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A Novel Data-Driven Approach to Examine Children's Movements and Social Behaviour in Schoolyard Environments

Maedeh Nasri [1,2,*], Yung-Ting Tsou [1,3], Alexander Koutamanis [4], Mitra Baratchi [5], Sarah Giest [6], Dennis Reidsma [7] and Carolien Rieffe [1,7,8]

1 Unit of Developmental and Educational Psychology, Institute of Psychology, Leiden University, 2300 RB Leiden, The Netherlands; y.tsou@fsw.leidenuniv.nl (Y.-T.T.); crieffe@fsw.leidenuniv.nl (C.R.)
2 Leiden-Delft-Erasmus Centre for BOLD Cities, Leiden University, 2300 RB Leiden, The Netherlands
3 Department of Computer Science, Faculty of Science, Vrije Universiteit Amsterdam, 1081 HV Amsterdam, The Netherlands
4 Faculty of Architecture & the Built Environment, Delft University of Technology, 2628 BL Delft, The Netherlands; a.koutamanis@tudelft.nl
5 Leiden Institute of Advanced Computer Science, Leiden University, 2300 RA Leiden, The Netherlands; m.baratchi@liacs.leidenuniv.nl
6 Institute of Public Administration, Faculty of Governance and Global Affairs, Leiden University, 2511 DC The Hague, The Netherlands; s.n.giest@fgga.leidenuniv.nl
7 Faculty of Electrical Engineering, Mathematics and Computer Science, University of Twente, 7522 NB Enschede, The Netherlands; d.reidsma@utwente.nl
8 Department of Psychology and Human Development, Institute of Education, University College London, London WC1H 0AA, UK
* Correspondence: m.nasri@fsw.leidenuniv.nl

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Abstract: (1) Many children in schoolyards are excluded from social interactions with peers on a daily basis. For these excluded children, schoolyard environments often contain features that hinder, rather than facilitate, their participation. These features may include lack of appropriate play equipment, overcrowded areas, or insufficient supervision. These can generate negative situations, especially for children with special needs—such as attention deficit or autism—which includes 10% of children worldwide. All children need to be able to participate in their social environment in order to engage in social learning and development. For children living with a condition that limits access to social learning, barriers to schoolyard participation can further inhibit this. Given that much physical development also occurs as a result of schoolyard play, excluded children may also be at risk for reduced physical development. (2) However, empirically examining schoolyard environments in order to understand existing obstacles to participation requires huge amounts of detailed, precise information about play behaviour, movement, and social interactions of children in a given environment from different layers around the child (physical, social, and cultural). Recruiting this information has typically been exceedingly difficult and too expensive. In this preliminary study, we present a novel sensor data-driven approach for gathering information on social interactions and apply it, in light of schoolyard affordances and individual effectivities, to examine to what extent the schoolyard environment affects children's movements and social behaviours. We collected and analysed sensor data from 150 children (aged 5–15 years) at two primary special education schools in the Netherlands using a global positioning system tracker, proximity tags, and Multi-Motion Receivers to measure locations, face-to-face interactions, and activities. Results show strong potential for this data-driven approach to examine the triad of physical, social, and cultural affordances in schoolyards. (3) First, we found strong potential in using our sensor data-driven approach for collecting data from individuals and their interactions with the schoolyard environment. Second, using this approach, we identified and discussed three schoolyard affordances (physical, social, and cultural) in our sample data. Third, we discussed factors that significantly impact children's movement and social behaviours in schoolyards: schoolyard capacity, social use of space, and individual differences. Better knowledge on the impact of these factors could help identify limitations in existing schoolyard designs and inform school officials, policymakers, supervisory authorities, and designers about current problems and practical solutions. This data-driven approach could play a crucial role in collecting information that will help identify factors involved in children's effective movements and social behaviour.

Keywords: children; affordances; social behaviour; schoolyard design

1. Introduction

Children spend a considerable amount of time in schoolyards, engaging in loosely structured activities under relatively mild supervision. The schoolyard environment, therefore, presents unique opportunities for children to play and develop their physical and social skills. Unfortunately, schoolyards may also pose unexpected obstacles that limit social play in various ways. For example, poor acoustics might hinder children who face barriers to communication, including children with hearing loss or autistic children. Examining children's behaviour in the context of the particular environment where it occurs could aid in identifying existing limitations and possibilities for schoolyard design. It could also inform the development of methods for improving schoolyards and make it possible to tailor designs for sensitivity to differences in children's needs, desires, and capacities. This, in turn, could help maximise opportunities for social learning for all children, including those who belong to vulnerable populations.

However, making this picture clearer requires a huge amount of data: precise information gathered over time, pertaining to not only different aspects of children's behaviour, but also to the specific environment in which the behaviour occurs. This study, therefore, presents a sensor data-driven approach for gathering the information necessary for examining the effects of the schoolyard environment on children's movements and social behaviours.

1.1. Affordances and Effectivities in Physical, Social, and Cultural Environments in Schoolyards

When children are in a schoolyard, they are constantly confronted with at least three layers of the schoolyard environment: the physical/built environment (physical layout and features) [1,2], the social environment (people to interact with) [3,4], and the cultural environment (rules and constraints set by schools) [5–7]. All three layers present different affordances to the children (see Box 1). Affordances are the actionable properties an environment presents to a child (e.g., a sandpit affords building a sandcastle) in relation to the children's individual desires, needs, and capacities. That is, an environment's affordances are relative to specific actions. For example, a sandpit that is empty makes no difference in affording opportunities to a child who wants to be running around. Certain interactions require an appropriate setting: a quiet, secluded corner for confidential talks or a wide-open area for a large game involving physical activity. Certain settings stimulate certain activities and behaviours, as one can observe around any piece of schoolyard equipment, and certain activities are subject to school rules and conditions, e.g., football or cycling may be permitted only in specific places and at particular times.

Several studies incorporated a perspective on affordances to focus on interactions of children in general with their physical, social, and/or cultural environment. Many affordance studies concerning children, schoolyards, and schools depart from Heft's categorisations [8]. Heft distinguished between ten types of outdoor environments, such as "flat, relatively smooth surfaces" (which may afford walking, running, cycling, skating, skateboarding) or "attached objects" (which may afford sitting on, jumping on/over/down from), and further extends affordances to include social and emotional behaviours [9,10]. Physical affordances are mostly studied in children-oriented research, including studies on how different environments (e.g., home, school, sport, leisure, neighbourhood, outdoor play) either promote or hinder various motor activities [11–13] and how physical, social, and cultural affordances influence physical activity levels in schoolyards [14,15].

Yet, when studying how schoolyard environments afford opportunities for children to play, it is important to consider all three layers of the environment: physical, social, and cultural. These are closely intertwined and ignoring any layer could bias any data analyses and interpretations. For example, if a play area is too small, children who come late to the game may be excluded simply because there is no room for them. Such an outcome due to capacity issues may not necessarily reflect social exclusion. However, this example illustrates restrictions imposed by the design and operation of a schoolyard. Moreover, if the social environment is not taken into account when considering the physical and cultural characteristics of a particular schoolyard, then schools, policymakers, and designers could be kept unaware of the limitations and possibilities of that schoolyard. Consequently, opportunities for improvement could be missed.

Of particular interest are vulnerable children (e.g., children with a clinical diagnosis or disability) who might have different desires, needs, and capacities ("effectivities") in their use of space. Specifically, these children may have different preferences, needs, or capacities as compared to other children in the same environment. For example, children with autism spectrum disorder (ASD) may be sensitive to certain ambient triggers (sounds, light, or touch) or avoid being in crowded areas [16–18]. They often prefer repetitive games with predictable results, such as spinning, twirling, and illuminating [19,20], and fixed routines with clear instructions and rules to follow [21]. Autistic children can also find initiating or maintaining social contacts with other peers quite challenging [22]. Children with attention deficit hyperactivity disorder (ADHD) are observed to often change activities during breaktime, and many ADHD children have difficulties sustaining interactions with peers [23–25]. Thus, for vulnerable children, it may be especially critical to unravel the relationship between their individual interactions and their environment.

By identifying affordances, we can be explicit and transparent in two critical aspects that are especially relevant to the inclusion of vulnerable children in schoolyards. First, working through a lens of affordances makes an explicit definition about vulnerable children's capacity, so as to know what they expect and want or can do. This, consequently, facilitates awareness of special needs. This is notable because although special needs are usually considered in the teaching activities in the classroom, they may be ignored in the design and use of the schoolyard. Second, taking affordances into consideration clarifies the influences of the physical environment on children's activities. Consequently, making affordances for vulnerable children explicit can help identify existing limitations and develop methods for the analysis and evaluation of school environments.

Taken together, we see a need for understanding individual interactions at the micro-level of peripersonal space while still taking into account the physical, social, and cultural layers of the children's direct environment and the challenges they may pose for excluded children. To the best of our knowledge, there are no prior studies that examine how the environmental triad of physical, social, and cultural affordances interact with children's behaviours and movements in the schoolyard. Moreover, in available affordance studies, vulnerable children have never been considered. While a large body of literature has reported on vulnerable children's physical activity levels, forms of play, and social connectedness in the schoolyard [26–29], outcomes that were reported were not linked to any environmental factors.

Box 1. Affordances in schoolyards

For the purposes of our research, we distinguish between three levels of affordances:

- *Physical affordances:* what the physical layout and features of the schoolyard afford to children and their activities. These are critical for many vulnerable children, to the extent that they may even exclude themselves from what takes place in the schoolyard. For example, what most humans tolerate as mild background noise can be insufferable to children with cochlear implants, who, consequently, tend to refrain from entering schoolyard areas where they are exposed to such noise [30,31].

- *Social affordances:* these refer to two complementary matters:
  a. *What features in the schoolyard afford social interaction*, i.e., social interactions in our case, should be accommodated and facilitated by the environment. For example, having a chat with a classmate requires some sitting furniture in a quiet part of the schoolyard. This involves not only the need for a suitable environment for social interactions, but also the features in the environment that stimulate social interactions (such as the presence of a seesaw, which invites play with another child).
  b. *How the presence of others adds to or detracts from the affordances of the physical environment*. For example, if a swing is already occupied by another person, then the child is unable to sit on it. However, a new affordance becomes available, e.g., pushing the person sitting on the swing.
- *Cultural affordances:* free play and schoolyard use are normally subject to constraints where, for example, some intensive or hazardous activities (such as football or cycling) are allowed only in certain parts of the schoolyard or for a specific period of time.

1.2. Present Study

How do we identify a schoolyard's affordances in relation to the effectivities of the children who use it? Most of the previous affordance studies relied on qualitative data, such as observations and self-reports. Although informative, these methods might not examine different interconnected aspects in a cost-effective way, nor give the detailed level of information necessary to draw reliable conclusions. Yet these objectives might be achieved by using newly available sensor technologies. Sensor data promise comprehensive coverage of what takes place in a schoolyard at a low cost. They make continuous, objective monitoring of activities and interactions feasible. They provide reliable reports on schoolyard performance and enable schools to identify problems as soon as they emerge. Some recent studies applied Global Positioning System (GPS) trackers and accelerometers. This new data-driven approach has been used, for example, to examine physical activity levels [32] and to compare active outdoor play in schoolyards and in natural environments, taking into account personal characteristics (e.g., age) as well as the physical and social environment [33–36].

The main challenge is to collect such precise information from different layers and unravel the complex relationship between environmental affordances in schoolyards and children's effectivities. To deal with this, we designed a data-driven approach for collecting data that would feature enough detail and precision to inform us about relations among three different environmental layers (physical, social, and cultural) and the children's role in these. We then examined the extent to which children's movements and social behaviours were affected by the physical, social, and cultural affordances of a schoolyard by identifying three successive aims.

First, we aimed to develop a novel sensor data-driven approach by integrating unobtrusive data collection. This technology included GPS loggers to obtain children's location and their trajectory and speed of movements, Bluetooth-based proximity tags to examine face-to-face interactions of individuals, and Multi-Motion Receivers (MMR) to obtain the physical activity level of children. This approach enabled the monitoring of children's activities in the schoolyard, their interactions with peers, and their movements within the environment during unstructured breaks at school. Multimodal analyses of sensor data yielded a detailed, precise picture of children's interactions with peers and their direct environment. Data and results obtained through these new methods based on sensor data were validated using video observations of these schoolyard events.

Second, we aimed to distinguish between three interconnected types of affordances (physical, social, and cultural) and gave each of these explicit and measurable definitions (see Box 1). By operationalising these terms, the data could be interpreted with greater precision and less bias. To illustrate the value that these data can have, we analysed data collected from two schoolyards. Integrating the sensor data based on the triad of affordances, in addition to providing extensive information on each individual aspect, provided extensive interdisciplinary knowledge on how the physical environmental features affected children's social participation and movements. In addition, it highlighted how the presence of other individuals affected children's behaviour and movement in the physical space. It also revealed how the rules set by schools and supervisors affected children's social participation and use of space.

Third, by considering the relevance of these data, we aimed to better understand how the collected data and their analyses could inform schools, planners, and designers about the possibilities and limitations a schoolyard presents and help plan for practical solutions and improvements, particularly with respect to the individual differences in effectivities of vulnerable children.

2. Methodology

Our methodology addressed two main goals simultaneously. On the one hand, we developed a setup of sensors to gather data in the schoolyards, and an approach to work with these, in the context of two schools. On the other hand, we also carried out a simultaneous study where we gathered data from children in these schoolyards and analysed them to gain insight on children's behaviour and their relation to the three environmental layers (physical, social, and cultural). This section presents this integrated methodology.

2.1. Selection

We developed our data-driven approach and applied our approach in the context of two primary special needs schools that were geographically located in the centre of the Netherlands. The schools and parents were informed about the purpose and planning of the study and supplied written consent for the children to participate in it. Approval for the study was obtained from the Leiden University Ethical Committee. The data management procedures were registered and approved by the Leiden University Research Data Management Plan. Prior to data collection, a video presentation was presented to children that explained the research in simple words in order to prepare them for participating in this study.

2.2. Reconnaissance

Prior to data collection, the researchers visited each school for a reconnaissance visit (i.e., to explore the situation with an aim to define a strategy) to investigate the physical and social environment. This first contact gave them the opportunity to familiarise themselves with the schoolyard, explore its environmental features, and conduct informal interviews with the school director, teachers, and caretaker during a tour of the school building and its surroundings. This go-along approach is common at the exploratory stage of similar research [36,37]. Interviews included questions about school customs, teacher and pupil preferences, habits, the organisation of breaks, and schoolyard activities. In combination with the visual inspection of the schoolyard, these provided an initial impression of physical, social, and cultural affordances and led to hypotheses about the social and cultural context of school breaks, as well as to the selection of locations where sensor facilities should be positioned. Ultimately, the reconnaissance visit informed us about: (1) the proper locations for installing the sensor equipment and video observers, (2) general rules about breaks (e.g., that children were not allowed to stay in classrooms except on special occasions), and (3) the general rules regarding the use of the schoolyard, such as soft boundaries and area allocation during breaks.

2.3. Participants

A total of 150 children aged between 5 and 15 years old participated from 21 different classes from two schools (schools A and B). Data collection took place over a period of two weeks at each school, split between two recess times on consecutive days for each class. Each measurement lasted a maximum of 50 min, depending on the playgroup (younger children usually have a more extended break than older children).

School A is for children who need extra care and support because their well-being is often under pressure due to learning pace, large-size classes, or overwhelming contact with others. The school, therefore, offers more structure, predictability, personal attention, and specialist support to improve their well-being. The majority of pupils are undiagnosed, or their diagnoses were unknown to us (63%). Of the rest, most had ADHD (20%) and ASD (14%) as their primary or secondary diagnosis.

This school is located in an urban residential area where streets abutted the school on three sides and the backyards of single-family homes abutted school property on the fourth side. Hard borders (e.g., fences or walls) separated the school area from its neighbours. As shown in Figure 1, schoolyard use is separated into two parts, with junior classes being allocated a different part (sub-areas I, II, and III) than the senior classes (sub-areas IV and V).

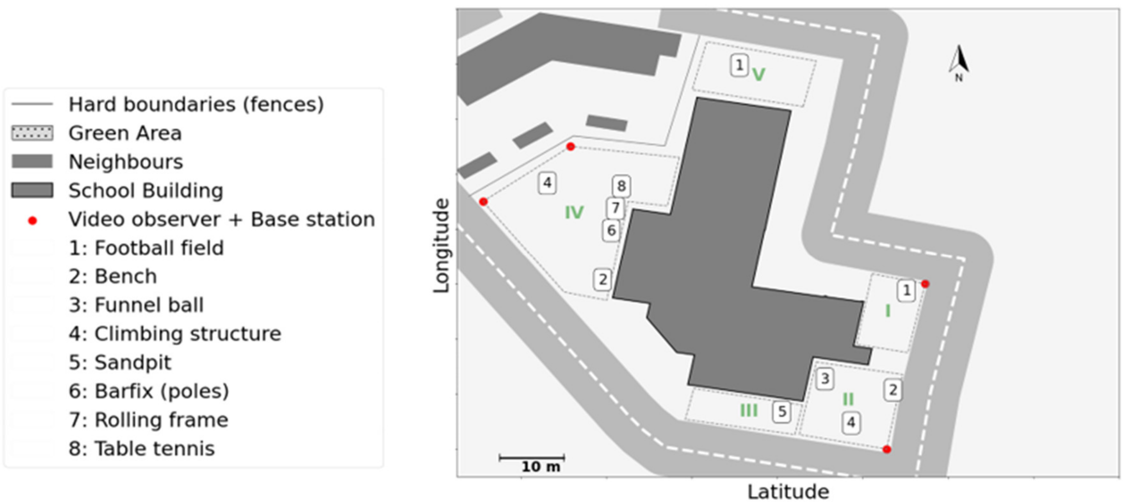

Figure 1. The layout of school A.

School B offers education to children whose development is disrupted or at risk of disruption due to reasons such as behavioural problems, emotional problems, or psychiatric issues. A total of 76% of students were diagnosed with ASD and 34% with ADHD as their primary or secondary diagnosis. Therefore, these two conditions accounted for the majority of students in School B.

The school is located in a rural area in close proximity to green spaces. It is located on the site of a larger complex of special needs facilities. In the first part of our study (Figure 2a), the school shared some outdoor areas of the complex, notably a football field. On the south side, the school bordered residential properties with green areas in between. The schoolyard was therefore demarcated by soft borders on practically all sides. During our study, the schoolyard was renovated. The new layout included a harder yet penetrable separation from the complex and a higher degree of self-sufficiency, primarily thanks to its own football field (Figure 2b). Data collection was conducted in three waves: (1) before the renovation, (2) after renovation, and (3) following minor, local improvements in the renovated schoolyard (6 months after the renovation).

Figure 2. Layout of school B: (**a**) before renovation, (**b**) after renovation.

2.4. Validation of Measures Obtained through Sensor Techniques

Two video recorders were present to supply validation for the data collected during the breaks using sensor techniques. Locations for video observers and sensor equipment were determined during reconnaissance visits. In the current study, video recordings were used for visually verifying the sensor data analysis and supporting the observations presented in the Results section.

2.5. Variables and Measures

2.5.1. GPS Loggers

GPS loggers record the location of the wearer, allowing us to track the movement of each child in the schoolyard, i.e., the trajectories they follow and the places they visit. The GPS loggers used were of the i-gotU GT-120 USB type. Noise in the GPS data was removed by keeping only sequences where at least five successive points were situated within a distance of 10 m of the schoolyard outline, to account for positional accuracy of GPS loggers. We excluded data points with unrealistic speed (10 m/s cut-off point) [38,39]. The remaining data points were used for further analysis. In schoolyard affordances, GPS locations were adopted in two directions:

- Trajectories of children contained the longitude and latitude of movements, through which the speed of movements was calculated (speed = displacements over time).
- A kernel density estimate (KDE) estimated the distribution of GPS locations in a playgroup and assessed the most visited areas.

2.5.2. Proximity Tags

OpenBeacon proximity tags were used in the research with two base stations (BeagleBone Black minicomputer augmented with custom OpenBeacon hardware). Proximity tags registered each other via Bluetooth at a distance of up to 1.5 m. They wirelessly sent data on these sightings to the base stations, which received signals 4 times per s [40,41] and registered information broadcast by tags up to 25 m away. The proximity tags were used to detect face-to-face interactions between subjects during recess. Since most children were involved in active play, their body movements or interfering objects, such as other individuals passing by and toys, may have interrupted the signal. To compensate for this error, the raw proximity data were interpolated by joining two successive interactions between the same peers if the time gap between the two contacts was less than a certain threshold [42]. The obtained variable was defined as follows:

- Spatial interaction was calculated by taking the face-to-face interaction from the proximity tag and fusing it with GPS locations. This gave crucial information on where interactions took place in the schoolyard.

2.5.3. MMR Sensors

The MMR sensor is a wearable device that includes a BMI160 6-axis accelerometer and gyroscope, a BMM150 3-axis magnetometer, and allows continuous monitoring of activities along three axes. In schoolyard affordances, MMR data were used as the following variable:

- Activity level is determined based on cut-off points proposed by Puyau et al. [43], who validated accelerometer-based activity against energy expenditure (EE) in children within a 15-s time frame. We were able to adopt Puyau's setpoints because: (1) the average participants' age was similar to our study (6–16 years old) and (2) the activities performed in the validation study were the same as children's activities in the schoolyard (walking, running, free-living activities such as computer games, playing with toys, aerobics, skipping, jump rope, soccer). This variable was date- and time-matched to each 1-s GPS data point to obtain how the activity level was related to environmental features and physical affordances.

Participants wore the three devices mounted on a belt of adjustable length which was worn around the waist. Subjects were asked to wear the belt only during the break and to take it off when the break ended. Teachers supervising the children during the break were also issued with sensor belts to capture their interactions with pupils. As established at the reconnaissance visit, all children were required to leave the classroom during breaks, except when the weather, sickness, or other major problems made it unwise.

3. Results

By adopting the above data-driven approach, we effectively carried out extensive data collection in two schoolyards. In this section, we present the results of our data analysis, which examined relations between children's behaviour and environmental characteristics. All analysis was performed in Python 3.6.1 within the Anaconda environment. Geographical data for location identification were extracted from the OpenStreetMap. For all three sensors, time was used as a unique identifier (uid) and the merging of datasets was based on the recorded timestamps.

3.1. Physical Affordances

With respect to physical affordances, the data revealed that the availability of equipment and furniture, as well as their condition, could be critical to attracting attention and activity. Figure 3 shows the KDE plot of all groups in the (a) morning break and (b) lunch break at school B around the multi-functional structure that was one of the key new features in the renovated schoolyard. This structure includes one plastic slide (solid white colour in Figure 3) and a metal slide (white with dot hatch), as well as stairs, rope and rock climbing, a catwalk area, and a spinner structure. On that particular day, due to the cold weather and low ambient temperature, the metal slide had frozen during the morning break. Since an icy surface has lower friction, the metal slide afforded higher sliding speeds and was, therefore, a popular spot, with a higher traffic density in comparison to the plastic slide in Figure 3a. Figure 3b shows the situation at the same structure during the lunch break. By that time the temperature had risen, rendering the metal slide less speedy and therefore less popular. In fact, at that time, spatial density around the plastic slide was higher.

Figure 3. Use of space around the slides on the multi-functional structure, analysed by GPS data, during (**a**) the morning break and (**b**) the lunch break in school B. The level of use is analysed via GPS data and obtained contours are colour-coded, from the lowest level of use to the highest, following the colour bar (from yellow to red).

This sophisticated, unusual play structure did spark children's curiosity and became a popular spot after it was added to the schoolyard through renovation. As the heatmap of young children in Figure 4a shows, before the schoolyard was renovated, the most heated spots were the sandpit and swings (Spots 2 and 3) and the areas around them where children could cycle around. Adding the new multi-structure on Spot 10 attracted children towards this new structure (Figure 4b). However, during the follow-up, many children lost interest and reverted to their old preferences (Figure 4c; on Spots 2 and 3).

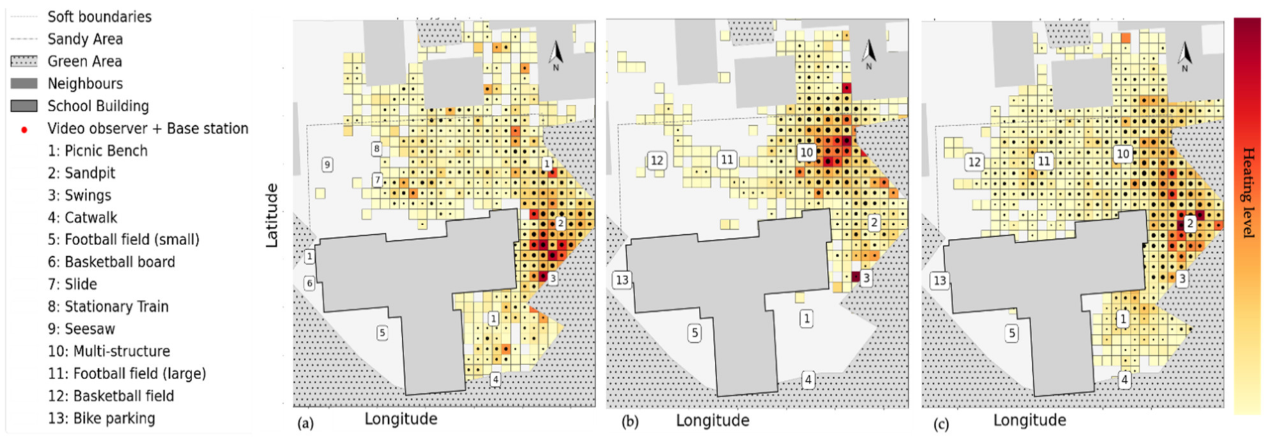

Figure 4. Young children's heatmap analysed via GPS data in school B. (**a**) Before the renovation. (**b**) Children attracted to the newly added structure after the renovation. (**c**) Children return back to their old habitat during the follow-up. The colour bar shows the duration of the visit. The warmer the colour (following the colour bar from yellow to red), the higher the duration of visits by children. The black dots indicate the number of children in each segment. The larger dots show a higher number of children in that spatial bin.

The layout of the schoolyards and the proximity of play structures relative to each other could also affect children's movements and activities. Figure 5 shows the physical activity level of children, fused with GPS locations and then mapped to the floorplan. Having a low proportion of vigorous activities in this playgroup suggests that the schoolyard does not offer enough space for high physical activity level activities and games.

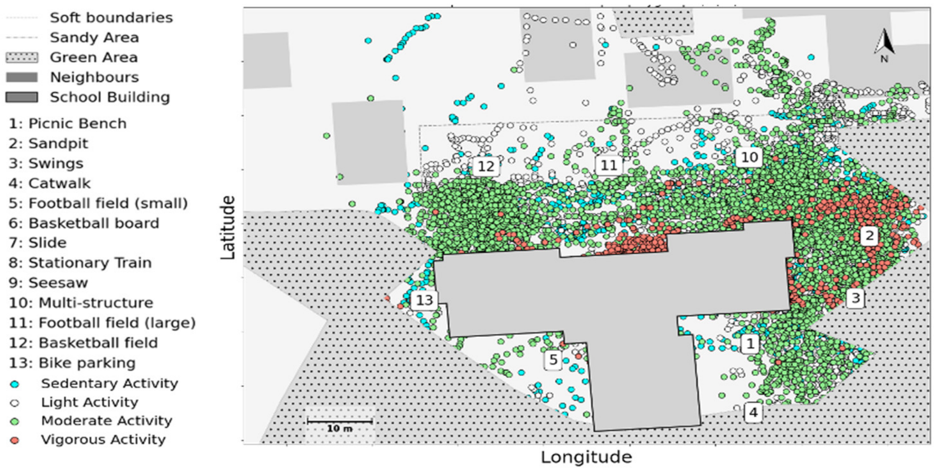

Figure 5. The location of physical activity levels in school B was analysed via accelerometer data and then fused with GPS locations.

3.2. Social Affordances

With respect to social affordances, it is equally clear that the density of users affects some activities, such as cycling, by pushing them away from crowded areas and causing intermittent trajectories. Figure 6 depicts the trajectory of a subject in school A, where the child is cycling in the schoolyard between the climbing frame and a yard fence. His speed reaches its highest value in the midway and is reduced near route endpoints and physical structures that provide opportunities for social interactions: the bench where supervising teachers are seated and the climbing frame where peers are playing. As illustrated in Figure 6, near the climbing frame the speed not only drops to a minimum, but stationary time also increases (as shown in the red circle with data points with low-speed levels and little displacement along the trajectories around the climbing frame), suggesting the possibility of quick chats with peers. Face-to-face contacts captured by the proximity tags confirm that such social interactions occurred near the climbing frame (green stars) and at the bench (green triangle).

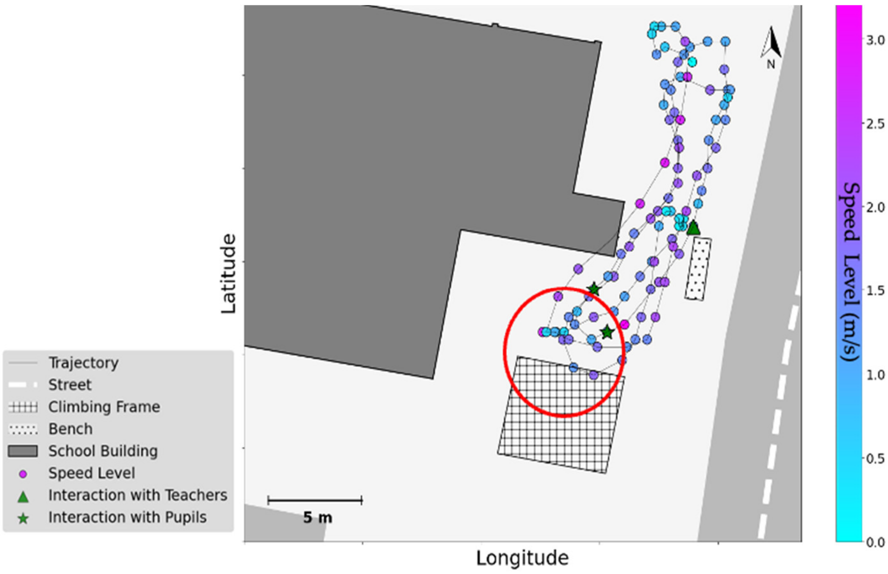

Figure 6. Cyclist in school A: the trajectory of movement is extracted from GPS data and colour-coded based on speed level (from light blue to light pink, following the colour bar). Face-to-face interactions are analysed from proximity tags, fused with GPS data, and mapped to the school floor plan (triangle—interaction with the teacher; star—interaction with peers).

Social affordances could also determine which physical affordances were established. Especially in senior classes, the use of space could be influenced more by who than by what. Children at this age often stay with a specific sub-group throughout the break in a certain schoolyard area that they "own". As Figure 7 shows, in school A, the areas around the tennis table and the bench were where most social contacts happened. GPS data confirm the presence of groups from senior classes in these areas. The table was used for sitting and mingling rather than for playing table tennis, which suggests that social affordances are more important than the expected use. Use of the bench by a specific group from senior classes was consistently observed across several break sessions and confirmed by the sensor data (see Figure 6).

Figure 7. Social use of space by senior classes in school A. The level of use is analysed via GPS data and obtained contours are colour-coded from the lowest level of use to the highest following the colour bar (from yellow to red). Face-to-face contacts are extracted from proximity data, fused with GPS locations, and mapped to the school floor plan (note that the base station could not cover the interactions that occurred in Area 1 and no interaction from that region was therefore registered).

Data also reveal movement patterns at the individual level, such as the behaviour of an ASD subject in comparison to the rest of the playgroup. Figure 8 shows the GPS data of one of the playgroups in School A, where the spatial data of an ASD subject indicate that the child remained close to the school building, avoiding dense areas.

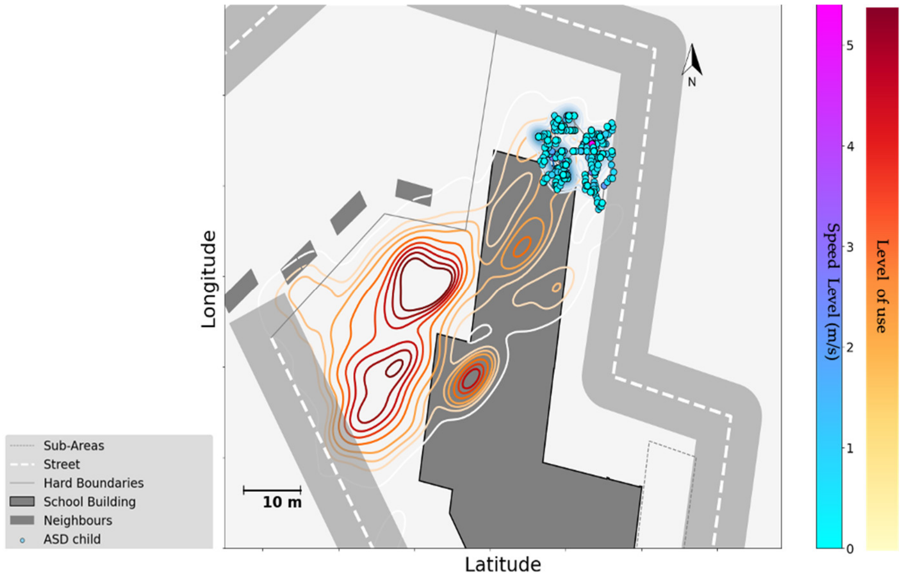

Figure 8. The use of space by an ASD child in comparison to their playgroup in school A. The level of use is analysed via GPS data and obtained contours are colour-coded, from the lowest level of use to the highest, following the colour bar (from yellow to red). The GPS location of the ASD child is plotted on the floor plan and colour-coded by speed level, from the lowest speed to the highest, following the colour bar (from blue to pink).

3.3. Cultural Affordances

Cultural affordances were quite strong, as expected for this age group and for the capacities of ASD children. For instance, in School A, younger groups were free to use all three sub-areas (I, II, and III). However, wheeled toys (bikes, steppers, scooters, etc.) were restricted to sub-area III when a specific supervisor was in charge (Figure 9a). Since biking was one of the most popular activities among young children, this restriction has a significant impact on the use of space in the schoolyard. Figure 9a shows the KDE plot when wheeled play was restricted to sub-area III: a high-density level around area III, with a peak at the end of III where the turning point was. Figure 9b shows a different day when children were not restricted to sub-area III for biking. On that day, spatial density was widely distributed over all three sub-areas.

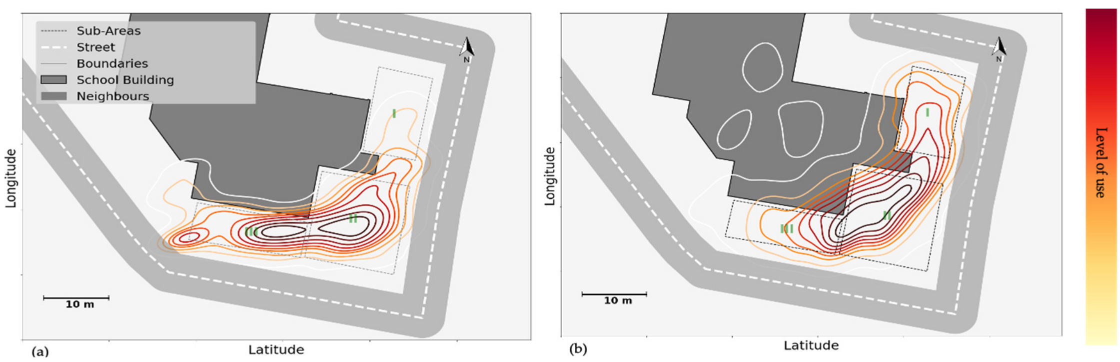

Figure 9. The use of space by cyclist children in school A (**a**) with restriction and (**b**) without restriction from the break supervisor. The level of use is analysed via GPS data and obtained contours are colour-coded, from the lowest level of use to the highest, following the colour bar (from yellow to red).

Violation of school rules was only occasionally observed, for example in the trajectories of a few subjects who wandered around in School B before renovation (green dots in Figure 10). This contrasted with the trajectories of subjects who went to play on the football field. These followed the shortest route to the remote football field, with no subjects wandering off (purple dots), according to the school rules (children were not allowed to cross the soft boundaries and move around in the residential area).

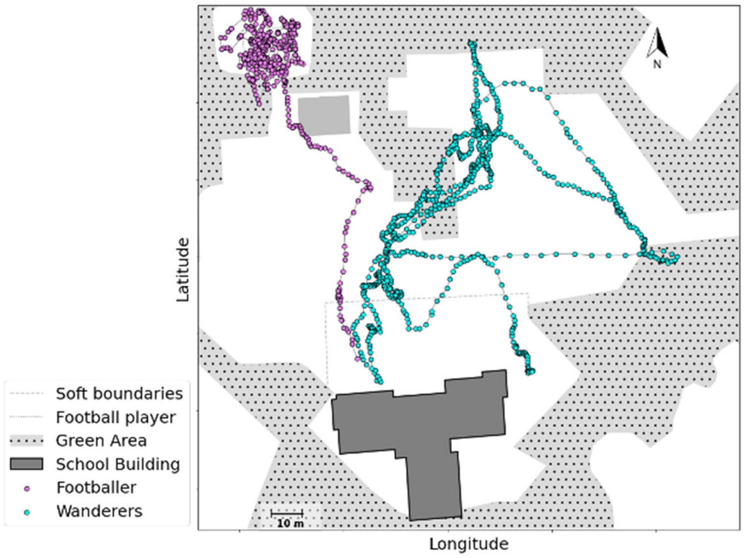

Figure 10. The trajectories of a group wandering around against school rules and football players in school B were extracted from GPS data.

Supervision naturally reinforced cultural constraints. In fact, in both schools, most constraints were designed with supervision in mind, i.e., how to make it more economical and more effective. This, however, also created an illusion of full control among the teachers, who were surprised when the researchers reported the above example which they had never observed and had not even suspected. Otherwise, they would have taken measures to prevent it.

4. Discussion and Conclusions

The purpose of this study was to show a data-driven approach that examined how three environmental layers (physical, social, and cultural) interact with children's movements and behaviour during unstructured play at recess time. Through modern sensor technologies, sensor data were collected on children's activities in two primary special education schools in the Netherlands. The obtained data were further analysed in light of schoolyard affordances.

Our first aim was to adopt a novel sensor data-driven approach to examine affordances in schoolyards. Observations by our researchers and feedback from the school demonstrated that the belt we had designed with sensors was not distracting for children. Instead, it was exciting to primary school children, who showed eagerness to participate in the research. Moreover, our data-driven approach allowed us to register more subjects over a longer period of time by including more activities (i.e., locations, face-to-face interactions, physical activity level) cost-effectively. Finally, the data and results obtained through this new approach were validated through corresponding video observations which resulted in sufficient precision, as discussed in the Results section.

Regarding our second aim, we examined three layers of affordances—physical, social and cultural—in two schoolyards. After analysing the sensor data, we interpreted the obtained results in light of physical, social, and cultural affordances. Using the physical affordances, the material of the play structure, the availability of a new play structure, and proximity of equipment in the schoolyards were identified as impactful factors on children's play and physical activity level. On the social level, the availability of certain equipment (e.g., bench and climbing frame) limited the cycling path, but also provided opportunities for the cyclist to interact with their supervisor and other peers in the schoolyard. Beyond that, several physical features, such as a bench and a table tennis table, offered hang-out spots for senior classes. Some physical spaces, such as adjacent backyards or areas close to the school building, served as areas of refuge for those who wanted to avoid crowds. Regarding cultural affordances, data showed how children's cycling, and therefore use of space, was impacted by a temporary rule set by one of the supervisors. Data also revealed that children from one of the schools violated a rule by trespassing beyond the soft boundaries, which was otherwise unknown to the supervisors.

Finally, three main environmental layers that influence children's movements and behaviour were identified. These addressed our third aim of identifying effective factors and informing relevant authorities about existing obstacles and opportunities.

First, the physical capacity of the schoolyard, such as its size, shape, equipment (e.g., availability and arrangement) and relevant rules and constraints, serves as a preliminary trigger that affects children's movements and behaviours. The schoolyard should have adequate capacity and offer a variety of options for children to play and engage in different activities. In addition, the options offered by the schoolyard, depending on its design (climbing frames, swings, seesaw, etc.) and arrangement (e.g., materials, height, size, and proximity to other equipment) could either hinder or attract children to the equipment and discourage or encourage play (e.g., the sliding example in Figure 3; physical activity level in Figure 5).

Earlier research also confirmed that schoolyard size and availability of play equipment, such as sports facilities, recreation areas, surface materials, and greenery elements, could promote children's physical activity level [44,45]. Green areas are also found to be a contributing factor in promoting children's resilience and reducing their stress levels [46]. Similarly, close proximity between play structures generates more spots for physical activity [36,47]. Yet, our data showed that close proximity between different play equipment in a small space could also result in lower physical activity levels. The overall shape of the schoolyard influences the supervision method and could result in demarcations that reduce the space available to children (e.g., restricted cyclists in Figure 9 versus wandering cyclists in Figure 10). Importantly, our three-wave data collection in school B shows that new, fancy equipment may not always remain attractive after the novelty wears off. With time, children may still return to equipment that affords a wider variety of creative activities. This again emphasises the importance of examining the capacity of the schoolyard according to its affordances.

Second, opportunities for social interaction often attract children towards certain spots and motivate children to use the space for social purposes. Our data confirmed that the spots where such opportunities were offered could indeed stimulate social interaction, even when they were not originally designed for that purpose (e.g., the bench and climbing structure in Figure 6; the tennis table in Figure 7). This outcome echoes previous findings about the impact of environmental aspects with green and natural elements, multi-functional equipment with diverse structures such as sandpits and stairs, and (semi-)secluded places, among others encouraging children's social interactions [48–52]. These features usually afford more variety and flexibility in children's play and may be helpful for the initiation of social activities, as well as offering a space to play and hang out without interruption or recover from active play [48,52].

Conversely, popular areas and equipment can also cause more conflicts over available resources. For example, play structures such as swings, slides, and seesaws can be locations that support constructive interactions, as well as foci of competition, irritation, or even bullying. School organisations and supervisors play a key role here in identifying these factors, taking the required precautions, and overruling the existing climate [53] (e.g., by planning a timetable for using a popular play structure by different sub-groups of children). These findings have important implications for developing interventions that adapt the environment to promote social participation. They also show the strengths of our proposed sensing system in evaluating the intervention and informing relevant outcomes to schools, designers, and policymakers.

Third, individual needs could lead to quite different patterns in the use of space. Despite the patterns shown in the above two points, our data showed that vulnerable children, who have different capacities and needs in their interactions with the environment, may use schoolyard affordances of any kind in a unique way. This is observed via sensor data in their trajectory of movements, use of space, and activities during the break, such as with the autistic child who remained next to the school building in Figure 8, away from the area where most of his/her classmates were playing. It also supports our hypotheses and highlights the need for school organisations to deliver extra support, customised rules, structures suited to vulnerable children, and an inclusive school climate that values diversity and individual differences. For example, the schoolyard could have different sub-areas in different colours and play structures, and children could choose in which colour (or sub-area) they would like to play before starting the break. In this way, supervisors could estimate high-demand areas and, by re-organising the available resources, try to strike a balance in the use of space. This could deliver substantial benefits to children who are overwhelmed by noisy crowded situations. While our sensing system enabled us to detect these “differences”, it is also important to identify whether these differences reflect the preferences of the child, or difficulties in joining others, or social exclusion.

Overall, the obtained results showed that making affordances explicit and measurable, through the use of approaches such as those presented in this paper, can help to better understand children’s behaviours and movementss as well as improve current layouts and forms of organisation, especially with respect to the capacity of vulnerable children.

Limitations and Future Directions

The sensor data configuration we used in this study allowed us to register more subjects and more activities with higher precision than we could have with observation methods. Yet, while a belt with sensors may be exciting to primary school children, it may not be suitable for adolescents in high school. In additional, in our current system, the valence of interactions and moves remains unknown. For example, while we could truly obtain from sensor data that a child played alone in the sandpit, we did not know their emotions or preferences. Therefore, one future direction of this research could be to improve the sensing system: first, it should be made suitable for a wider age range; second, it should incorporate a strategy to let participants actively express their emotions and preferences through focus group interviews and/or by providing real-time responses, for example, via smartwatches.

Another limitation of this study is that the obtained results were based on a small number of measurements at two special education schools. To design an automated monitoring system whose conclusions could be generalised to different environments and scenarios, more data collection would be needed. This was not possible due to the COVID-19 crisis but currently remains one of the major foci of this research team.

Finally, our proposed data-driven approach makes it possible to analyse particular play behaviour and environmental interactions among children at a specific school. While it makes it possible to gain a better understanding of the current challenges children face, it also holds the potential to reach beyond this understanding alone and empower schoolyard designers to define and monitor the effect of incremental improvements to schoolyards, for example, in the form of new equipment or changes in the physical organisation of the schoolyard. This approach could even be used to examine real-time adaptations to the rules and parameters of digital–physical interactive schoolyards. As such, the work presented here is the first step in what could become a long-term research program of a much wider scope.

For future studies that aim to adopt a similar approach, one of the most important lessons is that each case should be studied before collecting the data: all environmental layers (physical, social, cultural, and their interrelations) must be considered in order to form expectations for the data and their analyses. As described in Section 2.2., a reconnaissance visit that featured informal interviews and inspections helped us understand what took place in each schoolyard, its specific circumstances, and the intentions of the school (which should be respected but also critically analysed). As the data analyses demonstrated, there were many factors behind observed behaviours and patterns that may go unnoticed if researchers focus on a single aspect or goal. In other words, context matters. Depending on the research questions at stake, variables for capturing the environmental layers require clear definitions, and the particular sensing technologies should be chosen accordingly. For example, the positioning technology should be chosen depending on environmental conditions to appropriately record the location of the users, and thus reliably analyse the child's interaction with the environment. For example, GPS technology is more suitable for large outdoor areas, while UWB is a better option for relatively small areas. Integrating background knowledge obtained during a reconnaissance visit and the collected data from sensors allows for a better interpretation of environmental factors that affect children's movements and behaviour.

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Informed Consent Statement: Informed consent was obtained from all children's parents involved in the study before the test procedures. The informed consent form and the research protocol were approved by the Psychology Research Ethics Committee of Leiden University (V3-2685—date 24 October 2020).

Data Availability Statement: The data presented in this study are openly available in DANS

EASY at doi:10.17026/dans-2b6-y27b.

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