* 2023), and provisions such as drinking water, electricity, and Wi-Fi (UNICEF 2018, Sonti *et al.* 2020, Talal and Santelmann 2021). Having a *variety* of options is important 'because the wishes of everyone is different' (P1.4) (Refshauge *et al.* 2012, Lestan *et al.* 2014, UNICEF 2018, McAllister *et al.* 2022, Raney *et al.* 2023). Variety also makes greenspaces suit multiple generations, encouraging adults to accompany their children more often: 'it should be attractive for their guardians as well' (P1.4) (UNICEF 2018, Freeman *et al.* 2021, Sugiyama *et al.* 2021). Both children and adults value good *management* and *maintenance*, e.g. spaces without damaged or excessive vegetation (Jansson *et al.* 2014, Sefcik *et al.* 2019, Pedrosa *et al.* 2021), or spaces with proper hygiene and cleanliness, without litter lying around (Rupprecht *et al.* 2016, UNICEF 2018, Sefcik *et al.* 2019, Pedrosa *et al.* 2021). Poor upkeep may cause parents to regard greenspaces off-limits (Sefcik *et al.* 2019).

How? Barriers and encouragement along the route

Regarding the *route* to greenspace, *proximity* is key: the greenspace should be reasonably nearby the starting setting (Freeman 1977, Bell *et al.* 2003, McAllister 2008, Refshauge *et al.* 2012, Christian *et al.* 2015, Hordyk *et al.* 2015, Rupprecht *et al.* 2016, Willemse 2017, Hand *et al.* 2018, UNICEF 2018, World Health Organization Regional Office for Europe 2019, Freeman *et al.* 2021, Walker *et al.* 2021, Vidal and Castro Seixas 2022, 2022). The distance a child can travel depends on age, restrictions (McAllister 2008, Christian *et al.* 2015, Hand *et al.* 2018), and company (Freeman *et al.* 2021). Proximity, however, is not the only thing: 'sometimes it is nearby, but it does not feel nearby' (P2.9) (Walker *et al.* 2021, McAllister *et al.* 2022, Osborne 2022). *Modality* plays a role too, depending on the distance (Reyes *et al.* 2014, Osborne 2022). Access on foot is mentioned often (Refshauge *et al.* 2012, Willemse 2017, Freeman *et al.* 2021), while biking is an option as well, especially when children are older: 'they are then allowed to cycle in the streets' (P1.3) (Refshauge *et al.* 2012, Willemse 2017, Huang *et al.* 2020, Osborne 2022). Adult company opens possibilities to travel further by car or public transport (Refshauge *et al.* 2012, Willemse 2017, Freeman *et al.* 2021, McAllister *et al.* 2022, Osborne 2022). Such modalities, however, come at a *cost* (Hordyk *et al.* 2015, Sefcik *et al.* 2019), e.g. of owning and maintaining a vehicle, buying fuel or using public transport. Modalities further depend on the *infrastructure* connecting the starting setting to greenspace. Walking and biking infrastructure are important 'so that you can get to a place via decent sidewalks' (P2.8) and should be perceived safe (Gardsjord *et al.* 2013, UNICEF 2018, World Health Organization Regional Office for Europe 2022).

Along the route, children may encounter *barriers*, either spatial, e.g. major public transport infrastructure (Refshauge *et al.* 2012), or physical, e.g. uneven surfaces or narrow passages, especially for children

living with mental or physical health conditions (World Health Organization 2016, UNICEF 2018). A particular type of barrier is *traffic*: 'so I think that one of the big barriers is traffic' (P2.9). Traffic may cause safety concerns (UNICEF 2018, Huang *et al.* 2020, Purwohandoyo *et al.* 2023) restricting independence (Bell *et al.* 2003). Children should be kept away from traffic (Refshauge *et al.* 2012) and should not have to cross busy streets to get to greenspace (Refshauge *et al.* 2012, Willemse 2017, UNICEF 2018).

The route's *neighborhood* can increase opportunities to access greenspace, for instance when it is walkable, with a high land use mix (UNICEF 2018, Huang *et al.* 2020), where multiple trips can be combined, e.g. to cafes, shops, and greenspaces. However, when public school grounds are near, parents are less inclined to let children visit greenspace further away without supervision (Christian *et al.* 2015), and where public transport is close, fewer children are observed in urban parks (Huang *et al.* 2020). Access increases when a route is *easy* to traverse, especially for children with certain conditions (McAllister *et al.* 2022, Purwohandoyo *et al.* 2023), e.g. with clear signage, a smooth surface, and without difficult crossings. Routes may even have *appeal* in themselves: 'attractive routes' (P2.2) enhance accessibility further.

Why? Motivations to visit

Understanding *motivations* of children, and their companions, to visit greenspace is key: 'the question of, yeah, why does someone want to go somewhere is quite important' (P2.4). Motivations is driven by the *intention* to perform activities, and how well the greenspace suits those activities, e.g. playing, including exploration, seeking adventure, pretend play, and learning through play: 'they like to play, this is all the most important differences from we, adults' (P1.11) (Freeman 1977, Bell *et al.* 2003, McAllister 2008, Jansson *et al.* 2014, UNICEF 2018, Pedrosa *et al.* 2021, Sugiyama *et al.* 2021, Osborne 2022, Vidal and Castro Seixas 2022, Raney *et al.* 2023). Physical activity is mentioned as well: 'to feel free, be free, and move around' (P2.8) (World Health Organization Regional Office for Europe 2012, 2016, Willemse 2017, UNICEF 2018, Talal and Santelmann 2021, Raney *et al.* 2023); as are social interactions (McAllister 2008, World Health Organization Regional Office for Europe 2012, 2016, UNICEF 2018, Raney *et al.* 2023), enjoying privacy (Rupprecht *et al.* 2016), and relaxation (Jansson *et al.* 2014, Rupprecht *et al.* 2016, Osborne 2022). *Preferences* may simply vary from person to person, and motivation is also influenced by *interests, beliefs, and values*, for example parental interests in nature (Refshauge *et al.* 2012, Sugiyama *et al.* 2021), parental wishes to enjoy time with their children (Refshauge *et al.* 2012, Sonti *et al.* 2020, Talal and Santelmann 2021), parental beliefs regarding healthy activities and environments (Refshauge *et al.* 2012, Sefcik *et al.* 2019), feelings of attachment to certain places (Sonti *et al.* 2020), or personal receptivity by previous good experiences with greenspace (Hordyk *et al.* 2015). Children or adults may also assign educational, provisional, or socio-cultural value to nature in general (Cooper 2022). Safety *concerns* may limit motivations to visit (Bell *et al.* 2003, Sefcik *et al.* 2019, Pedrosa *et al.* 2021), caused by fear of hazards (Pedrosa *et al.* 2021), crime (Huang *et al.* 2020), injury (Vilalta 1997, Rupprecht *et al.* 2016), traffic safety (Rupprecht *et al.* 2016, Pedrosa *et al.* 2021), water banks and steep hills, or high voltage electricity (UNICEF 2018).

Overarching and contextual factors

A key overarching relationship is the trade-off between reachability and attractiveness: *Reachability* depends on the route connecting the starting setting to the greenspace, while *attractiveness* is determined by how greenspace characteristics match the motivations of children and their companions to visit: 'the more attractive the space is, the more the people go' (P1.16). Access depends on a *trade-off*, i.e. whether visiting is worth the effort, depending on how easy and pleasant, or dangerous and difficult reaching the greenspace is, and how well it appeals to the child and their companions: 'if it's attractive they go across the city' (P1.17) (Refshauge *et al.* 2012, Sefcik *et al.* 2019, Freeman *et al.* 2021).

Contextual factors play a role too. *Social norms* define how important people find children's visits to greenspace (Sefcik *et al.* 2019) and the level of independence they can be granted (Christian *et al.* 2015). *Temporalities* include effects of seasonal variance (e.g. heat, cold, ice, flooding) (UNICEF 2018, Huang *et al.* 2020, Pedrosa *et al.* 2021), the type of day (e.g. weekdays, weekends, holidays) (Huang *et al.* 2020), and the time of day (e.g. darkness, or need for shade) (Bell *et al.* 2003, Refshauge *et al.* 2012, UNICEF 2018, Sefcik *et al.* 2019, Huang *et al.* 2020, Raney *et al.* 2023). Additionally, children need sufficient free time to visit (Freeman *et al.* 2021, Vidal and Castro Seixas 2022), and particular time periods, such as the COVID-19 pandemic, may have effects (Marchi *et al.* 2022, Osborne 2022)). Differences in *spatial surroundings* may exist between geographic regions (Refshauge *et al.* 2012, Rupprecht *et al.* 2016), e.g. in deprivation (Huang *et al.* 2020) and urban density (Huang *et al.* 2020). *Organized* programs and activities in greenspace can promote children's visits further (World Health Organization Regional Office for Europe 2017, UNICEF 2018, Sefcik *et al.* 2019, Huang *et al.* 2020, Sonti *et al.* 2020).

Last but not least, *safety perception*, of both the child and their companions, relates to many aforementioned factors: e.g. how independently children may operate (Bell *et al.* 2003, Christian *et al.* 2015, Hand *et al.* 2018), through what neighborhood and via what route they may go (UNICEF 2018, Vidal and Castro Seixas 2022), and what greenspace they want, or are allowed, to spend time in (Refshauge *et al.* 2012, UNICEF 2018, Sefcik *et al.* 2019, Sonti *et al.* 2020, Osborne 2022, Vidal and Castro Seixas 2022, Purwohandoyo *et al.* 2023).

How these factors are accounted for in generalizable accessibility measures

We identify 22 articles, all academic, that implement a measure of children's access to urban greenspace. Additionally, 25 workshop participants share ideas and needs for such measures. In this section, we position all measures and needs as an extra layer to our conceptual model in Figure 5: In bold, we emphasize what factors participants find meaningful to measure, and in blue, we highlight factors that measures in literature account for. We differentiate between factors directly accounted for (dark blue, e.g. measuring distance to greenspace from houses directly accounts for factors *proximity* and *home*) and those only indirectly accounted for (light blue, e.g. a chosen distance threshold motivated as the distance children can traverse *independently*). In the following subsections, we explain and exemplify this overview of measures. Additionally, we provide two summary tables in Appendix B: Table B1 reporting factors accounted for in literature, and table B2 reporting what factors participants propose to measure.

The child as the true expert

Concerning the child

Participants emphasize the need to measure *independent* access to greenspace: 'the principle is that children should be able to meet friends on their own' (P1.16). In literature measures, however, independence is only touched upon. Various studies motivate their distance threshold as 'the area a child could be expected to be able to use independently' (Hand *et al.* 2018), with distances varying between 300 m and a kilometer (Wolch *et al.* 2005, Janssen and Rosu 2015, Hand *et al.* 2018, Mears *et al.* 2020, Baró *et al.* 2021). Reyes *et al.* (2014) use *age* and *gender* to determine the distance a child may travel to access greenspace, while Ghale *et al.* (2023) and Iraegui *et al.* (2020) touch upon *age* by differentiating between greenspace types for different age groups and corresponding distance thresholds. We identify no measures accounting for *character* and *conditions*, and neither are these emphasized by participants. Yet, participants do emphasize needing information on children's views on access: 'the true experts' (P1.12); 'what do those children think themselves' (P2.7); while other participants comment that 'sometimes children don't know exactly what good is for them' (P1.13).

Regarding the child's household

Participants emphasize housing: 'it should start with a nice play space near the house, so a garden or

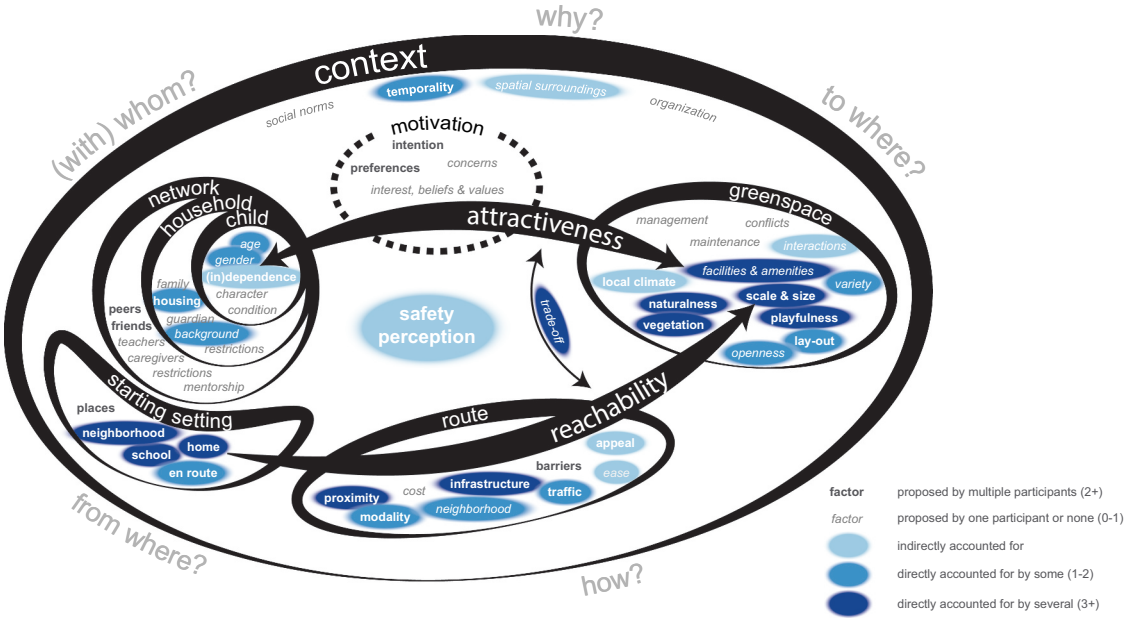

Figure 5. Overview of measurement needs and implementations: factors of the conceptual model that are accounted for by measures implemented in literature highlighted in dark blue (accounted for by several, 3+), medium blue (accounted for by some, 1-2), and light blue (indirectly accounted for). Factors deemed meaningful to measure by multiple workshop participants emphasized in bold.

something' (P.2.10); 'but not everybody has a garden, so the park is your garden' (P1.13). In literature, Mears *et al.* (2020) account for housing by measuring garden size as one of their indicators. Reyes *et al.* (2014) account for the household's background (e.g. income class) as a determinant for distance, and La Rosa *et al.* (2018) touch upon background by stating how their measure can adapt to different social groups. We do not identify any measures that account for *family*, *guardians*, or *restrictions*.

Regarding the child's social and support network

Participants emphasize needing information about access with *peers* and *friends*, but we do not identify measures accounting for those factors in literature, and neither for *teachers*, *caregivers*, *restrictions*, and *mentorship*.

Starting settings and missing places

All *starting settings* in our conceptual model are also emphasized by participants. The *home* is often mentioned: 'where does this target group live?' (P2.9); and accounted for by over half of the literature measures (Christian *et al.* 2015, Hand *et al.* 2018, Ribeiro *et al.* 2019, Mears *et al.* 2020, Xing *et al.* 2020, Alderton *et al.* 2022, Almeida *et al.* 2022, Purwohandoyo *et al.* 2023, Robillard *et al.* 2023, Teeuwen *et al.* 2023, Weber *et al.* 2023, Ye *et al.* 2023). Several studies measure access from residential *neighborhoods*, such as census or postal code areas (Wolch *et al.* 2005, Janssen and Rosu 2015, La Rosa *et al.* 2018, Mears *et al.* 2020), and others measure access from *schools*: some to complement measuring access from home (Ribeiro *et al.* 2019, Almeida *et al.* 2022, Purwohandoyo *et al.* 2023, Teeuwen *et al.* 2023, Ye *et al.* 2023), while others focus on schools in particular. Examples include Walker *et al.* (2021) studying greenspaces near schools, and Baró *et al.* (2021) studying greenness on school premises, in surrounding streets, and nearby greenspaces. Measuring access *en route* is also emphasized by participants 'so we know where do we invest our money to make spaces better, to adjust the environment because we now know where children move' (P1.14). In literature, Ye *et al.* (2023) model home-to-school routes and assess how vegetated these are, and Teeuwen *et al.* (2023) model children's commuting patterns within a city to assess which greenspaces they traverse. Baró *et al.* (2021) touch upon access *en route* as a motivation to measure street trees surrounding schools. Other *places*, such as sports clubs or shops, remain unaccounted for in literature measures, while participants do emphasize them: 'the sports club, the shops where they go to [. . .] schools and play spaces are part of the total network that they use' (P2.2).

The route: broad needs, narrow implementation

Regarding the *route*, literature gravitates towards measuring *proximity* and *infrastructure*. Participants emphasize a broader range of factors, but also stress proximity and infrastructure: 'it would be interesting to know how far a child of 6 to 12, what is the range of such a child' (P2.8); 'and what the sidewalk there is like to get there' (P1.15). All literature measures operationalize some indicator of *proximity* (Wolch *et al.* 2005, Onder *et al.* 2011, Reyes *et al.* 2014, Christian *et al.* 2015, Janssen and Rosu 2015, Gupta *et al.* 2016, Hand *et al.* 2018, La Rosa *et al.* 2018, Ribeiro *et al.* 2019, Iraegui *et al.* 2020, Mears *et al.* 2020, Xing *et al.* 2020, Baró *et al.* 2021, Walker *et al.* 2021, Alderton *et al.* 2022, Almeida *et al.* 2022, Ghale *et al.* 2023, Purwohandoyo *et al.* 2023, Robillard *et al.* 2023, Teeuwen *et al.* 2023, Weber *et al.* 2023, Ye *et al.* 2023): Studies deem anything within a given distance accessible (Alderton *et al.* 2022), identify the nearest greenspace (Christian *et al.* 2015), or use distance as one of many parameters (Xing *et al.* 2020). Distances are measured as straight-line distance (Onder *et al.* 2011, Reyes *et al.* 2014, Janssen and Rosu 2015, Hand *et al.* 2018, Mears *et al.* 2020, Baró *et al.* 2021, Walker *et al.* 2021, Purwohandoyo *et al.* 2023, Weber *et al.* 2023, Ye *et al.* 2023), or along the street network, thereby also accounting for the *infrastructure* (La Rosa *et al.* 2018, Iraegui *et al.* 2020, Mears *et al.* 2020, Baró *et al.* 2021, Alderton *et al.* 2022, Almeida *et al.* 2022, Ghale *et al.* 2023, Robillard *et al.* 2023, Teeuwen *et al.* 2023).

Participants also emphasize *traffic*: 'if I want to know how children can easily reach greenspace then I actually want to know how much traffic there is for the accessibility' (P2.9); and to a lesser extent *modalities*: 'by foot by bike or by tram' (P1.16). Purwohandoyo *et al.* (2023) use distance to high-traffic roads as an indicator promoting accessibility, indirectly touching upon *ease* in their motivation, and Gupta *et al.* (2016) touch upon *traffic* and its effect on walking speed. Robillard *et al.* (2023) also account for traffic by identifying children's infrastructure, e.g. by excluding high-speed streets, or solely including streets with sidewalks. Robillard *et al.* (2023) also account for *modality* by differentiating between walking and cycling infrastructure, and Reyes *et al.* (2014) by using the traffic modes available to a family, e.g. cycling or driving, as indicator for distance travelled. Several other studies touch upon modality by differentiating between walking and driving distances and infrastructure (Ghale *et al.* 2023, Ye *et al.* 2023).

Participants also emphasize needing information on *barriers*: 'next to distance of course the physical barriers' (P2.2); while such barriers remain unaccounted for in literature. Two participants refer to the *appeal* of a route, touched upon by Teeuwen *et al.* (2023) through incorporating detours that children may make, for instance to more desirable streets. Reyes *et al.* (2014) account for the route's surrounding *neighborhood* by considering land use and built environment as indicators for distance travelled. *Costs* remain unaccounted for.

Diversity in measures of greenspace

Measures in literature account for a variety of *greenspace* characteristics – most often scale and size, playfulness, vegetation, naturalness, or facilities and amenities.

Regarding *scale and size*, participants stress the need to measure small-scale greenspace, as 'we have neighborhood greenspace and that is of course mostly important for children' (P2.10), and connectivity between greenspaces: 'how is that connected neighborhood level up to city level' (P1.1). In literature, measures categorize greenspaces based on size or scale (Onder *et al.* 2011, Christian *et al.* 2015, Gupta *et al.* 2016, La Rosa *et al.* 2018, Iraegui *et al.* 2020, Ghale *et al.* 2023, Weber *et al.* 2023). Xing *et al.* (2020) include area as one of many parameters in their accessibility formula, and Janssen and Rosu (2015) quantify the percentage of land covered by vegetation. Several studies touch upon size by including greenspaces of a certain size (Mears *et al.* 2020, Walker *et al.* 2021, Teeuwen *et al.* 2023), while others explicitly include greenspaces of any size (Ribeiro *et al.* 2019, Almeida *et al.* 2022).

Regarding *vegetation*, participants mention the need to measure, for instance: 'the area of green per inhabitant' (P2.10); or 'streets without trees' (P1.13). Studies quantify tree or vegetation cover, e.g. within a greenspace (Janssen and Rosu 2015, Xing *et al.* 2020, Purwohandoyo *et al.* 2023), on school premises (Baró *et al.* 2021), or within an area (Mears *et al.* 2020). Other studies use satellite-derived vegetation indices to quantify vegetation within an area (Almeida *et al.* 2022, Ye *et al.* 2023) or to distinguish between densely and sparsely vegetated greenspace areas (Ghale *et al.* 2023). Weber *et al.* (2023) analyze, among others, greenspaces classified as 'lush'.

Concerning *playfulness*, participants emphasize interest in 'how many play spaces there are', and in playful natural elements, e.g. 'bushes that we [adults] overlook' (P2.8). Measures typically focus on playground presence (Christian *et al.* 2015, Mears *et al.* 2020, Alderton *et al.* 2022, Weber *et al.* 2023) or count (Xing *et al.* 2020) within the greenspace. Some studies consider playgrounds to be a type of greenspace as they 'are generally located within greenspaces (or tree-covered public spaces such as squares) in Barcelona' (Baró *et al.* 2021), or classifying 'tot lots' as the smallest greenspace type (Gupta *et al.* 2016, Ghale *et al.* 2023). Purwohandoyo *et al.* (2023) touch upon playful nature by motivating measuring green waterfronts as 'space for children to play'.

Some participants connect playfulness to *naturalness*, needing to know 'whether it's really a nature place because in my opinion, a nature play area, it's green, it's soft, it has a soft on the ground, it has enough light, water, sand, trees, natural things' (P1.10). Other participants express interest in measuring naturalness as 'birds in the park' (P1.3), 'green and blue infrastructure, so how is it performing and how is it connected?' (P1.1) and 'biodiversity value as well' (P1.1). Measures in literature account for naturalness through waterbodies (Xing *et al.* 2020, Ghale *et al.* 2023, Purwohandoyo *et al.* 2023), biodiversity or bird counts (Hand *et al.* 2018, Ghale *et al.* 2023), greenspaces 'having a predominantly natural feeling' (Mears *et al.* 2020), or by studying 'wild', 'soughing' and 'serene' greenspaces (Weber *et al.* 2023), or, indirectly, by assuming large-size greenspaces are natural (Iraegui *et al.* 2020).

Facilities and amenities are not particularly emphasized by participants, yet studies account for e.g. toilets (Xing *et al.* 2020, Alderton *et al.* 2022), walking paths within the greenspace (Xing *et al.* 2020), sports facilities (Onder *et al.* 2011, Xing *et al.* 2020, Weber *et al.* 2023), social or commercial facilities (Purwohandoyo *et al.* 2023), swimming pools, benches, and picnic areas (Xing *et al.* 2020), and terraces (Iraegui *et al.* 2020). Conversely, local climate and lay-out were emphasized by participants, but measured by few. Participants need information about the *local climate*, including air quality, light and shade, sound and noise, and water quality: 'what quality of air, what noise you have in that' (P1.5). In literature, Baró *et al.* (2021) touch upon the local climate, motivating measuring canopy cover as an indicator of good air quality and heat mitigation. Participants also emphasize *lay-out*, specifically in relation to other greenspaces: 'you do not only want to know the green space but also the green structures' (P2.10). In literature, Ghale *et al.* (2023) account for lay-out of individual greenspaces through a measure of spaciousness, with highest values for greenspaces with a relatively large area given their perimeter.

While *openness* is not emphasized during the workshops, measures account for it by measuring presence of green open space (Purwohandoyo *et al.* 2023) or studying greenspaces characterized by 'soughing openness' (Weber *et al.* 2023). As to *interactions*, one participant expresses the need to understand where children 'can meet each other' (P2.8). Studies touch upon such interactions as motivation for measuring the presence of play and sports facilities (Mears *et al.* 2020), or for focusing on neighborhood- and community parks as places where children interact (Ghale *et al.* 2023). Xing *et al.* (2020) account for *variety* within greenspaces through a multi-component attractiveness score, including indicators of playfulness, facilities and amenities, naturalness, and vegetation, where only greenspaces scoring well on all indicators achieve a maximum score. Christian *et al.* (2015) touch upon variety by assuming large greenspace size implies a variety of attractive characteristics. We identify no measures that account for management, maintenance, or conflicts, and neither are they emphasized by multiple participants.

Motivations: important yet uncovered

Children's *motivations* are important to participants: 'the question like motivation, why, why do you want to

be there at all?' (P2.2); 'I think the question like yeah, why does someone want to go somewhere, is quite important' (P2.4). Participants particularly stress *preferences* and *intentions*: 'which greenspace do they find interesting, do they want to use?' (P2.1). However, we do not identify any measures implemented in literature that indirectly or directly account for any motivation-related factors.

About the context

Several participants emphasize the key overarching factor *safety perception*: '[it should be] safe enough that the parents would let them go' (P1.17). In literature measures, however, safety perception is only touched upon by Robillard *et al.* (2023), measuring access to greenspace via pedestrian infrastructure to reflect 'a safer way to travel by foot'.

Only one participant mentions the need to measure *trade-off* between a reachability and attractiveness, while multiple measures in literature account for this trade-off, typically differentiating between greenspace size, scale, or type, and a corresponding distance visitors would be willing to travel (Onder *et al.* 2011, Gupta *et al.* 2016, Iraegui *et al.* 2020, Ghale *et al.* 2023): for instance, residential greenspaces serving local populations located within hundreds of meters, opposed to city-level greenspaces serving populations within kilometers. Xing *et al.* (2020) quantify a greenspace's accessibility as a function of attractiveness (e.g. size, facilities, natural qualities) and reachability (e.g. travel time from surrounding populations).

Regarding contextual factors, participants express interest in accounting for *temporalities* in several ways. Participants stress the difference between moments in time: 'spring and summer and autumn and yeah winter because it's going to differ … at school time, not school time, weekends, vacation time, holidays' (P1.15). In literature, Ye *et al.* (2023) combine measures for access from various starting settings, weighted by the (daylight) hours children spend at these settings, i.e. during weekdays, eight at school, one commuting, and three at home. Other studies measure access during both school and leisure time (Baró *et al.* 2021, Ghale *et al.* 2023), or quantify duration of greenspace traversal (Teeuwen *et al.* 2023). Participants also emphasize need for repeated measurement as 'this relationship will be constantly different (P1.2)'. In literature, studies consider using greenspace data from several years, but merge them given strong collinearity (Ribeiro *et al.* 2019, Almeida *et al.* 2022). Participants further wish to account for future scenarios 'in spatial planning processes that are about long-term reservations of space and about the arrangement and actual use not yet in sight' (P2.4); which we do not find implemented in literature. Lastly, several studies touch upon *spatial surroundings* by stating parameters can be adapted to the geographical context (La Rosa *et al.* 2018, Iraegui *et al.* 2020, Robillard *et al.* 2023), while *social norms* and *organization* remain unaccounted for.

Discussion

In this section, we interpret our main findings, discuss implications for future work, and consider the limitations of our approach.

Interpretation of main findings

As to our conceptual model of factors, we observe that the characteristics of the child can hardly be separated from those of the people in its direct social surroundings, such as parents and peers. In our model, we materialized this entanglement through various nested circles – depicting the child, their household, and the wider network – inspired by the ecological model by Bronfenbrenner (1979).

Many other factors in our conceptual model cannot be seen in isolation either. Key relationships concern the relationship between the starting settings, route, and greenspace that constitutes reachability, and the relationship between the greenspace, child, and motivations, constituting attractiveness. Yet these are not the only relationships, as can also be understood from the accompanying descriptions in section *Factors affecting children's access to urban greenspace: a conceptual model*: Traffic relates to restrictions and reduced independence, and concerns may be caused by conflicts, and mitigated by openness for good visibility. We chose to keep our model clean and clear, by materializing only the most key relationships, while we do emphasize that relationships are prevalent. As such, our model can be interpreted with respect to the concept of the *exposome* — i.e. the totality of exposures during lifetime from conception onward, complementing the human genome (Wild 2005) – and the inherent inter-linkages between the multitude of factors affecting a child's well-being (Persson Waye *et al.* 2023).

Additionally, in line with recent conceptualizations of the (children's) exposome (Gudi-Mindermann *et al.* 2023, Persson Waye *et al.* 2023), the factors we identified are not only physical (e.g. proximity, starting settings, greenspace scale and size), but also social (e.g. interactions, conflicts, social norms), or on the intersection between physical and social (e.g. safety perceptions, playfulness).

As to accessibility measures, we identified only one measure that indirectly accounts for safety perception (Robillard *et al.* 2023), while safety perception is a key overarching factor in our model. One could hypothesize that, in the case of children, links between safety perception and other factors are so apparent that safety perception as a factor is no longer explicitly

articulated, or approximated through other factors, such as traffic or independence, instead.

Other notable clusters that remain unaccounted for are motivations, the child's network, an several other factors related to the child and their household. Participants, however, emphasized interest in understanding the child and their motivations, or to assess accessibility in collaboration with them: 'we need the children for this' (P1.12). As such, our findings align with literature calling to integrate subjective with objective data for most valuable insights (Zhang *et al.* 2021). Other participants, however, highlighted the value in measures that can be applied at large scale: 'data we can access in the country level [. . .] the world level' (P1.2); for instance, for epidemiological research on levels to which subjective data collection methods do not scale easily.

A factor often accounted for in literature, but emphasized by only one participant, is the trade-off between attractiveness and reachability. We observed that measures typically operationalize this trade-off by assigning different distance thresholds to different greenspace scales. A possible explanation could be that participants, during the workshops or their work in general, scope to one particular scale, and thus distance threshold, at a time.

Lastly, while our conceptual model focuses on *children's* access to urban greenspace, many factors may also apply to the general population: While some factors may be child-specific (e.g. restrictions, playfulness, and schools), other factors may affect children more strongly than the general population, but are not unique to them (e.g. traffic, openness). Conversely, also within the children's age group, differences between subgroups remain. Our corpus included studies on children with autism spectrum condition (McAllister *et al.* 2022) and children from immigrant families (Hordyk *et al.* 2015). One could expect that each subgroup of children may come with its particular barriers and preferences.

Implications and future work

A challenge for future work is how to design measures that put the factors center stage that remain, to date, unaccounted for or only touched upon. Examples include independence, company of peers and friends, intentions and preferences, the local climate of the greenspace, the appeal and ease relieving the burden of traversing the route, barriers along the route other than traffic, and the places that children routinely spend time at and may access greenspace from, other than home and school.

A *low hanging fruit* may be to account for missing spatial factors, such as these other places, the greenspace's local climate (e.g. noise and air quality), or other physical barriers along the route. Promising explorations towards accounting for these factors may be available in adjacent domains, for instance, on measuring children's independent access to *play space* and the barriers they encounter (Teeuwen and Psyllidis 2023). Measuring social or perceived factors, often less directly linked to the spatial surroundings, has great potential, but comes with practical challenges to be addressed in future work: How to account for such factors in generalizable measures, and how well are they captured in data? Furthermore, one could argue that accounting for such oftentimes sensitive factors, for instance family background, the child's condition, or parental beliefs and values, could raise ethical concerns when implemented at scale and taken out of context.

Our overview of measures may provide researchers and practitioners with guidance in selecting measures for children's access to urban greenspace, for instance when studying spatial equity, urban planning, or environmental health. The possibilities are numerous and depend on the aims and context of the study at hand. We do, however, emphasize that our overview should not be treated as a rating, ranking, or advice on which measures to use. Instead, we argue that for measuring children's access to urban greenspace, or access in general, no *one-size-fits-all* solution exists. All measures remain a simplification of reality, in which choices on what to represent should consciously be made. One could also consider, as several studies already do, to complement various measures with each other.

Lastly, our model aims to support the design and evaluation of urban planning policies and interventions by highlighting how interlinkages between factors may cause changes directed at one factor to spill over to others. Furthermore, policies and interventions, as well as exogenous processes such as climate change, may have long-term or delayed effects. While presenting prototypes of our conceptual model, we observed it helped to illustrate the complexity of children's access to urban greenspace, sparking discussions and exchange of experiences and advice among researchers and practitioners as to how to enhance or measure children's access to urban greenspace.

Limitations

Several limitations remain in this study. First, not all relevant literature used in our scoping literature review may have been indexed in Scopus. We complemented the literature sourced from Scopus – a multidisciplinary database that integrates content from various other specialized databases (Pranckute 2021) – with literature from the policy-making domain and conducted complementary workshops with researchers and practitioners. This approach is what sets our work apart. Although our results may not be all-encompassing, we did experience reaching a level of saturation while identifying factors, that may indicate our results are rather complete. Furthermore, with developing the first version of our conceptual model of factors, a process of rethinking and

revising starts, depending on new insights, comments, and literature (Jabareen 2009). Regarding measures, we acknowledge more measures may exist. Yet, we are confident that the overall patterns we identified hold. Second, the academic literature in our corpus largely stems from contexts in the Global North (77%), opposed to the Global South (23%), and our workshops participants all work within Europe, which may bias our results towards the European geographical and cultural context. Third, we note that academic literature may not explicitly mention all considerations made when describing their measure for children's access to urban greenspace: We may have missed factors implicitly accounted for *behind the scenes*. Fourth, one could argue that some factors extend broader than the indicator measured to account for it, e.g. playfulness may encompass more than just the presence of playgrounds that studies measure. We aimed to provide insight into *how* measures account for such factors, without judging on quality or completeness, but do note this could be interesting future work. Fifth, some generalizable measures in our overview incorporate a manual step in their workflow, e.g. by using data from earlier audits, or from manual interpretations of imagery. As these measures remain largely generalizable, we did choose to incorporate them. One could argue that data without any manual component are scarce, with satellite index or object detection data sets as exceptions, while many widely used data sets such as land use data and local data registries depend on manual work by someone. Moreover, by incorporating these measures, we aim to exemplify the value of such data in future research, and we call upon both researchers and practitioners to open their data for reuse wherever possible.

Conclusion

In this article, we contributed (1) a conceptual model of factors affecting children's access to urban greenspaces and (2) an overview of how generalizable accessibility measures account for these factors. Children's access to greenspace is determined by a trade-off between greenspace reachability and attractiveness. Reachability concerns the route connecting the child's starting setting with the greenspace, whereas attractiveness is determined by how well the characteristics of the greenspace suit the child, their companions, and their motivations to visit. Perceptions of safety play a role throughout. While researchers and practitioners wish to understand the child and their motivations to visit greenspace, measures implemented in literature typically ignore these factors, or only touch upon them. Measures do account for a variety of greenspace characteristics that make it attractive, including scale and size, playfulness, vegetation, naturalness, or facilities and amenities, and the route's characteristics that make the greenspace reachable, gravitating towards proximity and infrastructure.

Future work could explore how factors ignored or only touched upon to date can be put center stage in novel accessibility measures. Our overview of measures may support researchers and practitioners to make better informed decisions, selecting measures depending on the factors they aim to capture, while our conceptual framework may foster common understanding among disciplines about the multitude of factors affecting children's access to urban greenspace.

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Appendices

Appendix A. Workshop materials

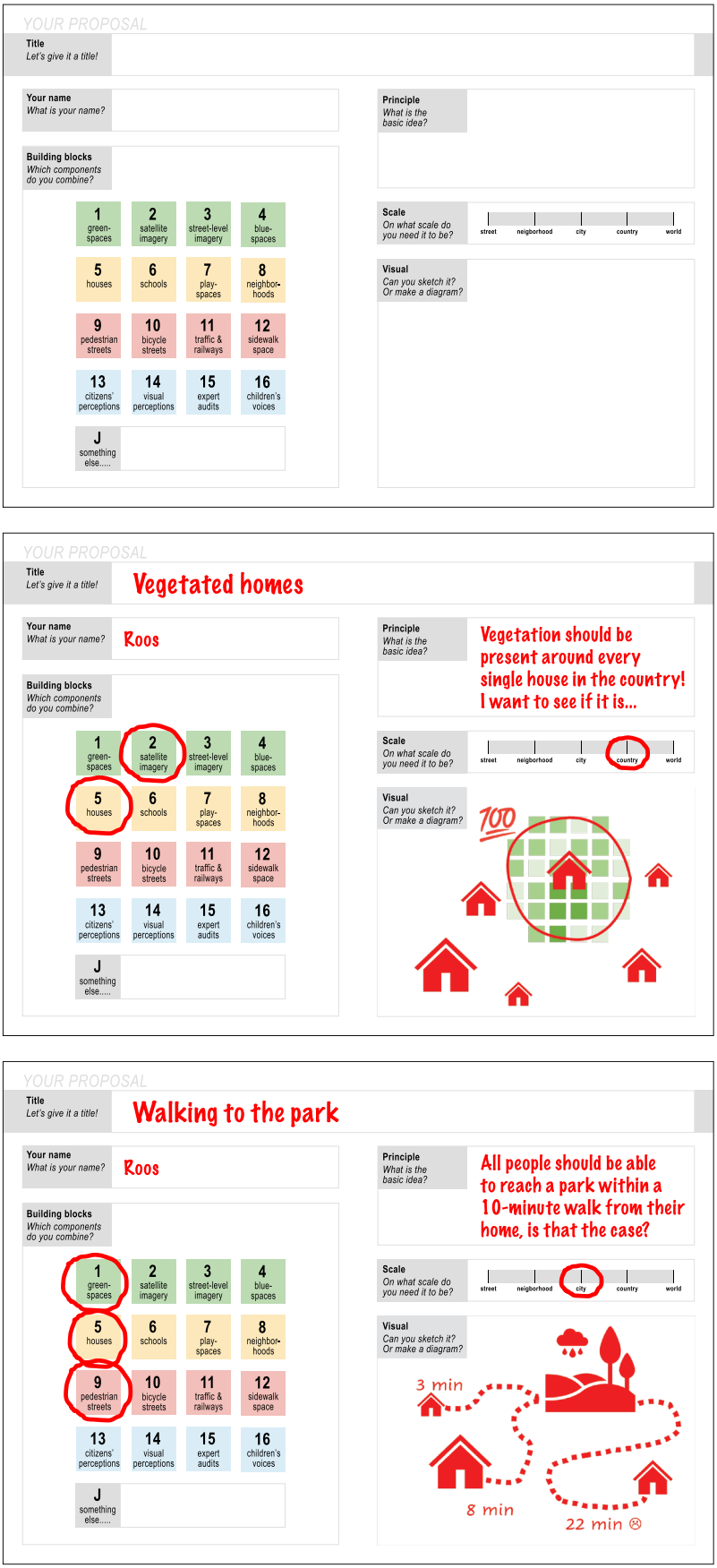

Figure A1. Workshop forms with guiding questions for the workshop participants, including two filled examples: What would they like to measure, why that, on what scale, using what information, and how could the idea look like?

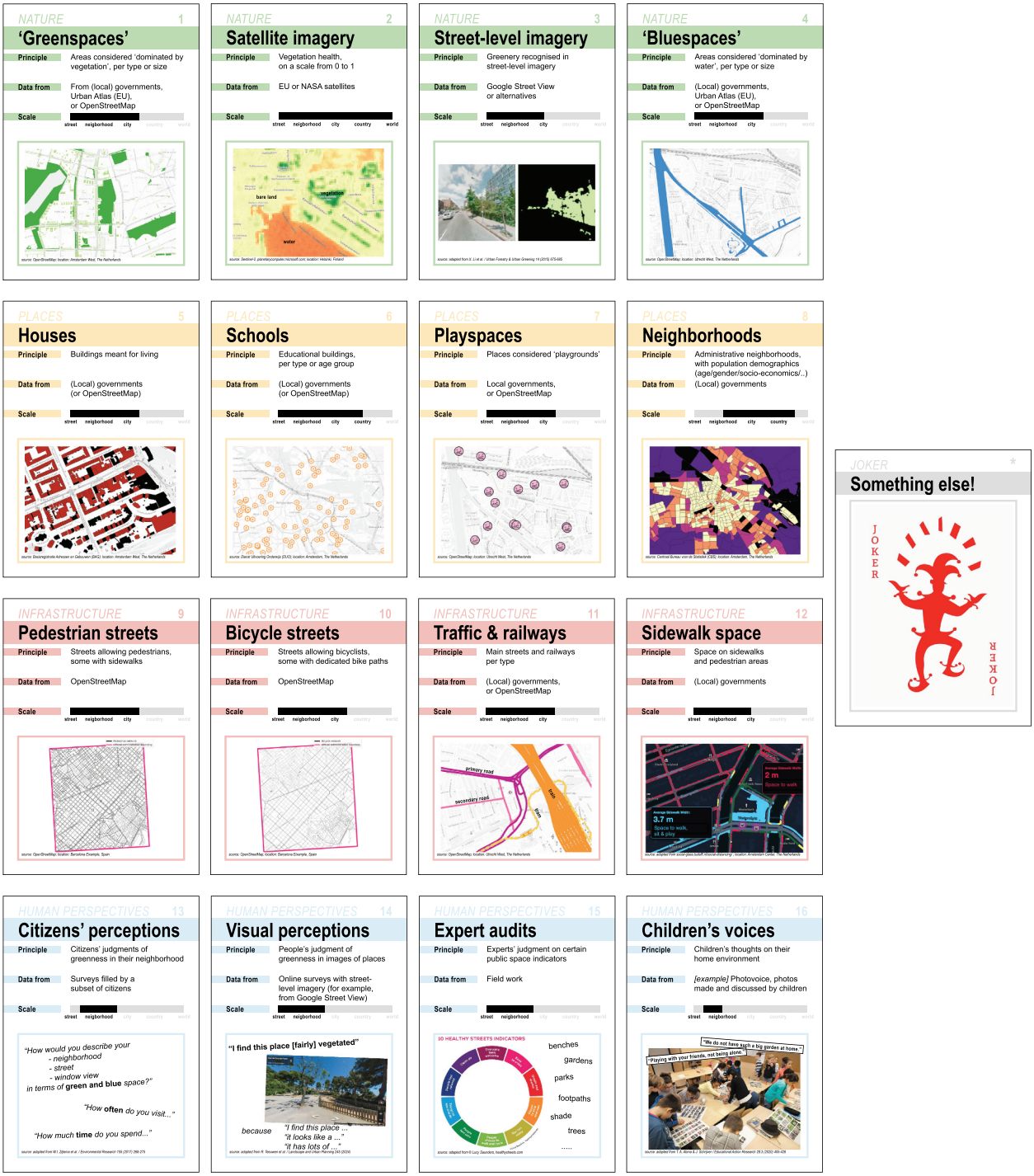

Figure A2. Workshop card deck introducing potentially relevant information types. Top to bottom: green- and bluespace data, locations where children perform activities, infrastructure, and people's perspectives on greenspace. To the right, a joker card is included to remind participants to bring up any other information they deem relevant.

Appendix B. Measures in relation to factors

Table B1. Measures in literature, and the factors they account for, either directly (black cells) or indirectly (grey cells). Measures in literature often account for starting settings, the route (proximity and infrastructure) and several characteristics of the greenspace, while motivations and the child's network remain unaccounted for.

	(with) whom?																from where?					how?									to where?													why?											
	child					household					network						starting sett.					route									greenspace													motivation				overarching				contextual			
reference	age	gender	(in)dependence	character	condition	family	housing	guardian	background	restrictions	peers	friends	teachers	caregivers	restrictions	mentorship	home	school	en route	neighborhood	places	proximity	modality	cost	neighborhood	infrastructure	barriers	traffic	appeal	ease	management	maintenance	conflicts	interactions	playfulness	local climate	variety	facilities & amenities	naturalness	vegetation	lay-out	scale & size	openness	intention	concerns	preferences	interests, beliefs & values	safety perception	trade-off	reachability	attractiveness	social norms	temporality	spatial surroundings	organization
Alderton et al. (2022)																																																							
*Almeida et al. (2022); & Ribeiro et al. (2019) **																																																							
Baro et al. (2021)																																																							
Christian et al. (2015)																																																							
Ghale et al. (2023)																																																							
Gupta et al. (2016)																																																							
Hand et al. (2018)																																																							
Iraegui et al. (2020)																																																							
Janssen & Rosu (2015)																																																							
La Rosa et al. (2018)																																																							
Mears et al. (2020)																																																							
Onder et al. (2011)																																																							
Purwohandoyo et al. (2023)																																																							
Reyes et al. (2014)																																																							
Robillard et al. (2023)																																																							
Teeuwen et al. (2023)																																																							
Walker et al. (2021)																																																							
Weber et al. (2023)																																																							
Wolch et al. (2005)																																																							
Xing et al. (2020)																																																							
Ye et al. (2023)																																																							
n accounting for	3	1	5	0	0	0	1	0	2	0	0	0	0	0	0	0	16	6	3	6	0	23	4	0	1	14	0	3	1	1	0	0	0	2	10	1	2	7	8	11	1	14	2	0	0	0	0	1	6	23	19	0	5	3	0

* Two studies with partial overlap in authors (Almeida et al. 2022; Ribeiro et al. 2019) seemingly apply the exact same measure and are counted as one.

Table B2. Workshop participants and the factors they propose to measure, either directly (black cells) or indirectly (grey cells). In light grey, clusters of factors are highlighted that participants explicitly stated as critical to measure, without further explanation. In contrast to measures in literature (table 2), participants emphasize the importance of understanding the child, and to a lesser extent, their household and network, as well as their motives for visiting greenspace.

	(with) whom?																from where?					how?									to where?													why?											
	child					household					network						starting sett.					route									greenspace													motivation				overarching				contextual			
participant	age	gender	(in)dependence	character	condition	family	housing	guardian	background	restrictions	peers	friends	teachers	caregivers	restrictions	mentorship	home	school	en route	neighborhood	places	proximity	modality	cost	neighborhood	infrastructure	barriers	traffic	appeal	ease	management	maintenance	conflicts	interactions	playfulness	local climate	variety	facilities & amenities	naturalness	vegetation	lay-out	scale & size	openness	intention	concerns	preferences	interests, beliefs & values	safety perception	trade-off	reachability	attractiveness	social norms	temporality	spatial surroundings	organization
P1.1																																																							
P1.2																																																							
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n accounting for	1	0	5	0	0	1	3	1	1	0	2	2	0	0	1	0	12	8	6	7	4	11	8	0	1	7	7	10	2	1	0	0	1	1	13	8	1	1	8	6	3	3	0	5	0	9	0	6	1	20	20	0	5	0	0