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GEOGRAPHY | RESEARCH ARTICLE

Investigating the spatial network of playgrounds during covid-19 based on a space syntax analysis case study: 10 playgrounds in Delft, the Netherlands

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Abstract: Playground plays important roles for children not only to accommodate their physical activities but also to improve their mental health. However, it is currently difficult to conduct playground activities regularly due to COVID-19 outbreaks. This study aims to explore the spatial structure of the playground based on space syntax analysis. It specifically investigates six different criteria through simulations (i.e., street accessibility, occupancy rates, visibility graph analysis), and an on-site observational approach (i.e., time sampling and user characteristics). As a result, this study presents playground catalogues that allow one to rethink new configurations of future playgrounds when dealing with pandemic and post-pandemic situations.

Subjects: Urban Studies; Theory of Architecture; Spatial and Regional Planning; Urban Design; City and Urban Planning

Keywords: space syntax; covid-19; playgrounds; spatial networks; street accessibility

1. Introduction

The unpredicted presence of the Coronavirus disease (COVID-19) has drastically changed the global movement behavior of society socially, economically, and politically. To delay the rapid spread of this COVID-19 outbreak, a range of non-pharmaceutical interventions (NPIs; Flaxman et al., 2020; Soltesz et al., 2020) have been applied by the government during the early phase of pandemic such as lockdown, social and physical distancing, self-isolation, and closure of

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community services. These strategies gradually enforce people to shift and adapt to a new working environment at home called work-form-home (WFH; Vyas & Butakhieo, 2020). Although the trend of WFH shows positive progress towards minimizing the risk of COVID-19 infection, side-effects such as distraction of family members (Xiao et al., 2020), noise (Dümen & Şaher, 2020), and internet costs (Whitelaw et al., 2020) cannot be denied as considerable factors that affect working productivity.

Likewise, with adults, difficult situations also apply to children during the lockdown. Due to the closure of schools and nurseries, children's play activities are significantly limited (S. Moore et al., 2020). Many parents struggle to facilitate play-based learning activities for their children, especially with regard to social-emotional skills and gross motoric skills. This is not only due to limited space (Toran et al., 2021) but also a lack of freedom for uninterrupted play (G. Wang et al., 2020). In this case, children cannot express their creative play easily and loudly because of neighborhood constraints that require a calm environment at certain hours, especially in densely populated areas.

Therefore, playgrounds play a crucial role in accommodating children's active play activities during the pandemic because in many cases, playgrounds are the only option for playing and interacting informally with other children. For young children (0–3 years), playgrounds aim not only to boost their physical and mental health and wellbeing (De Lannoy et al., 2020; R. Moore & Young, 1978) but also to construct knowledge about their surroundings (Smoyer-Tomic et al., 2004). Moreover, playgrounds can be categorized as creative media that enhance children's immune health systems (Laselin et al., 2016) and avoid negative psychological effects (G. Wang et al., 2020). According to studies from Lee et al. (2020) and Zimmermann and Curtis (2020), children infected with COVID-19 are relatively less vulnerable than adults due to age-gradient factors. For this reason, countries such as the UK (Weedy, 2021) and the Netherlands (Rijksoverheid, 2021) have kept some of their playgrounds open during the lockdown. In our view, this regulation also facilitates families who do not have enough space for children's play activities at home.

Nevertheless, safety remains a top priority for both children and parents when accessing the playground during the Covid-19 outbreak. The main concerns are not only about physical contacts that may occur during play activities but also virus transmissions around the neighborhood in the playground area. For example, playgrounds have many shared spaces and surfaces that have the potential to lead to increased disease transmission. Also, the lack of procedures with improper supervision during play activities can trigger unwanted crowds (Freeman & Eykelbosh, 202). To reflect these concerns, there is an urgent need to investigate safe ways to visit playgrounds during the Covid-19, especially regarding the street connectivity around the playground and the density level of playgrounds when it is occupied (Aarts et al., 2012). As such, safe play activities can still be obeyed by parents and children without neglecting the Covid-19 protocol.

In architecture and urban design, one relevant concept that specifically deals with street network analysis is related to space syntax. Initially introduced by Hillier and Hanson (1989), space syntax is a concept and analytical method that aims to describe the morphological logic of urban grid networks. It is specifically used to measure the relational pattern of the street by means of potential movement from each street segment to another (*the to-movement*) and potential movement through from each street segment with respect to all other street pairs (*the through-movement*) (Hillier et al. 2012, Van Nes & Yamu, 2018). The concept of space syntax was then further elaborated by Turner (2003, 2004) to describe the relationship between the spatial structure and components in urban areas and buildings.

As a network analysis model, space syntax has been used in a broad range of studies and projects. For example, the regeneration of Trafalgar Square in 2005 in London (Van Nes & Yamu, 2021), the spatial accessibility of the Olympic Park in London 2009 (Syntax, 2012), study of the relationship between mortality rates and street networks of Banda Aceh based on Tsunami 2004

(Fakhrurrazi & van Nes, 2012), and the integration of spatial planning and design support based on space syntax analysis and qualitative spatial-cognition approach using a case study in Bari, 2020 (Esposito et al., 2020). These existing cases show the potential development of space syntax that is relevant to address the aforementioned issue during COVID-19. This is especially related to potential features (Klarqvist, 1993) in space syntax such as axial map for syntactic map, graph and depth for the analysis, connectivity, integration, control value, and global choice for syntactic measures. However, only a few studies specifically address the context of playgrounds using potential features in space syntax analysis. The only research that comes close to our research is an investigation of the interface space of children in primary schools in Turkey (Atam & Salgamcioglu, 2022). Their findings show that spatial configuration matters in how children use and interact in space.

Therefore, this study aims to investigate the spatial structure of playground areas during the COVID-19 outbreak based on the space syntax method. In this regard, space syntax features such as street connectivity, occupancy rates, and visibility graph analysis (VGA) contribute not only to understanding the spatial integration complexity of various playground locations but also to configuring different playground typologies. The typology can then be used to identify architectural characteristics and physical properties of each playground, as well as the density and volumetric capacity of each playground. In addition, VGA combined with on-site observations can be used to configure a safe layout for accommodating activities and the visitor movement within the playground such as seating, standing, and play positions. The integration of on-site observational analysis into the simulation model will evaluate and fulfill the missing information in the simulated environment, especially regarding the characteristics of the playground users and the time frame of visiting hours. For example, some playgrounds may be located at isolated locations but have a lot of visitors during specific hours and vice versa.

The ultimate goal of this study is to provide a comprehensive analysis regarding playground safety criteria in relation to COVID-19 measures. For parents and kids, this study contributes not only to identify the traffic safety in the playground but also to map the density of playground activities. This study can also be used by researchers and local municipalities to generate new framework or guideline regarding future playgrounds. Furthermore, this study will discuss existing works that can be used as key references in the following section.

2. Theoretical background

Before discussing further urban spatial analysis in the playground during the pandemic situation, there are several variables of urban features that require further attention beforehand. For example, (Megahed & Ghoneim, 2020) describe that path configurations and urban park layouts are recommended to be formed in horizontal, decentralized, and low-density configurations. This is not only for the sake of geometrical adaptation to the pandemic situation but also to identify the pattern of people activities in the urban park. In a similar vein, Ma et al. (2007) and Wilson (2000) suggest that decentralized networks of playgrounds should be set up on smaller scales. This idea will allow people to have a more accessible path to nature in close proximity while reducing the spread of Covid-19 and improving physiological well-being.

Having specific considerations on the aforementioned idea, the decentralization of the playground paths may provide great contributions in distributing the level of crowdedness of playground activities. This is relevant to the aim of designing play areas with a low-density pattern. In this regard, Hamidi et al. (2020) indicate that controlling the connectivity becomes a matter as it can be useful for minimizing dense interactions between local neighborhoods. It is also worth noting that the occupancy rate plays a significant factor when measuring the density of visitation levels of the playground. Franch-Pardo et al. (2020) describe several keywords from existing studies that may relate to occupancy rates such as spatiotemporal analysis, health and social geography, environmental variables, data mining, and web-based mapping. For example, Curtis et al. (2021) analyze a weekly cell phone location of people using Google Mobility and SafeGraph to identify the increasing COVID-19 spread in the park. Geng et al. (2021) investigate the impacts of COVID-19 and government response policies regarding park visitation via Google's Community Mobility Reports and the Oxford Coronavirus Government Response Tracker. Rice and Pan (2021) and Larson et al. (2021) use geo-tracking data to assess the use of outdoor park spaces during the pandemic. Also, Herman and Drozda (2021) utilized social media information to analyse the use and operational tactics of two parks in promoting green urban infrastructures during pandemic. Their study suggests improving more flexible and less rigidly built places for multifunctional spaces through tactical adjustments due to lockdown and social separation. Furthermore, this study specifically investigates street connectivity by analyzing the distribution of urban features of the playground. As the output, it is expected to provide information regarding the optimal configuration of playgrounds based on Covid-19 health protocol criteria.

Some authors have also attempted to employ agent-based models to analyze and predict the spread of COVID-19 in urban parks. For example, Wang and Wang (2021) and Tang (2021) investigate the visitor behavior and social distancing for pedestrians, Silva et al. (2020) propose the COVID-ABS to simulate the pandemic dynamics using a society of agents. In addition, relevant studies are also found regarding the use of space syntax features to analyze the spatial configuration of street networks during pandemic. For example, Kumari (2021) evaluates the movement in urban pedestrian streets in relation to urban spatial planning. Kozer et al. (2021) reveal that the SARS-CoV-2 can still be found in public playgrounds and water fountains so that strict compliance with the environment needs to be fully addressed. In addition, a positive correlation is also found between the spatial organization of the roadway network and the dispersal of Covid-19 cases (Yao et al., 2021). (Gören Soares & SERDOURA, 2021) explore tracking tools using Space Syntax modelling to study a qualitative evaluation of playground accessibility and convenience for children's development in Lisbon and Istanbul. In general, these studies present great relevance in examining the issue of urban density based on geospatial analysis during the COVID-19 pandemic. However, specific methods of space syntax such as street connectivity and playground occupancy rates and visibility graph analysis remain an interesting gap to follow up, especially in the context of playground layout based on COVID-19 safety criteria. Furthermore, this study will now present a method to investigate the spatial configuration of playgrounds based on space syntax analysis during the COVID-19 pandemic.

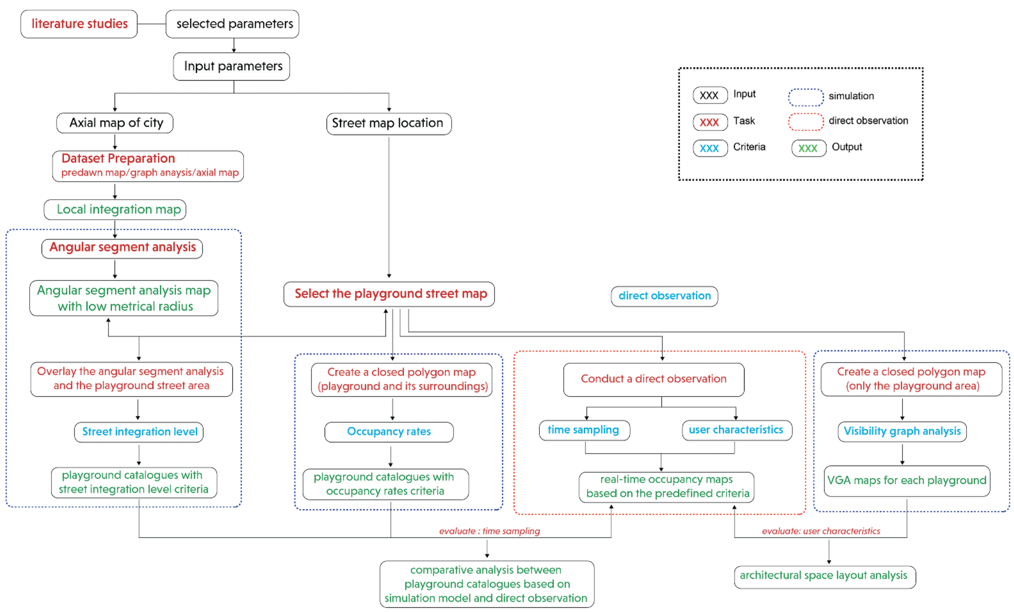
3. Method

This study has developed a workflow to conduct spatial structure analysis of the playground based on space syntax features and safety criteria from COVID-19 (see, Figure 1). In general, the workflow consists of three main parts, which are input, model development, and output. This workflow is supported by several tools. For example, the DepthmapX software is used not only to analyze the spatial configuration of the street neighborhood but also to identify the spatial characteristics of the playground. QGis is employed to capture and export a selected map with axial lines the-so-called predawn map. Given that this predawn map only represents axial lines, Google map is also used and overlaid using a raster graphic editor to identify specific attributes (e.g., housing, street names, and public spaces) of selected areas in the built environment. In addition, vector-based tools were used to select specific sites within the predawn map and export it with designated formats (e.g., DXF).

As stated previously, this study has formulated three parts that contain different procedures and tasks. First, **input** contains two main datasets, namely axial map of the city and street map location.

- The axial map is captured through several preparation tasks. In principle, it is created by obtaining an accurate map and drawing a series of intersecting lines through all urban network spaces to cover the entire grid and create all circulation circles (Hiller&Hanson, 1984; Turner et al., 2005). It is started with making a visibility graph through a predawn map (illustrated as a line drawing map). This map needs to be in DXF format to process the various space syntax analyses in the DepthmapX software. Furthermore, a predawn map is converted into an axial map to show the colored axial

Figure 1. An overview of the general workflow for generating playground spatial integration mapping.



lines. This is important, not only to identify the number of line intersections but also to illustrate the visibility values stored in each line. Afterward, a graph analysis is run based on the resulting axial map. This step aims to compute visibility values of each line within a predefined radius. Before moving to the street integration analysis, the axial map needs to be corrected beforehand to ensure all streets are properly connected. This action is done by fixing the broken lines through linking and unlinking procedures. Furthermore, the axial map produced from the previous step is converted into a segment map in order to conduct the next spatial configuration analysis.

- The street map of selected playgrounds. In principle, this map aims to show the real condition of specific locations so that further spatial analysis can take place accordingly. By using satellite images and street view features from the Google map, site properties and their surrounding elements such as vegetation and other relevant properties can be accessed to support the spatial analysis of selected areas. The resulting street map will be used to conduct further simulation analysis based on predefined criteria.

The second part is **model development**. This part follows up on input parameters that have been prepared in the first part to proceed further based on predefined criteria. This study specifically employs five different criteria, which have been conducted through a digital simulation and an on-site observational approach. The simulation consists of street accessibility, occupancy rates, and visibility graph analysis (VGA), while the on-site observation contains time sampling (e.g., hour and date) and user characteristics criteria (e.g., age, activities, and positions). In this regard, the street accessibility is examined based on axial and angular segment analysis, occupancy rate is investigated based on agent-based models, and visibility graph analysis is carried out based on the COVID-19 measures regarding a physical distance of 1.5 meters (Rijksoverheid, 2021) and public playground safety standard (Commision, 2015).

For the simulation, this study carried out three specific criteria as the basis for investigating further spatial configuration analysis, namely street integration level analysis, occupancy rates, and visibility graph analysis. Each of which is discussed in detail below.

- Street integration level analysis

Street integration analysis contains several tasks such as the analysis of the angular segment map and their overlays with the street map, and the generation of playground catalogues based on street integration level. In this regard, the angular segment analysis aims not only to refine intersecting lines with multiple fragmented curves but also to examine the shortest path of each line or street by considering the bank angle (e.g., 90°, 180°; Turner, 2007). In principle, when taking a route, people prefer straight roads without many turns (Dalton, 2003) or roads that can minimize trip length and maximize trip efficiency (Hillier, 1989). Turner et al. (2001) consider each angle on a road turn as part of the measurement parameters to calculate the street integration. The less the angle from one point to another, the shorter the resulting path. A shorter path is later attributed as a more integrated street and become a popular route for people to take.

Technically, the angular segment analysis is conducted based on low and high metrical radius. In this case, the lower metrical radius is 3, while the higher one is 7 (Van Nes et al., 2013). The local integration with a radius of 3 means that each street is connected to another street in the neighborhood scale within 3 times the change of direction. This can be used to show various local substances and indicate highly integrated streets in the neighborhood (Van Nes & Lopez, 2013). This analysis can be further employed not only to map the main routes of the playground in the local neighborhood but also to identify the most accessible walking path chosen by local inhabitants when visiting the playground.

Furthermore, the angular segment analysis map is overlaid with the playground street map. This step aims to identify actual street properties on the axial lines map such as street names, specific location of the playground, and integration level of selected playgrounds. This further helps us to categorize playground catalogues with the highest integration and the most segregated streets.

- Occupancy rates

The occupancy rates are examined to analyze the movement of people and frequency of their visits to the playground based on an agent-based model. This model can be used to simulate the movement behavior pattern of people in predefined areas (Van Nes et al., 2013). The selected agent will demonstrate the likely behavior of people that is similar to the real environment. Before starting agent-based simulations, four parameters (Al Sayed & Turner, 2012) are required to consider such as *time steps* to set the analysis time period, *gate counts data* to record the number of agents that will pass through a predefined area, *release rate* to define how many agents will be simulated in each time step, and *release location* to illustrate the agent's starting point when running the simulation.

In this study, each agent is set with a field of view of 170° with three movement steps before establishing a new direction. By considering the movement behavior of people (i.e., walking activities) between predefined grid points and the walking distance on urban pedestrians (Al Sayed & Turner, 2012), the total number of agents used in the simulation is 500 agents for 1000 steps. In this regard, the total number of agents is obtained by estimating the number of people walking in urban areas, while the number of steps indicates the sum of time intervals required by the agents to move in the simulation until they disappear. This is often based on the distance selected between grid points and the possible walking distance for pedestrians in a particular urban or building setting.

As a result of this agent-based simulation, aspects such as occupancy level of people movement and the level of social interaction on the street around the playground can be further identified into the catalogue based on occupancy rate criteria.

- Visibility graph analysis (VGA)

VGA is one of the main spatial analysis features within the field of Space Syntax (Turner et al., 2001), formulated further from Benedikt's work on isovist and isovist fields (Benedikt, 1979). It aims to measure regular units of spatial configuration caused by human behavior and movement. In this regard, VGA is carried out based on the COVID-19 measures regarding a physical distance of 1.5 meters (Rijksoverheid, 2021) and public playground safety standard (Commision, 2015). Before running the VGA, a grid map needs to be defined first to visualize the scale of the playground. A 2.00 grid is applied to indicate the physical distance of 1.5 × 1.5 m of the playground. The resulting VGA simulation will then show high and low integrated streets so that congested areas by movement of people can be further identified.

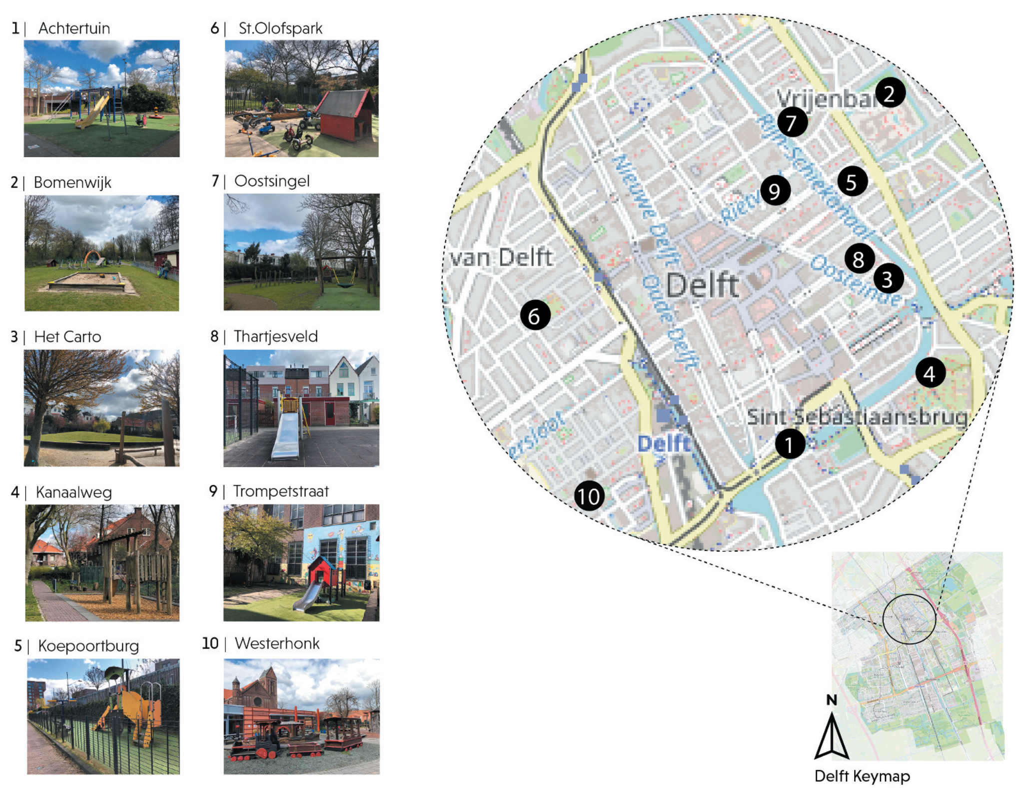
Furthermore, this study also conducts an on-site observational approach as part of the proposed method. It aims not only to investigate playground occupancy rates based on time sampling and user characteristics criteria but also to identify the parameter discrepancies between the simulation model and real-time observation. In this regard, time sampling criteria are used to evaluate the occupancy rate of playground catalogues produced by the agent-based model, while user characteristics criteria are investigated based on the generated VGA map.

The third part of the workflow is the final **output**. This study produces a series of analytical frameworks regarding playground catalogues based on safety criteria. The framework can be used not only to assess the performance configuration of existing playgrounds but also as a basis for designing new playgrounds that can adapt to future pandemic situations.

4. Dataset collection

This study applied the proposed method to 10 selected playgrounds in Delft, the Netherlands, which have different sizes and urban characteristics. The selection is based on a 1 km radius from the Delft city center where most of the hidden playgrounds are located in Delft (see, Figure 2). The playground datasets were collected by referencing to the collaborative map of Delft's playgrounds on the Delfts MaMa community social media pages (https://www.facebook.com/DelftMaMa/). This collaborative map is an open map of Delft's self-initiative parents, whose aim is to share the latest information on playground activities in Delft. In parallel, some practical information about playgrounds in Delft was supplemented by an open platform (i.e.,http://playdelft.com/), especially with regard to hidden and small playgrounds on a neighborhood scale.

Figure 2. Dataset collection of 10 selected playgrounds in Delft.



As for an on-site observation, this study selected one-day observation on weekends and weekdays with a time span of 2 hours, from 10 am to 6 pm. Thus, the total observation days for each playground are 2 days. All field surveys were conducted on a clear day, with temperatures around 9–11 degrees Celsius. Meanwhile, for user characteristics, several parameters are considered during the survey such as age groups (i.e., children, adults) and type of activities (i.e., walking, sitting, standing, playing). All parameters were then plotted to real-time occupancy maps. Since the on-site observation only focuses on the mapping of playing activities in the playground, this study does not involve the direct intervention of human participants (i.e., interview, clinical experiments, and personal data collection).

5. Results

The present study has formulated the developed workflow into four main parts based on predefined criteria for each part. Each part is subsequently examined in detail below.

5.1. Street integration analysis

Before discussing specific characteristics for each playground in Delft, axial-line analysis is conducted firstly in Delft city center to identify the global (see, Figure 3-A) and local street configuration map (see, Figure 3-B). The axial analyses show the to-movement potentials on a city and a neighborhood scale (Van Nes & Yamu, 2021). According to Figure 3-A and 3-B, Delft city center generally illustrates a higher degree of street accessibility as compared to other areas. This can be viewed from the number of yellow and red axial lines. The higher the level of street accessibility, the more urban vitality will be generated, which turns out to be more vibrant and denser street life.

Figure 3-C generally illustrates a mixed pattern of colored axial lines. This is the angular segment analyses with a topological radius (three times the direction changes). This map shows the through-movement potentials and highlights the main route system in a built environment (Van Nes & Yamu, 2021). In this regard, the main streets seem to be integrated with the local neighborhood street. The low radius analysis (three direction changes) shows a high degree of integration for pedestrians in the local neighborhood. This can be seen from the number of red axial lines that exist on the alleys in Delft city center. This configuration may provide a high contribution to local streets especially regarding small businesses in city center areas.

Furthermore, the street integration analysis can be used to identify various characteristics of playgrounds in Delft. For example, due to the large number of hidden pocket parks, some playgrounds are easy to spot, while others require extra effort to find as most are located in small

Figure 3. Street integration map of delft city center.

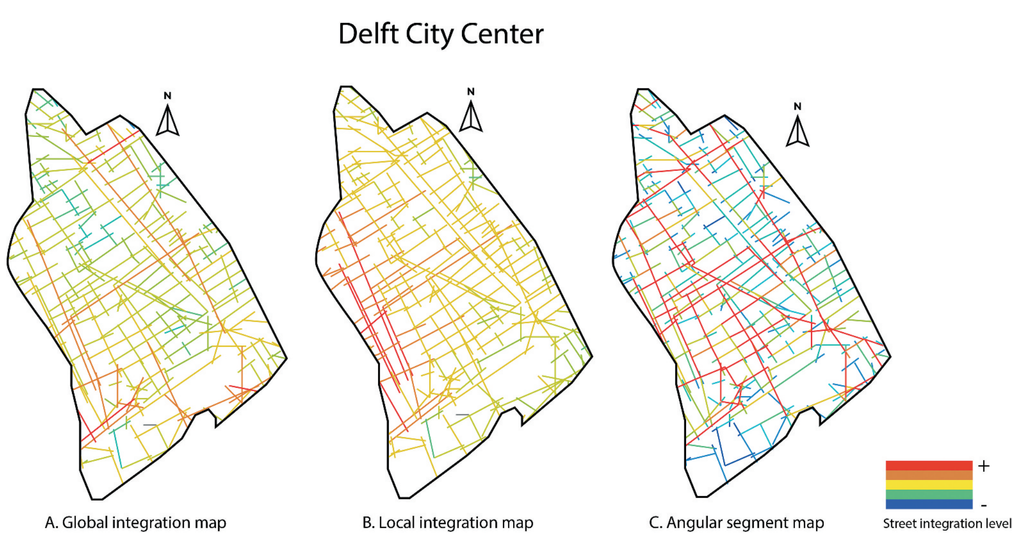
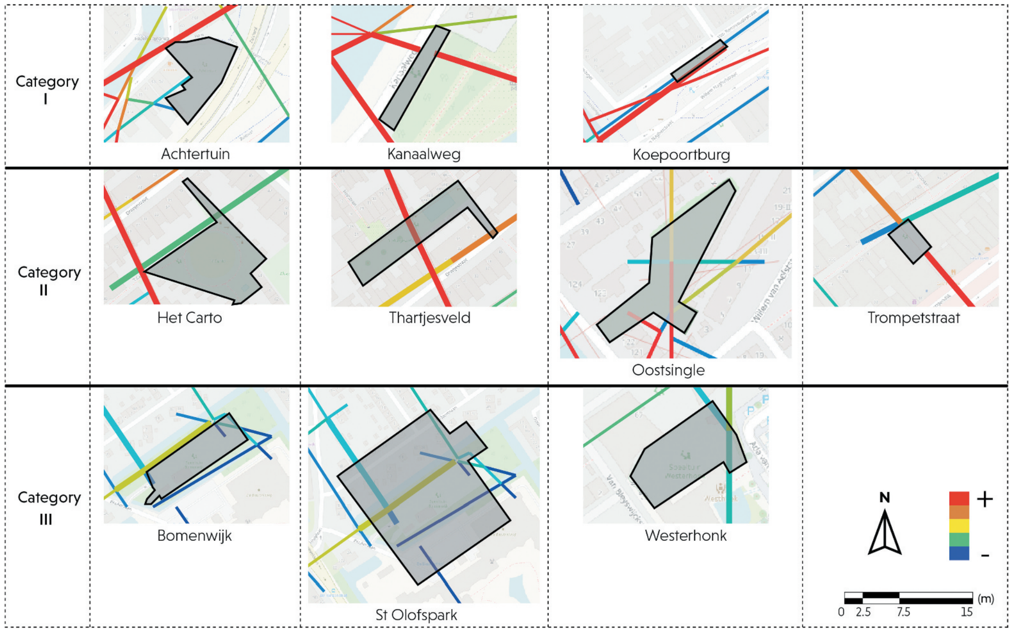


Figure 4. Playground catalogues based on street integration analysis.



alleys behind the main street. This study then reveals three groups of playgrounds (see, Figure 4) after overlaying the angular segment map (see, Figure 3-C) with a global street map.

- Category I—open access on a highly integrated street

This category refers to a group of playgrounds located mostly on major high-traffic streets. It is specifically characterized by short fences and crossroads of multiple paths around the playground such as pedestrians, bicycle lanes, and busy streets. This group can be found at Achtertuin, Kanaalweg, and Koepoortburg (see, Figure 4 - Category I). Considering that these playgrounds illustrate multiple thick red lines compared to the other two categories, it can be said that the level of visibility and ease of access of playgrounds in Category I is moderately high.

- Category II—hidden access from a highly integrated street

Similar to the previous group, playgrounds in Category II are also located on streets that are high integrated with additional local businesses. However, most playground locations are not quite visible on the main street as they are characterized by isolated entrances in secret backyards or small alleys. Thus, a little walk is required to discover the playground area by some visitors who are not familiar with the location. This category consists of four playgrounds such as Het Carto, Thartjesveld, Oostsingel, and Trompetstraat (see, Figure 4 – Category II). These playgrounds are characterized by a small distribution of the red axial lines and the intersection of the orange, yellow, and green lines. A consequence of this pattern can be found in the blurred zoning boundaries between private and public playgrounds. For example, access to Het Carto and Thartjesveld is directly connected to the backyard area of private house so that to some extent, it creates confusion for visitors who are not familiar with the surrounding environment.

- Category III—hidden access on low integrated street

This category is characterized by low integrated areas with high isolated locations. This can be seen through the distribution of the green and blue axial lines across the playground area in Figure 4 – Category III. This category contains three identified playgrounds such as Bomenwijk, St Olofspark, and Westerhonk. Although these playgrounds have a larger play space and complete toys, they are relatively quiet from visitors. This is because they are surrounded by high fences combined with dense vegetation so that people cannot easily find the playground from outside. Moreover, some of these playgrounds also have limited opening hours such as Bomenwijk and Westerhonk which can only be visited on weekdays from 13.00 to 17.00.

5.2. Occupancy rates

In order to calculate the occupancy rate of people movements, this study employs an agent-based model for simulating each playground. This specifically aims to identify the level of interaction between visitors in the playground. In order to do so, gate count values of each agent released in the simulation model are calculated (see, Figure 5). In this regard, the higher the gate count value the more people across the location and this means that the level of interaction will also increase. This is important to address, especially during the COVID-19 pandemic where playground visitors are suggested to avoid a busy street and maintain physical distance from other people. Furthermore, after identifying the maximum number of gate counts on each playground (see, Figure 5), this study classifies the playground into three categories as follows:

- Category I—high occupancy rates

This category consists of three playgrounds that have more than 1500 gate counts, which are Het Carto, Achtertuin, and Bomenwijk. Although the movement of people in this category is greater than in other categories, none of the identified playgrounds are located on high integrated streets except Achtertuin that is located on the main street. This indicates that the occupancy level of the playground will not always move simultaneously with the street accessibility in certain neighborhood. This is because factors such as the size and physical boundaries of the playground may affect the level of visitor attractions. For example, Bomenwijk and Het Carto attract more visitors that other playgrounds due to fenceless boundaries. Ultimately, this study reveals that this category contains high-risk playgrounds regarding COVID-19 parameters due to high agent movement.

- Category II—middle occupancy rates

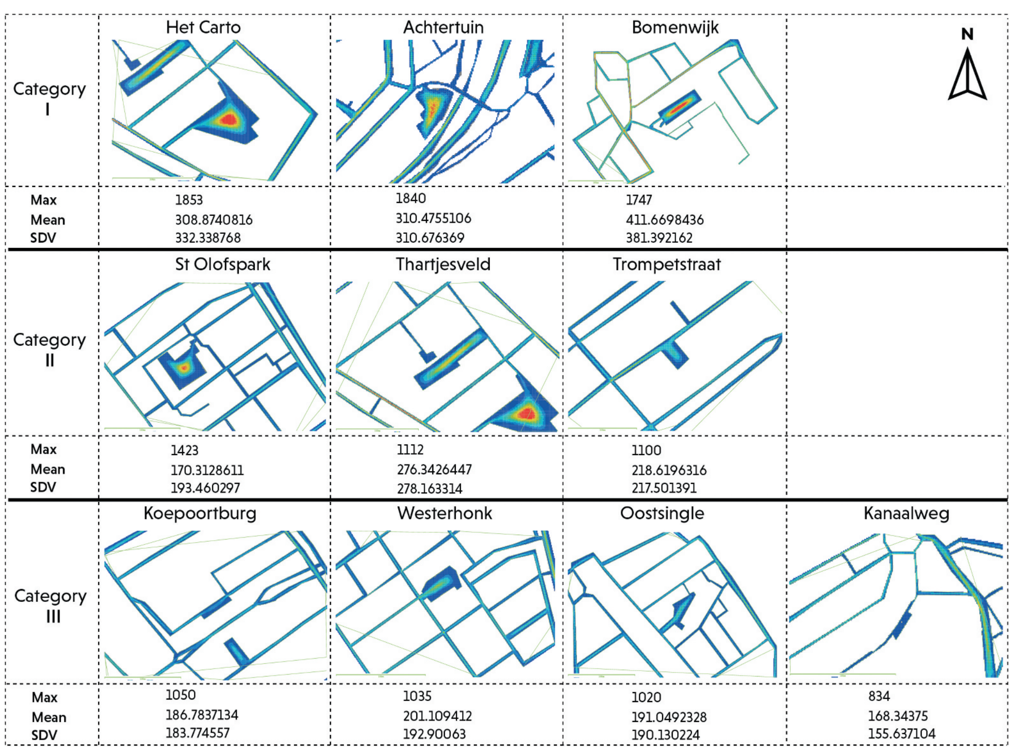


Figure 5. Playground catalogues based on agent-based model.

This category is grouped based on the number of gates counts between 1100 – 1500. It contains three playgrounds such as Olofspark, Thartjesveld, and Trompestraat. Although these playgrounds are included in one category, they have different urban characteristics. For example, Olofspark has a large number of gates compared to the other two playgrounds but is located on a low integrated street where the level of connectivity between the main street and its surroundings is extremely low. In contrast, Trompetstraat and Thartjesveld are located on a high integrated street but are relatively difficult to spot due to their isolated location from the crowds. This makes the playground visitors mostly come from those who live around the area. Having said that, this category can be marked as a safe playground to visit due to the low frequency of visitors and little opportunity for physical interaction in the play area.

- Category III—low occupancy rates

This category comprises of four playgrounds with gate count values of less than 1100. It contains Koepoortburg, Westerhonk, Oostingel, and Kanaalweg. Surprisingly, Koepoortburg, Oostsingle, and Kanaalweg are located on high integrated street but have low occupancy rates. This indicates that not all playgrounds located on the main street have many visitors due to several factors such as less attractive and less variety of toys. Accordingly, people only spend very little time when visiting these playgrounds. On the other hand, different characteristics are shown by Westerhonk. Although Westerhonk constitutes as one of the largest playgrounds in Delft with lots of toys and a large play area, in fact, it falls into the low occupancy category based on the agent-based model. Therefore, this category can be considered safe for people to visit due to its moderated accessibility and low gate density value.

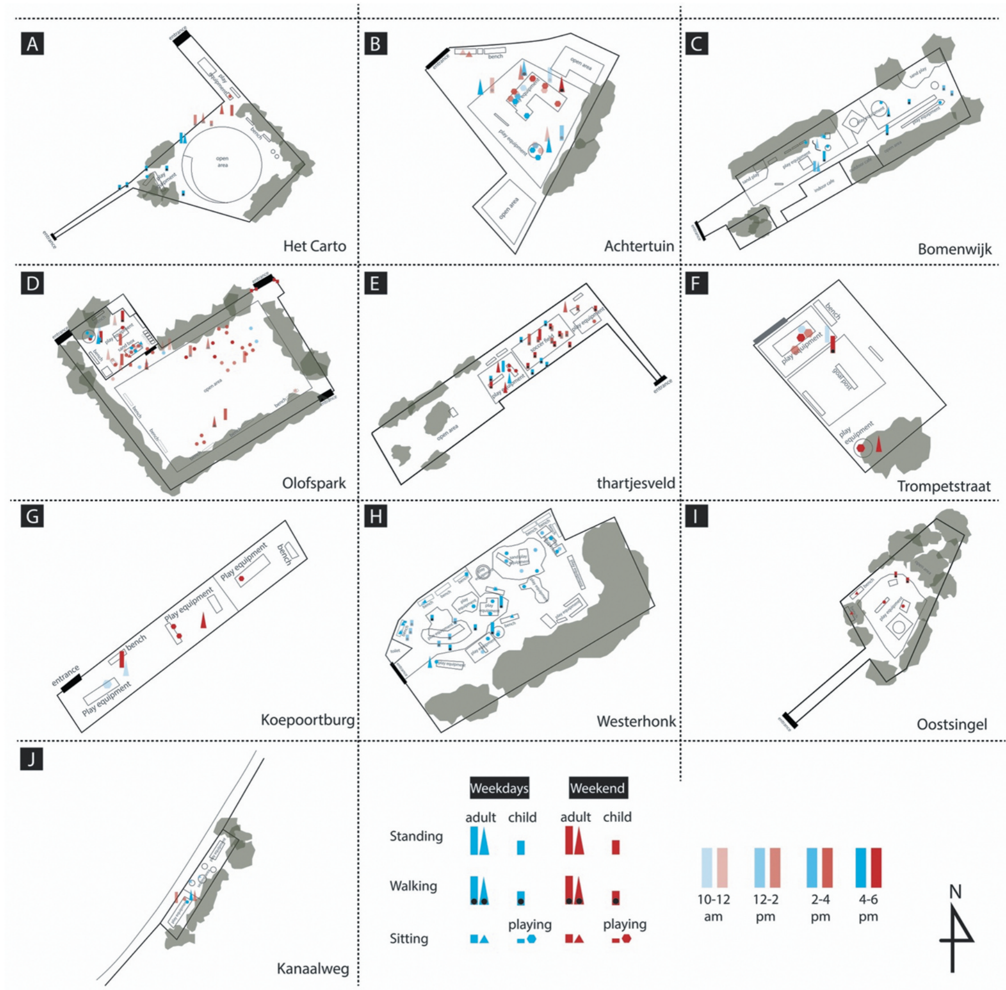
5.3. On-site observations

This study also conducts an on-site observation of the playground in order to investigate the occupancy level of each playground based on time sampling and user characteristics. The aim is not only to identify significant trends in occupancy rates but also to analyze further discrepancies found when comparing the observation results with playground catalogues in Figure 5. Furthermore, these observations are then formulated into Figure 6.

Based on on-site observations (Figure 6), there are several interesting patterns that can be drawn for further analysis as follows:

- Achtertuin (Figure 6B) has always had visitors for four different time frames both on weekends and weekdays. Due to its location on a highly integrated street with high occupancy rates, this playground attracts more families to visit, especially in the morning and afternoon.
- Although Het Carto (Figure 6A) shows a high occupation rate, the number of visitors is moderately low due to its remote location behind people’s house. On average, the visitors identified during the on-site observation were school-aged children who played around 4–6 pm on weekdays. This is because Het Carto is located close to public schools.
- The number of visitors in Bomenwijk (Figure 6C) shows quite low. This is because of limited opening hours that are only available from 1 to 5 pm on weekdays while closed on weekends.
- Olofspark (Figure 6D) contains the highest number of visitors of the 10 other playgrounds in Delft. It consists of more than 10 people including adults and children who play both in the morning and afternoon. This playground is categorized as a middle occupancy rate based on the simulation result while on on-site observation, it was found that the busiest time is between 2 and 4 pm on weekends, and there were no visitors during weekdays.
- Thartjesveld (Figure 6E) has also been identified as middle occupancy level. This playground is relatively quiet in the morning due to school hours while in the afternoon, it starts to get busy from 2 to 6 pm. At these hours, especially on weekends, most people living around Tharjesveld and Olofspark spend their time playing and exercising in the outdoors. This situation is a bit of a contrast compared to Trompetstraat, which is only occupied by 2–3 people in a 2-4-hour observation.
- Kanaalweg (Figure 6J) is identified as high integrated street with open access gates. On weekend observations (between 12–2 pm and 4–6 pm), the visitors identified are mostly families, while on weekdays they consist of individuals passing through this playground. A similar pattern is shown in

Figure 6. Occupancy map of playgrounds based on on-site observations.



Koepoortburg (Figure 6G) that is also located on a high integrated street. On weekdays, the playground is mostly empty between 12 and 4 pm and is occupied only by individuals.

- As one of the largest playgrounds in Delft, Westehonk (Figure 6H) is in fact, located on low integrated streets with limited opening hours (i.e., 1–5 pm on weekdays and closed on weekends). Nevertheless, this playground is considered relatively attractive to visitors due to its high provision of various play facilities

According to on-site observation results above, this study reveals at least three different trends that are identified compared to playground categories based on the simulation model. For example, first, playgrounds identified as having high occupation rates do not always have a large number of visitors due to its isolated locations and limited opening hours. Second, playgrounds belonging to medium occupation rates on average have many visitors due to lively family activities in the surrounding environment. Third, the completeness of the playground facilities affects the number of visitors to the playground although it is categorized as low occupancy rates. These trends indicate that the simulation parameter needs to be coupled with on-site observation analysis to draw the distinction between two different approaches.

5.4. Playground layout analysis

This study furthermore analyses the layout of each playground described in Figure 6 by making use of visibility graph analysis (VGA). This step aims to identify the density and the movement patterns of visitors within the play area based on physical distancing criteria. To do so, three samples of playgrounds are selected based on the highest occupancy rates, namely Achtertuin, Olofspark, and Westerhonk. Each of which will be discussed below.

(A) Achtertuin

The Achtertuin consists of 280 m^2. It is divided into three main areas, namely bench, open space, and play equipment areas. According to Figure 7, the activities identified in Achtertuin are mostly located in the play equipment area, especially on the large slides and roundabout playgrounds. This area is predominantly occupied by adults (i.e., mostly women) and seems to be a favorite spot for parents to chat while sitting on benches. That is why the color of the visual integration in the play equipment areas is displayed in red, which indicates a higher value compared to other areas. On the other hand, less activities are spotted in open areas and play equipment based on the resulting color gradients. Thus, these areas can be assumed to be safer to occupy due to less playing activities.

(B) Olofspark

Among selected playgrounds in Delft, Olofspark is the most popular playground to visit for outdoor activities. The number of visitors at **Olofspark** is relatively high both on weekdays and weekends such as parents, school aged-children, and teenagers. For example, parents usually spend the weekends meeting their friends at the playground while monitoring their kids play. According to the observation map in Figure 6D, the crowds are identified in the playground equipment and open areas while on the VGA map (see, Figure 8), the highest visual integration is spotted only in open areas. This can be assumed that the play equipment area is less integrated due to the isolated location in the corner of the playground and this, thus leading us to label this area as belonging to a private playground.

(C) Westerhonk

As compared to the two previous playgrounds (i.e., Achtetuin and Olofspark), Westerhonk contains the most complete set of play equipment. It consists of around 1260 m^2, surrounded by benches to make visitors evenly distributed around the play area. This size is relatively able to make visitors maintain a safe distance during play. Although this playground has limited opening hours (from 1 to 5 pm on weekdays while fully closed on

Figure 7. The layout and VGA of playground Achtertuin.

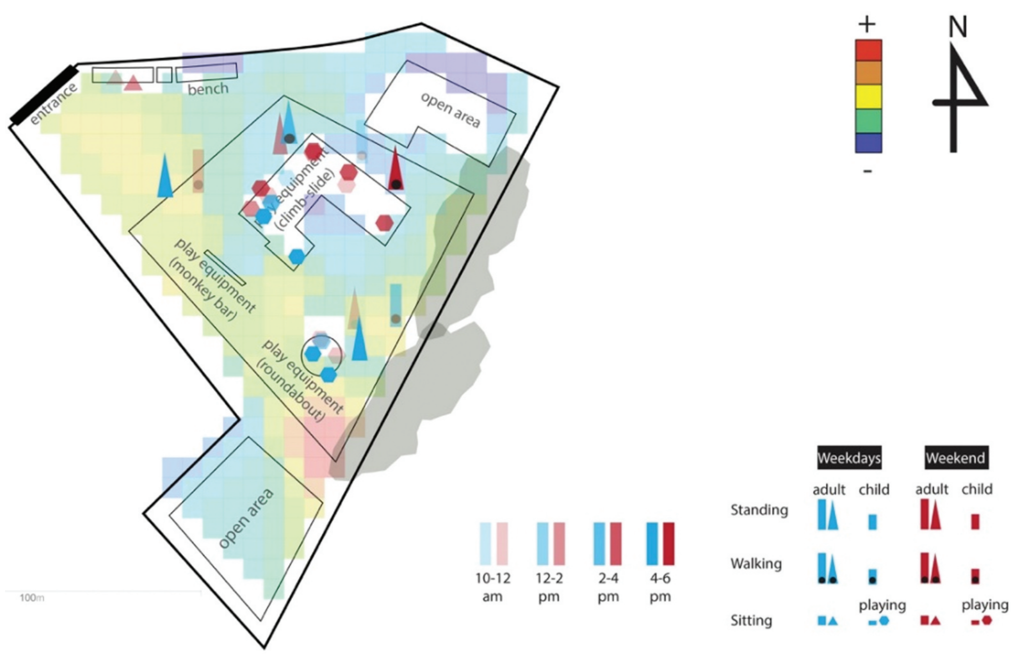
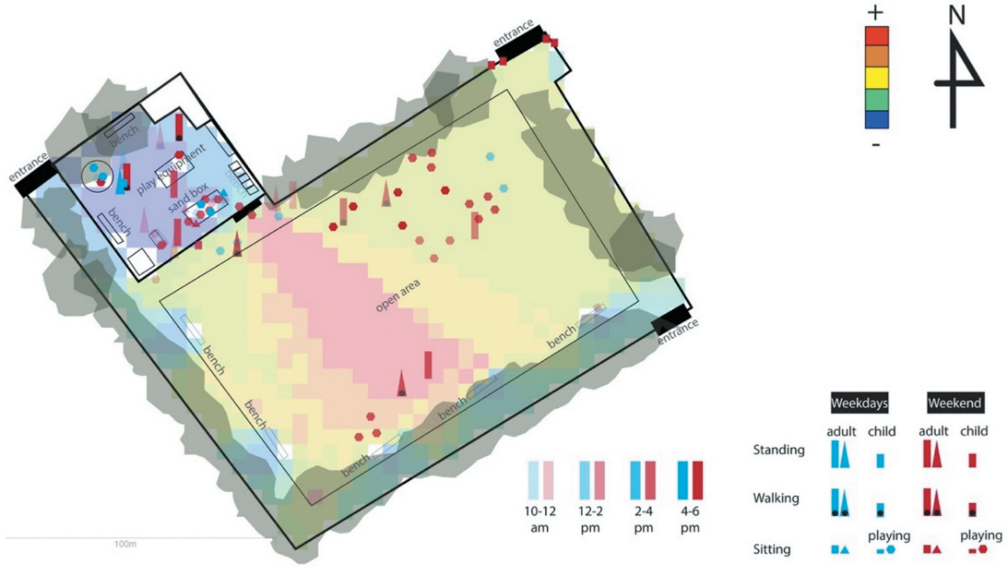


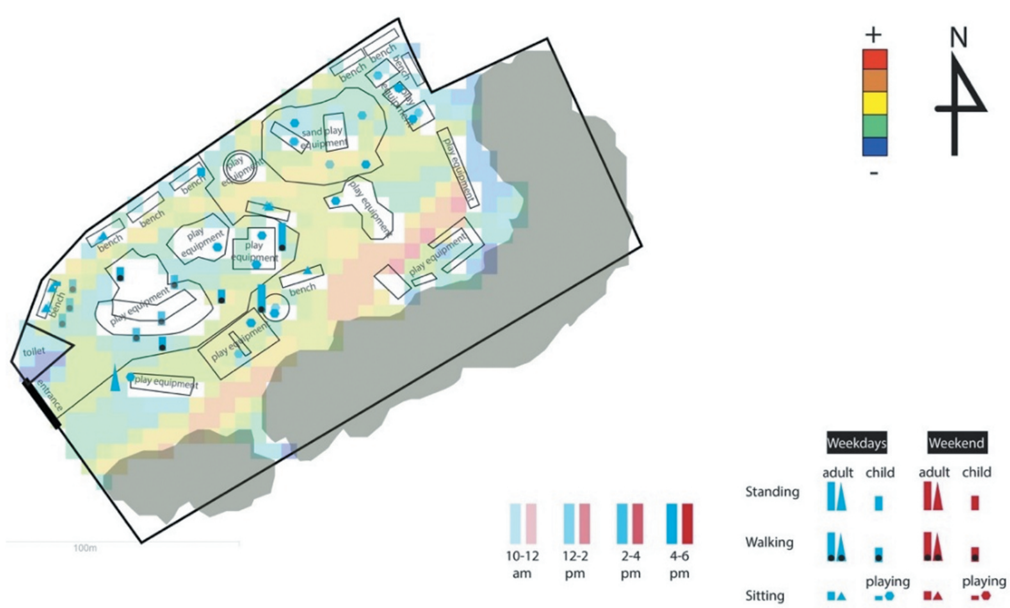
Figure 8. The layout and VGA of playground Olofspark.



weekends), it can be included as a dense playground. According to the VGA simulation in Figure 9, highly integrated areas are spotted in the play equipment area while less integrated areas are mostly identified around trees and toilets.

Based on the discussion of the playground layout analysis above, the VGA map (Figure 7,8,9) is generally useful to identify and map the density level of the playground. Thus, the visitor's movement can be predicted based on the layout configuration of each playground. Nevertheless, some areas identified as having high density level do not always show the same pattern when compared to on-site observations due to the surrounding environment characteristics and observation period.

Figure 9. The layout and VGA of playground Westerhonk.



5.5. Discussion

- During lockdown situations, playgrounds are a great alternative for families looking to access the outdoor play spaces. However, many people still avoid visiting the playground due to the high possibility of social interaction and exposure to the Coronavirus disease. For example, recent studies show that people's habit in Sweden have drastically changed in experiencing public space during the Covid-19 pandemic (Legeby & Koch, 2021). This is because some public spaces have set restrictions on their facilities and thus, it affects the decision of people in Sweden to visit them. Another rising issue in urban parks or playgrounds during pandemic and post-pandemic situations is the need to balance outdoor activities (i.e., recreation and social gathering) while maintaining safety measures (i.e., physical distancing). (El-Darwish, 2022) points out that during the pandemic, the setting of the playground will affect the way users use and connect to it. In this regard, regulating the path hierarchy and adjusting the layout of the playground may potentially reduce the significant crowd of playing activities, especially during peak visiting hours. This study proposes some strategies regarding the safe layout configurations of playgrounds, as follows: This study suggests that the configuration of public open spaces can be encouraged with a more decentralized layout in order to have an evenly spread pattern of playing activities (Megahed & Ghoneim, 2020). For example, the entrance of the playground can be arranged and divided based on the street integration level. It can be placed on the side of a less busy street connection to distribute the circulation crowds. Moreover, the accessibility of visitor movement can be regulated based on the street occupancy level.

- Determining the characteristics of playgrounds based on Covid-19 criteria is principally similar to Aldo van Eyck's idea (Withagen & Caljouw, 2017) about expanding the role of playgrounds as urban properties. It refers to two categories, namely *first*, the playground that has a small area, often called a pocket park due to its open and strategic location (Blake, 2013). Although this pocket park offers less play facilities, it is an essential place to play for the children and is frequently visited as a transit point by people passing through the area (Badger, 2020). *Second*, a playground that has a larger scale and more play facilities compared to the previous one. This playground applies stricter rules not only regarding the opening hours (i.e., limited hours on weekdays while closed on weekends) but also the implementation of 1.5-m physical distance signs at the playground. Nevertheless, the occupancy rate remains high for this type of playground. Nevertheless, the occupancy rate remains high for this type of playground and has the potential to cause massive crowds of people, which should be avoided during the pandemic era. Thus, the study suggests that playgrounds located in more secluded areas, or pocket parks, should have more facilities that stimulate the visitors to visit such as proper play equipment, workout facilities, and expanding user's visiting duration. This study also encourages the enhancement of tiny local par features not only to be as transit points but also as livability supports based on surrounding characteristics.
- Decentralization and social distancing are influenced by how meeting places are set up and people are seated (Hamidi et al., 2020). The idea of clustering can reduce the density of people in meeting places. In this regard, the seating position can be organized based on the density points in the VGA layout analysis. It can also be designed to be multipurpose with the play equipment. This will distribute the children's attractions when they search for the play equipment because each spot or object has a unique design. The same distribution should also apply to the location and amount of vegetation in the playground. In the current situation, most of the vegetation is concentrated at one point and organized only in the form of a vegetation fence around the playground. By distributing the location of vegetation (i.e., based on type, height, and density), each playground spot can be more attractive and evenly distributed to be used as meeting points. Furthermore, the proposed playground catalogues in this study have the potential to be applied to other types of public spaces in order to propose future post-pandemic city scenarios. Nevertheless, it should be noted that the test cases used in this study are still limited to developed countries, which have well-designed infrastructure pedestrians and people who have a habit of walking. Besides, safety parameter applied in the playground based on street network analysis might also be irrelevant when it comes to the car-oriented city. This is because the agent-based model analysis proposed in this study aims to identify the level of pedestrian crowds passing through the playground area.

6. Conclusion

In general, this study aims to analyze the spatial structure of playground areas during the Covid-19 pandemic by utilizing the space syntax method. This study particularly focuses on exploring 10 selected case studies of playgrounds in Delft based on safety criteria of Covid-19 measures. It contributes not only to mapping traffic safety to the playground but also to calculating the density of activities on the playground. The present study presents several concluding remarks as follows:

- The street accessibility level of the playground affects the frequency and the duration of visits to the playground. In this regard, the playgrounds located on high integrated streets principally invite more people to come. On the other hand, however, it contains a high level of vulnerability regarding the Covid-19 situation. This is because highly integrated streets tend to create more social interactions due to the dense activity between visitors. As a response to this, the entrance to the playground can be arranged and divided based on the level of street integration where the playground is located by selecting a less busy street connection in order to distribute crowd circulation.
- Playground catalogues allow architects and urban designers not only to understand the spatial structure of existing playgrounds but also to rethink new configurations of future playgrounds, especially when dealing with pandemic and post-pandemic situations.
- According to agent-based analysis, playgrounds located on highly integrated streets do not always have high occupancy rates. This is not only because accessibility to these playgrounds is often found isolated or hidden from the main street but also because of the characteristics of the playground that make them less popular to visit such as less play equipment, high fences, limited opening hours, and small play areas. Nevertheless, the identified playgrounds indicate they are safe enough to visit. Hence, the findings of this study strongly imply that playgrounds in more remote areas, or pocket parks, should offer more visitor-interesting amenities (i.e., appropriate play equipment, exercise equipment, and increased user visit time). Moreover, this study suggests promoting design planning recommendations based on the characteristics of urban parks or playgrounds so that the livability of small local parks can be improved.
- An on-site observation approach is used not only to identify the occupancy rates on each playground based on predefined time but also to map the movement of visitors during the play activities. This is important to determine the layout configuration analysis of the playground based on the density of activities of visitors. This study recommends that playgrounds should have spacious internal corridors, shorter paths, and multiple access points to the outside in order to distribute the walking path and reduce overcrowding within the play area.
- VGA allows architects and urban designers to arrange the density level of activities in each playground. This particularly relates to the play equipment areas where kids usually congregate for certain favorite pieces of play equipment. Thus, by managing the distance of each play equipment based on physical distancing criteria, it will create a safer environment for playing activities. In practice, as a design strategy, seating positions can be created and integrated with the play equipment to serve multiple purposes. This will provide more features of play equipment in such an iconic and unique way so that children are not just fixated on one area of play equipment.

Acknowledging the limitations of this study, there are some parts that would benefit from further consideration. For example, this study only focuses on examining three samples of playgrounds for layout analysis. The analysis results can be more comprehensive by investigating more playgrounds and in more detail characteristics of play equipment in each playground. Besides, this study also focuses on the 2D simulation analysis based on digital datasets. A 3D simulation analysis can improve the robustness of the study by examining the airflow in particular playgrounds. Further development of this study may extend several potential features, some of which may include investigation of materials used in the play equipment in relation to hygiene. For example, material surfaces such as stainless are easier to clean, while natural materials such as wood easily absorb microbes, making them difficult to clean.

Finally, what matters for the frequency of use of a playground is on how it is connected to the overall street network on a neighborhood and city scale, how visible the playground is from integrated streets, and the spatial configuration and the location of various play equipment inside the playgrounds. Seemingly, a spatially well-integrated playground on all scale levels implies high usage of children. Conducting interviews and questionnaires to playground visitors may broaden further investigations of this study for in-depth information regarding the frequency of visits, favorite playgrounds, and other relevant aspects.

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