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Navigating Safety and Urban Challenges: A Study of Children's Pedestrian Experiences in Jeddah's School Zones

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Abstract: This study examines the factors influencing children's walkability in the automobile-centric city of Jeddah, Saudi Arabia, highlighting the urgent need for pedestrian-friendly infrastructures around school zones. Our objectives were threefold: to conduct an exhaustive literature review identifying critical walkability factors; to administer a survey throughout Jeddah's school complexes; and to assess children's walkability via street audits, GIS analysis, and pedestrian flow dynamics evaluation. Our findings underscore the imperative for enhancements in school zones, particularly in the areas of crossing facilities, street signage, and speed control measures. We advocate for the augmentation of shaded green spaces within an 800-meter radius of schools to foster a cooler, more inviting walking environment for children. The study also points to the significance of parking space design in managing vehicle overflow effectively and suggests prioritizing uninterrupted sidewalks and minimized intersections to elevate pedestrian safety. Conclusively, our research offers essential insights for urban planners and policymakers, who are aiming to create a safer, more walkable environment for children in cities heavily dependent on automobiles, like Jeddah.

Keywords: School-Zone, Children walkability, auto-dependency and urban design, GIS analysis, Pedestrian safety.

1. Introduction

1.1 Research background

It is becoming prevalent that the number of children walking to school is on the decline (Fyhri et al., 2011). This shift towards predominantly automobile-based commutes to schools has notable repercussions on children's physical health and development, including a marked increase in children's obesity rates (Fusco et al., 2012). Physical activity associated with walking or biking to school can improve cognitive function and academic performance, potentially due to increased blood flow and reduced stress levels. Furthermore, waking to school has minimal environmental impact (Silva et al., 2017) and contributes to reducing air and noise pollution and alleviating traffic congestion, especially during peak hours (Mammen et al., 2014). Furthermore, it plays a significant role in decreasing a person's emissions, carbon footprint, and the overall lifecycle of CO2 emissions (Brand et al., 2021).

The decline in walking or biking to school also impacts social interactions and community engagement. Active commutes offer opportunities for children to interact with their peers and familiarize themselves with their community,

fostering a sense of belonging and safety. Moreover, (Kingham & Ussher, 2007) suggest that active commuting (through walking school bus) can enhance social cohesion within communities by increasing interactions among residents, promoting a more connected and engaged society.

Safety concerns, particularly traffic-related dangers, are often cited as a primary reason for the preference for automobile commutes. However, this perception may overlook the broader safety benefits of active commuting. Increased pedestrian activity not only encourages more attentive driving but can also lead to broader community investments in safer infrastructure, such as improved sidewalks and crosswalks, which benefit everyone. (Jurak et al., 2021) for the implementation of targeted interventions to improve pedestrian safety, which can encourage more active commuting.

The shift towards automobile-based commutes has far-reaching consequences on children's health, the environment, and societal well-being. The port city of Jeddah is no exception. Located in Makkah province, Saudi Arabia (Figure 1), it is the second Largest city in Saudi Arabia with a population of the metropolitan area over 4.8 million inhabitants (2023). The average population density varied a lot across districts, ranging from 2.02 persons/hectare to 199.27 persons/hectare (Jeddah Municipality and Statistical Authority, 2016). The estimated average density is 54 persons/hectare for the metropolitan area, within the range often considered a good balance to support vibrant, walkable communities with sufficient population to sustain public transit, local businesses, and amenities within walking distances (Jeddah, Saudi Arabia Population 2024, n.d.; Ministry of Municipal and Rural, 2019).

1.2 Research problem

Jeddah, like most Saudi Arabian cities, exhibits a pronounced auto-dependency, a characteristic that mirrors a concerning trend across the nation. Between 1988 and 2020, overweight children in Saudi Arabia surged by 9%, a phenomenon closely linked to this car-centric lifestyle (Shaikh et al., 2020). Students walking to school are rare. According to Fatani et al. (2017), hot weather significantly limits the number of students who walk or bike, while (Belarem et al., 2018) notes the lack of a school bus system as another factor. Together, these studies suggest that walking or biking students are a negligible minority, mostly those who live very close to school.

The alarming statistic of 81 pedestrian fatalities per million population in Jeddah (Jeddah traffic police), sets the stage for understanding the broader traffic safety context in Saudi Arabia. The Kingdom's Vision 2030 has made traffic safety a

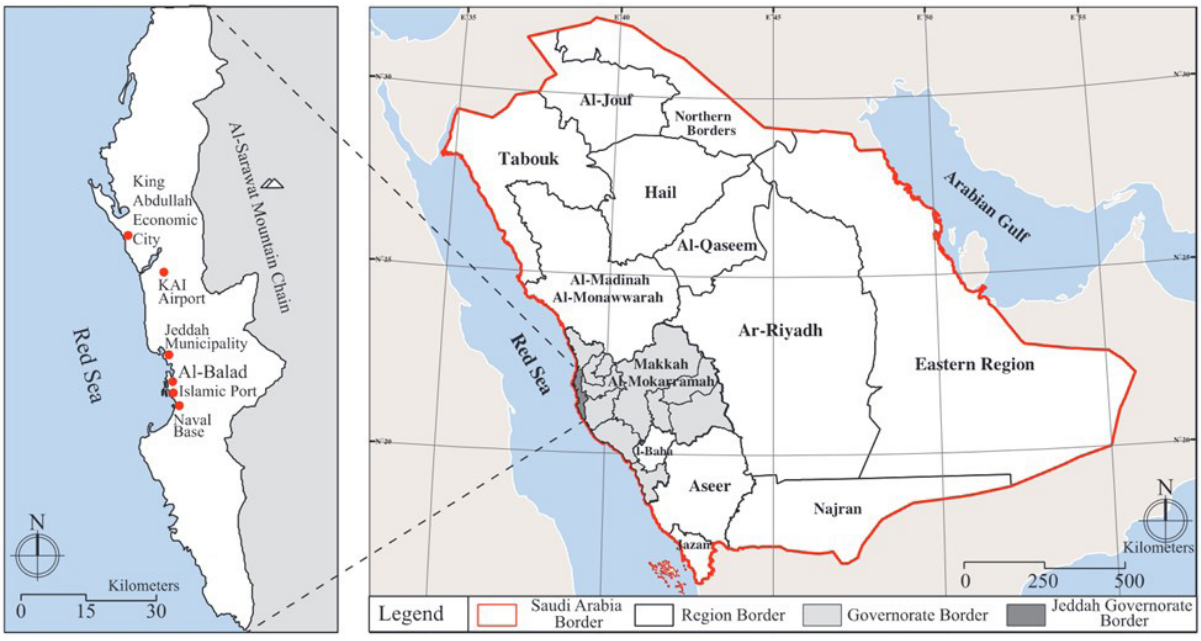

Figure (1). Map of Saudi Arabia (right), including the Jeddah Governorate area (left)

priority (Al Turki, 2014), but despite efforts, the number of road traffic fatalities has been on the rise, as evidenced by the increase from 17.4 to 27.4 deaths per 100,000 people over recent decades (Jamal et al., 2019; World Health Organization, 2018). This disturbing trend, coupled with the high number of deaths and injuries recorded in Ministry of Health hospitals, underscores the urgent need for focused interventions.

Jeddah, being a polycentric city with a car-dominated transportation system and limited pedestrian infrastructure, faces unique challenges. With the rate of pedestrian fatalities in Jeddah being significantly higher than in other global cities, children, as a particularly vulnerable group, face an increased risk due to their developmental characteristics such as a lack of attention and awareness of traffic hazards. Thus, a focused examination of the school zone environment becomes critical. By addressing these issues, there exists a tangible opportunity to mitigate traffic-related accidents. In doing so, we not only bolster the perceived safety among parents and their children but also lay the groundwork for a cultural shift towards more active, sustainable modes of transportation for schoolchildren (Masoumi, 2017). Considering the patterns indicating a rise in car accidents involving pedestrians and the rise in obesity in Saudi children, it is essential to examine the factors that contribute to the accidents that affect the safety of children walking to their chauffer or walking home and explore the factors that encourage children to walk between homes and schools.

1.3 Research Objectives.

This study aims to identify the risks and challenges that children encounter in the vicinity of their schools and to derive actionable insights for crafting a safer school-zone environment. By extending these insights to the routes between homes and schools, this should eventually foster a conducive atmosphere that encourages children to walk to school. Specifically, the study sets forth the following objectives:

1. to conduct a comprehensive literature review on the elements that effect the walking experience of children between home and school;
2. to detail the characteristics of school zones in Jeddah neighborhoods according to neighborhood typology, neighborhood density and land prices;
3. to examine the factors of safety and encouragement that affect pedestrian children between home and school, with a particular focus on the immediate surroundings of school premises.

1.4 Research Methodology.

Diverse data collection processes and data analysis were carried out to accomplish the stated objectives. The methodology was executed in a sequential manner as outlined below:

1.4.1 Identifying Factors

A comprehensive review of literature from the past 15 years, utilizing keywords such as “active school travel,” “children’s school zone safety,” and “assessing walkability for children.” Scholarly databases including Google Scholar, ScienceDirect, Sage Journals, and MDPI were instrumental in this search. The literature was rigorously examined to distill factors that influence the encouragement of walking and the safety of children in school zones. These factors were selected based on relevance, the frequency of which they were mentioned, and those specific to Jeddah’s context.

1.4.2 Schools Survey and 3D scatter model

A thorough search identified 64 school complexes in Jeddah, utilizing both official government websites (e.g., www.jeddah.gov.sa) and commercial portals (e.g., www.yaschools.com). The schools were then categorized by 1) neighborhood characteristics, as drawn by Maddah et al., (2016); and 2) neighborhood density [person/hectare]; and 3) neighborhood land value SAR/m2 based on data provided by the Saudi ministry of justice. This information was synthesized into a 3D scatter model to discern commonalities in school types and select representative samples for the city.

1.4.3 Site Audit, GIS and Pedestrian Flow Diagram

The analysis of selected school zones was conducted through a tripartite approach: 1) a street audit, where school zones were inspected on-site to assess the physical environment’s condition using a structured checklist; 2) Geographic Information Systems (GIS) tools, such as Google Maps, were employed to map and analyze spatial patterns of

crucial elements like crossing facilities, green spaces, and traffic flow within an 800m radius of school zones; and 3) Pedestrian flow dynamics, drawn using AutoCAD, aimed to elucidate the walking routes of children as they enter and exit the schools.

2. Literature review

The decline in physically active school commutes (such as walking and cycling) is a well-documented phenomenon across the globe, marking a significant shift in how children commute to school. Studies from various countries underscore this trend: in the USA, there's been a 35% reduction (McDonald et al., 2011), UK by 17%, Canada by 11% (Buliung et al., 2009), Australia by 31% (Schoeppe et al., 2016). This data highlights a widespread transition away from physically active school commute, leaning more towards vehicular transportation.

In the context of Saudi Arabia, a study conducted in Najran a substantial, safe, and secure city reveals that a mere 19% of children engage in walking to school. Conversely, a significant 70% of the student population relies on automobile transport. Interestingly, this study also notes that half of the students reside more than 1.5 km away from their educational institutions. Despite Najran's safe environment, several factors play a pivotal role in discouraging walking as a mode of school commute. These include the uneven distribution of educational facilities, inadequate pedestrian infrastructure, and parental concerns over traffic safety (AlQuhtani, 2023).

To better understand those factors, they are better understood by identifying the distinction between uncontrollable factors and elements related to urban design or policy, highlighting their significance in influencing commuting choices, and laying a foundation for addressing controllable factors. Then presentation of controllable factors affecting walking to school, emphasizing the role of urban design and policy in facilitating safe and encouraging environments for school commutes. Then, it will be overlayed in the context of neighborhood categories in Jeddah, as found in the literature.

2.1 Uncontrollable factors affecting walking (Demographic and Socioeconomic)

(AlQuhtani, 2023) provides an insightful analysis into the characteristics influencing commute mode decisions. It highlights demographic aspects such as age and gender alongside socioeconomic factors including parental income, level of education, and the household's number of cars. These elements are crucial in understanding the decision-making process behind selecting a particular mode of transportation to school.

Socioeconomic factors influence school commuting patterns in ways that vary by culture. In countries like the United States, Canada, China, and Iran, higher household car ownership often leads to students being chauffeured; however, in Istanbul, car ownership is linked to increased walking, likely due to better pedestrian infrastructure in affluent areas. In contrast, Australian studies show little or no correlation between car ownership and active commuting (Mehdizadeh et al., 2017; Mitra & Buliung, 2014; Ozbil et al., 2021; Zhang et al., 2017).

Income effects on active commuting are mixed: studies in Europe, North America, and Saudi Arabia found that higher income reduces active commuting, while research in Taiwan showed little impact, reflecting differing cultural contexts (Assi et al., 2018; Dias et al., 2022; Lin & Chang, 2010).

Parental education mostly correlates negatively with active commuting, although this relationship varies across regions, such as North America, Europe, and Iran, compared to Australia (DeWeese et al., 2013; Mehdizadeh et al., 2017; Spallek et al., 2006).

Lastly, in California, China, Sri Lanka, and Ireland, households with nonworking adults or multiple school-aged children tend to have higher rates of walking to school, highlighting how family structure and employment influence commuting behavior across regions (Kelly & Fu, 2014; Sidharthan et al., 2011).

In conclusion, socioeconomic factors such as car ownership, household income, parental education, and family structure influence student commuting patterns to school, but these effects vary significantly across cultural contexts. While car ownership might typically reduce active commuting, effect, likely due to local infrastructure.

Similarly, income and education levels affect commuting behaviors differently depending on regional expectations and values, underscoring that a one-size-fits-all approach cannot apply. This variation highlights the importance of considering cultural nuances when analyzing socioeconomic impacts on commuting and planning urban policies that support diverse, context-sensitive commuting solutions.

(McMillan, 2005) previously integrated these factors into his framework, referring to them as "moderating factors." He posits that while these factors do not directly pertain to urban form, they significantly impact the choice of commute mode. This delineation underscores the multifaceted nature of transportation decisions, suggesting that individual and family characteristics can moderate the effects of environmental and policy initiatives promoting active commuting.

The literature recognizing the influence of demographic and socioeconomic characteristics on commute mode choices identifies these uncontrollable factors, potentially allowing for the development of more targeted and effective strategies to promote walking as a viable option for schoolchildren.

2.2 Controllable factors affecting walking (Built environment)

Recent investigations underscore the significant impact of the built environment surrounding schools on children's mobility decisions. (Carver et al., 2014) highlighted the critical role of the built environment in shaping children's mobility patterns. Further detailed by (AlQuhtani, 2023; Kweon et al., 2023), factors such as distance to school, urban form, land-use mix, presence of greenery, sidewalks, intersections, and population density strongly correlate with children's choices regarding their commute mode. (McMillan, 2005) introduced these aspects as "mediating factors" within the built environment, suggesting that strategic placement of intersections, optimal walk zone distances, and the incorporation of green spaces can significantly enhance the

Table (1). Built environment features mentioned in literature (Author's synthesis of reviewed literature).

	Distance	Greenness	Pedestrian infrastructure	Street signage	Intersections density or Critical	Traffic Volume	highways, main roads	Parking	Land use
(Al-Qahtani, 2023)	X	X	X			X			
(Wangzom et al., 2023)	X					X			X
(Kweon et al., 2023)	X	X	X		X	X			
(Torres et al., 2022)	X	X	X	X		X		X	X
(Zhao et al., 2022)	X		X		X	X			
(Shafik et al., 2021)	X		X		X	X	X		X
(Ozbil et al., 2021)	X	X	X						X
(Corazza et al., 2020)		X	X	X	X	X			
(Shaaban & Abdur-Rouf, 2020)			X	X		X	X	X	X
(González et al., 2020)	X		X			X		X	
(Banerjee et al., 2014)	X	X	X		X	X			X

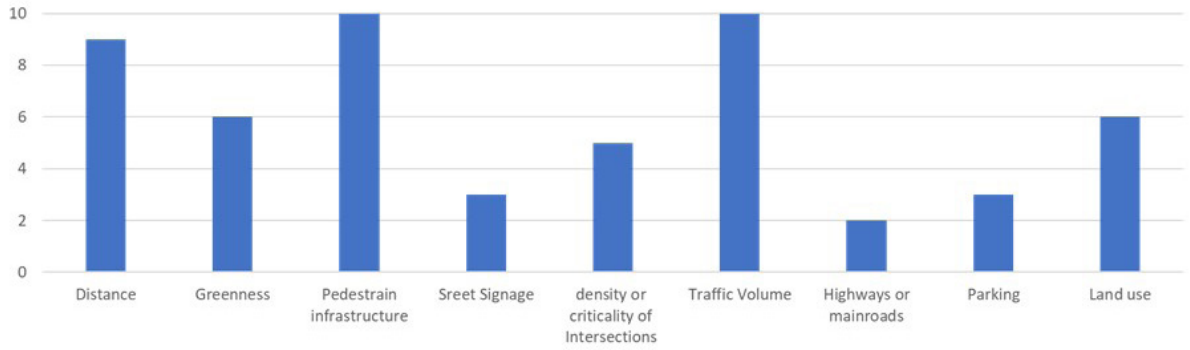

Figure (2). Graphical representation of Table 1 (Author's synthesis of reviewed literature)

Table (2). Thresholds of walkable distances to schools by country.

Study	(Kweon et al., 2023)	(Timperio et al., 2006)	(Nelson et al., 2008)	(AlQuhtani, 2023)	(Wangzom et al., 2023).	(Ermagun et al., 2016) and (Mehdizadeh et al., 2017)
Country	Texas, USA	Australia	Ireland	Saudi Arabia	Japan	Iran
Distance to school	3.2 km	0.8 km	2.4 km	1.5 km	3.2 km	1.9 km to 0.71 km

walking experience and, by extension, increase the likelihood of children walking to school. Table 1 demonstrates the built environment features and their mentions in the literature. It clearly shows the rate of recurrence of these features. Figure 2 reflects the number of times each feature is mentioned.

The analysis shows that the built environment features can be split into two categories: 1) walking encouragement factors; and 2) safety (traffic danger) factors. It is worth noting that there is the security (strangers' danger) factor, mentioned in international studies, which were overlooked in this study, as most Saudi cities are very secure; this applies to the city of Jeddah, thus across all schools in this study.

2.2.1 Distance

The distance between a child's residence and their school emerges as the most influential factor influencing the choice to walk. (He & Giuliano, 2017) notes the variability in the ideal walking distance across different countries and contexts. For instance, in Texas, USA, students living within 3.2 km usually are expected to walk to their schools (Kweon et al., 2023), while in Australia this distance is closer to 0.8 (Timperio et al., 2006). Senior Irish students can walk to school up to 2.4 km (Nelson et al., 2008). Most Iranian students can walk up to 1.9 km (Ermagun et al., 2016), but the threshold increases at 10 min walk to approximately 0.71 km (Mehdizadeh et al., 2017). Najran, Saudi Arabia students walked if they lived closer than 1.5 km to their schools (AlQuhtani, 2023). In Japan, almost all students walk to school, knowing that the average distance can reach up to 3.2 km. Such disparities highlight the cultural and geographical nuances affecting walking preferences, with societies in Western countries generally tolerating longer distances compared to those in the Middle East, and societies in far-eastern cultural can be presumed to be even more dependent on walking. Schools in higher-density neighborhoods tend to optimize the walking potential, maximizing the utility of their location (Wangzom et al., 2023) as shown in (Table 2).

2.2.2 Greenness

The association between greenness and walking propensity has been well-documented. (Kweon et al., 2023) confirms that greenness is associated positively with walking. This is also confirmed with many previse studies such as (Ozbil et al., 2021)Since Jeddah's climate is mostly hot and sunny, the strategic placement of shade-providing

trees and shrubs within school walk zones (which typically cover a radius up to 3.2 Kilometers around the schools) could facilitate walking by ameliorating the microclimate around schools and improving overall environmental quality.

2.2.3 Pedestrian infrastructure

While some studies (McMillan, 2007), have downplayed the role of built environment features (aside from distance) in school commute choices, a growing body of evidence underscores their significant influence. Pedestrian infrastructure is a broad term that includes: 1) the condition of the sidewalk in terms of walkable width, stability, slipperiness, and cleanliness, 2) traffic lights and crossing marks, 3) Pedestrian bridges, 4) curb ramps and curb cuts.

2.2.4 Intersections and Traffic volume

The susceptibility of children as pedestrians, coupled with their developmental stage, makes navigating traffic environments particularly hazardous (Stoker et al., 2015). The density of intersections, the presence of dangerous crossings (Huertas-Delgado et al., 2017), and traffic volume (Kim & Lee, 2020; which is traffic density multiplied by traffic speed (Mammen et al., 2012)) are all factors that negatively impact child safety.

2.2.5 Street signage

Effective street signage, including school zone warnings, stop signs, and speed limits, plays a crucial role in urban environments, offering high levels of safety for pedestrian children. The existence of street signage has been used in previous literature to assess the school zone's environment (Corazza et al., 2020; Shaaban & Abdur-Rouf, 2020; Torres et al., 2022).

2.2.6 Highways and main roads

The presence of highways and main roads can significantly hinder school zone accessibility, splitting the urban fabric, and imposing barriers children cannot safely cross. The high-speed traffic and volume associated with these roads further compromise child safety as it is demonstrated in (Figure 3) (Shafik et al., 2021).

2.2.7 Parking

Most children are driven or chauffeured to school in auto-dependent cities like Jeddah. Managing the influx of vehicles during school hours is crucial. The parking situation for the school zones is vital in insuring a safe environment for children in the presence of many moving cars. A well-planned parking infrastructure can mitigate safety risks, reducing the likelihood of accidents in congested school zones (González et al., 2020).

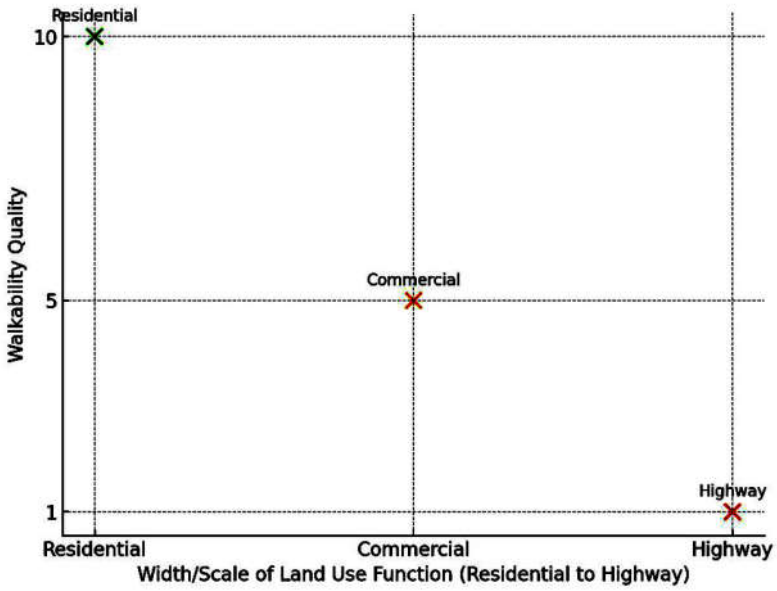

Figure (3). Impact of Street width and scale on walkability (Shafik et al., 2021)

2.2.8 Land use and abandoned buildings

Neighborhood safety is affected by factors such as harm or child abduction (Carver et al., 2008). Furthermore, built environment factors can affect perceived risk and fear, these factors include the appearance of degraded building conditions and under-maintenance, abandoned buildings, and broken windows (Loukaitou-Sideris, 2006). On the contrary, mixed-use and higher density can increase the sense of safety (De Meester et al., 2014). Increasing perceived neighborhood safety will improve the likelihood of children walking to school (Foster et al., 2014). While Jeddah's high security level might mitigate concerns over harm or abduction, ensuring an inviting and well-maintained built environment remains essential for promoting walking.

2.3 Neighborhoods categories

Saudi Arabian schools are mostly gender segregated. They fall into three categories: Public, Private, and International. Some are standalone institutions catering to a specific educational stage (Single schools), while others are part of a complex encompassing all educational stages (Complex schools).

Complex schools were selected for this study due to their larger student populations across multiple educational stages, offering a comprehensive overview of potential challenges. It is posited that any issues identified around school complexes likely mirror those at single schools (being lesser for single schools). All three school types (public, private, and international) in Jeddah were surveyed, encompassing both genders, to assess the challenges that were universally faced.

A total of 62 school complexes were identified: 19 public, 16 private, and 27 internationals, as depicted in (Figure 4). These schools were categorized based on three characteristics: 1) neighborhood typology, as per the study by Maddah et al. (2016); 2) neighborhood density (persons per hectare); and 3) land price value (SAR/m²), with the latter two sourced from data provided by the Saudi Ministry of Justice.

Subsequently, this data was visualized in a 3D scatter model (Figure 5) to analyze the distribution of school types. This model facilitated the selection of school complexes representative of the common types in Jeddah, based on the clustering of data points. The axes of the model are defined as follows: X axis for neighborhood density (persons per hectare), Y axis for land price value (SAR), and Z axis for the neighborhood typology. The analysis revealed a variety of school complex types within different neighborhood settings. The predominant types identified were as follows:

- Low-density, mid-price, Villa Neighborhood: This type included eight school complexes, typically found in lower-density residential areas with moderate property values, primarily composed of villas.
- Mid Density-Low Price-Villa Neighborhood: Encompassing fifteen school complexes, these areas represent mid-density neighborhoods with affordable housing, mainly characterized by villa-style residences.
- Mid-Density-Mid Price-Apartments Neighborhood: This category, with 5 school complexes, reflects mid-density areas with moderately priced apartment buildings that cater to a diverse population.
- Mid-Density-High Price-Apartments and Villa Neighborhood: Found in mid-density settings, this type, with five school complexes, features a mix of high-value apartments and villas, appealing to a higher socioeconomic demographic.
- Mid-density-high-price-apartmentsand Villa Neighborhood: Another mid-density category, this one included seven school complexes situated in affluent neighborhoods with a blend of apartments and villas, supporting a more upscale urban environment.
- High-Density, High-Priced Apartments and Villa Neighborhood: This type consisted of 8 school complexes located in high-density urban areas with high-value properties, combining apartment complexes and villa residences.

A representative school complex was selected from each identified prominent neighborhood type, reflecting the characteristics and challenges specific to its category. These selected complexes serve as focal points for analyzing the unique dynamics of school zones across varied residential contexts, offering insights into how neighborhood features influence walkability, safety, and accessibility for children within different socioeconomic and urban settings. By examining model clusters and focusing on the areas with the highest concentration of similar types, the analysis enabled the identification of school complexes that accurately mirror the

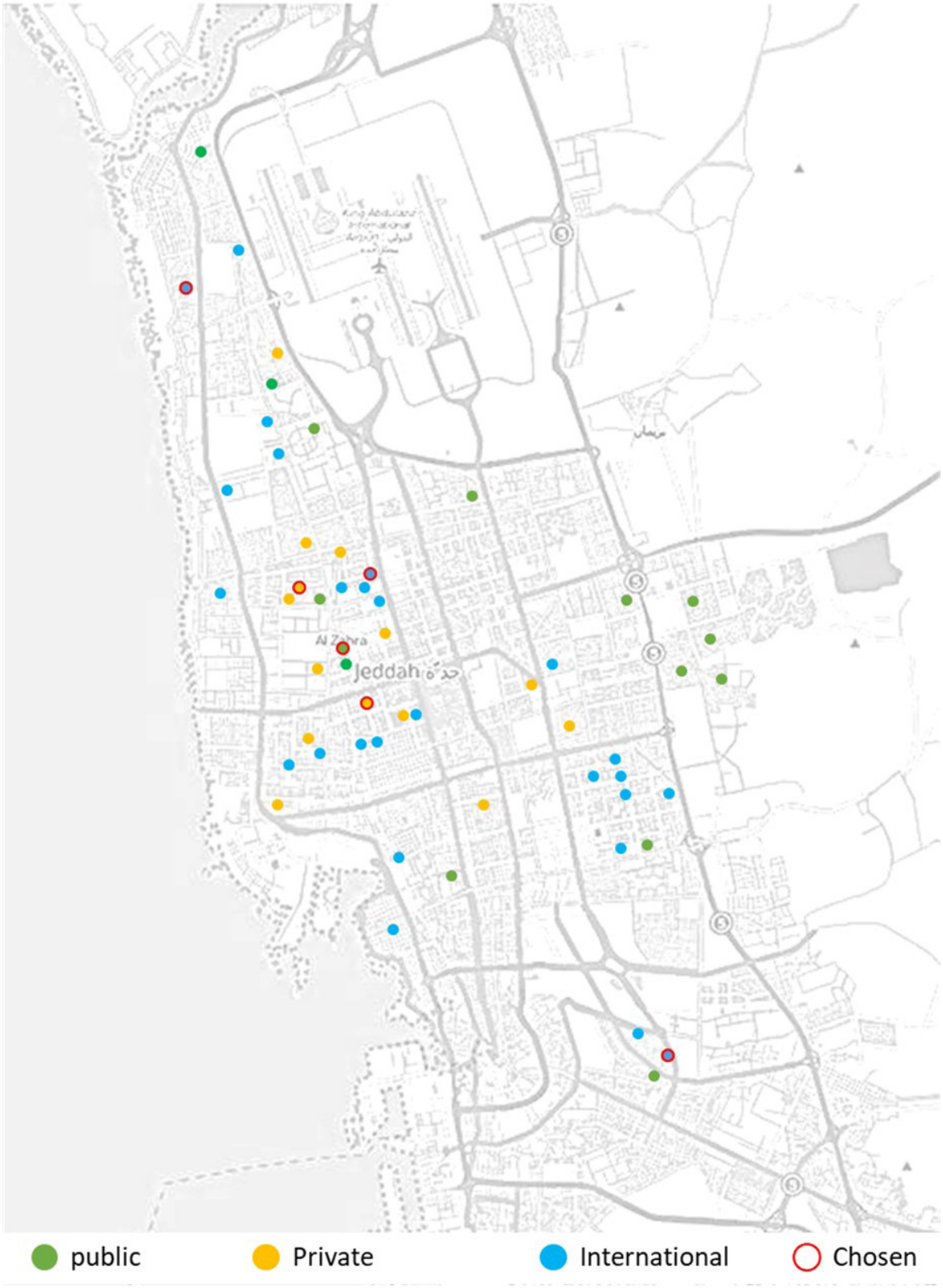

Figure (4). Schools complexes distribution in Jeddah city

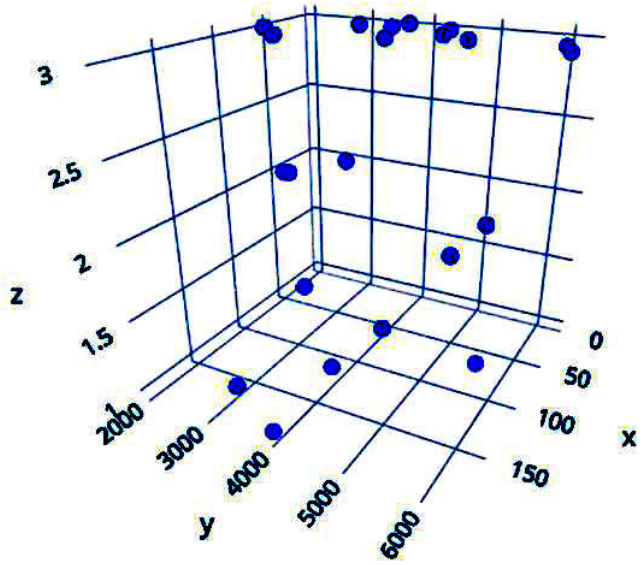

Figure (5). 3D scatter model of schools' types in Jeddah

Table (3). List of schools' names, school type, and students' gender

Name	Type	Gender	Symbol
Dar Al-Fikr schools	International	Boys and Girls	S1
Al-Anjal schools	Private	Boys and Girls	S2
Ammer Sultan Complex	Public	Boys	S3
Dar Al-Hanan schools	Private	Boys and Girls	S4
Jazeerat Al-Banat schools	International	Girls	S5
Al-Furat schools	International	Boys and Girls	S6

diversity within Jeddah's educational landscape, as detailed in Table 3. This approach ensured that we covered the most significant neighborhoods in Jeddah, representing those with the highest concentration of school complexes.

3. Field Survey

3.1 Site audit

The site audit was conducted by the researcher, examining the streets surrounding each school based on established factors (Section 2). Utilizing a checklist, the following built environment features were audited: 1) Sidewalk Condition, assessing factors such as occupancy, existence on both sides, surface stability, and slope changes; 2) Crossing Facilities, evaluating the presence of crosswalk markings, curb cuts, and pedestrian lights; 3) Street Signage, including school zone signs, speed limit signs, and stop signs; and 4) Traffic Factors, specifically the use of speed bumps for speed reduction.

Figure 6 demonstrates a collection of images showing the physical features of the sidewalks around the schools showing the poor pedestrian infrastructure around the schools. Whereas sidewalk 1 features excellent forestation but is entirely non-walkable due to the lack of sufficient width. Sidewalk 2 provides adequate walkable width, yet its continuity is disrupted by infrastructure surrounded by broken pavement. Sidewalk 3, a mid-street sidewalk, suffers from insufficient walkable width and is located above dangerous 110,000-volt cables. Sidewalk 4 has severely damaged pavement, with no crossing marks or facilities in the designated crossing area. On Sidewalk 5, the crossing marks are faded and barely visible. Lastly, Sidewalk 6, despite being a mid-street sidewalk, lacks adequate walkable width

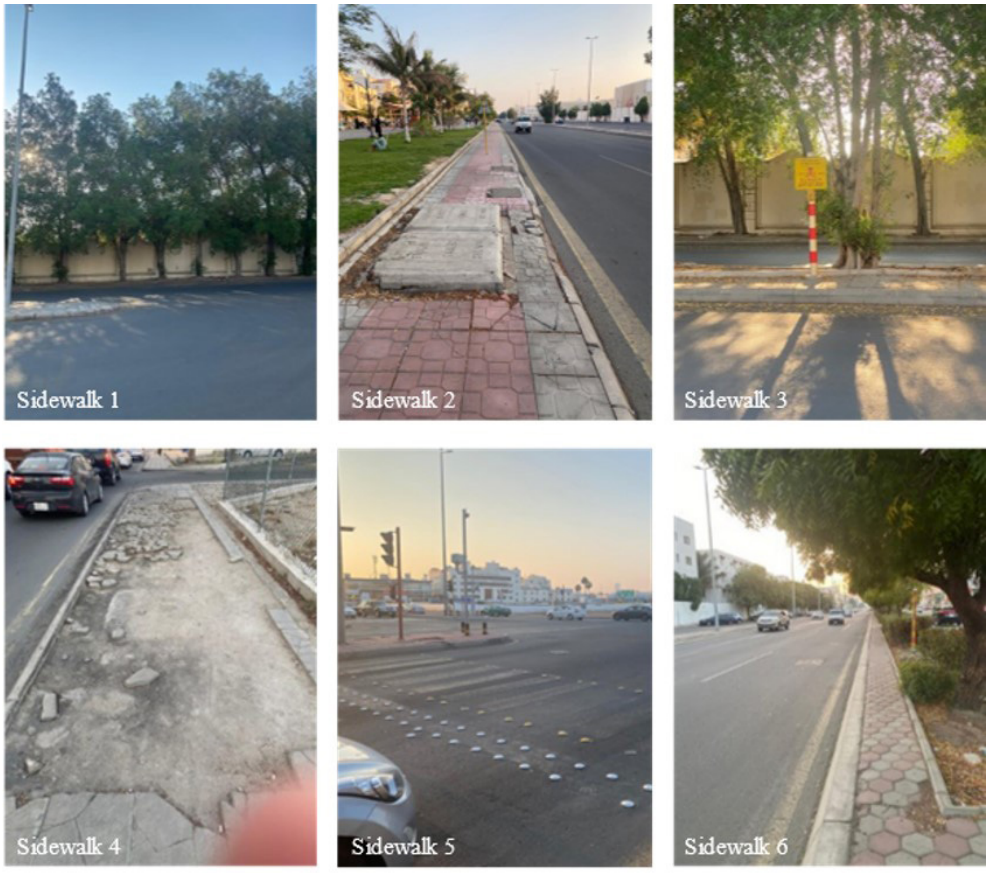

Figure (6). Pictures of the streets surrounding the schools

to accommodate pedestrian movement, particularly for school routes. Lastly, Table 4 illustrates the site audit results for each of the six schools according to the relevant factors.

The findings revealed that: 1) 66% of schools had sidewalks on both sides but lacked pedestrian crossing signs and speed bumps; 2) Half of the schools featured sidewalks with slope changes or unstable surfaces; 3) Nearly all school zones had sidewalks obstructed by plants or décor, without any stop signs, traffic lights, or curb extensions; and 4) Half of the schools lacked clear crosswalk markings, with the remaining displaying faded markings.

Certain factors consistently yielded negative results across all school zones, such as missing school zone and speed limit signs, and no instances of slippery surfaces. Conversely, positive findings included high cleanliness levels and pedestrian islands in all school zones.

3.2 Geographic information system (GIS)

Spatial data were collected from Google Maps within an 800-meter radius doubling the distance used in (Torres et al., 2022) based on prior research suggesting 800 meters as an ideal walkable distance, especially considering Jeddah's climate (see Figure 7). Analyzed features included tree coverage, intersection count, and the presence of highways and main roads within school zones. Additionally, traffic volume near each school was documented (Table 5).

GIS data analysis concluded that: 1) 66% of school zones exhibited good greenery, others did not; 2) Half of the zones had a high number of intersections within an 800m radius, contrasting with schools in lower density areas; 3) 33% of school zones were adjacent to highways interrupting the school pedestrian catchment area, disrupting the walkable area. In addition, 66% were intersected by main roads lacking pedestrian crossing

Table (4). The result of the sites audits for each of the six schools of the relevant factors

Factors	Section	S1	S2	S3	S4	S5	S6
Sidewalk Condition	Both sides exist	YES	YES	YES	YES	NO	NO
	slope change (e.g., driveways)	YES	YES	NO	NO	YES	NO
	Occupied sidewalk (trees, décor)	YES	YES	NO	YES	YES	YES
	Unstable surface	NO	YES	YES	NO	YES	NO
Street signage	Stop signs	NO	NO	YES	NO	NO	NO
	Pedestrian crossing signs	NO	NO	YES	NO	YES	NO
Street crossing	Crosswalk Markings	Not clear	NO	Not clear	NO	Not clear	NO
	Traffic light	NO	NO	YES	NO	NO	NO
	curb extensions	YES	NO	NO	NO	NO	NO
Traffic	Speed bumps	NO	NO	YES	NO	YES	NO

Figure (7). Locations of the GIS data analysis

facilities, leading to sidewalk discontinuities and safety concerns for parents; and 4) 66% of schools experienced medium traffic volume during peak hours (i.e. school entering and school exiting with exception to S2 which had high traffic being adjacent to a main road and S4 having low traffic volume) with notable exceptions due to proximity to main roads. 5) Almost all schools had planned adjacent parking, with the exception of S5 and S6, which did not have planned parking. The parking was insufficient, barely enough to meet half of the school's needs.

3.3 Pedestrian motion analysis

Following the methodology of (Davidich & Köster, 2013), Individual children's motion paths between parked cars and schools were drawn using AutoCAD on site plans of each of the schools' complexes based on observation during three periods: school entry (6:30 a.m., 6:45 a.m., and 7:00 a.m.) and school exit (1:30 p.m., 1:45 p.m., and 2:00 p.m.).

Table (5). Built environment features data extracted from GIS

Factors	Section	S1	S2	S3	S4	S5	S6
Greenness	Tree coverage area	231	332	210	165	24	34
Intersections	Number of intersections	55	300	200	160	75	60
Roads	Existence of highways	YES	NO	NO	NO	YES	NO
	Existence of main roads	YES	YES	YES	YES	NO	NO
Traffic	Traffic Volume	M	H	M	L	M	M
Parking	Planned	YES	YES	YES	YES	NO	NO
	Proximity to entrance	Adjacent	Adjacent	Adjacent	Adjacent	near	Adjacent
	Sufficient	YES	NO	NO	YES	NO	YES

Figure (8). Pedestrian flow dynamics of the six school complexes' premises (the yellow lines are the closest to the entrance, followed by the green lines, and the blue lines are the farthest from the entrance; red areas highlight challenging streets).

Figure 8 illustrates the pedestrian flow dynamics within the premises of six school complexes in Jeddah, focusing on the movement of children between parking areas and school entrances during peak times (arrival and dismissal). The diagram highlights key elements such as parking configurations, pedestrian routes, and traffic interaction zones. Three colors were used to differentiate between the pedestrian flows regarding proximity to entrance providing a comparative analysis of conditions across the six schools (S1–S6).

The diagram revealed significant variations in pedestrian flow based on parking design and site layout. In schools with linear parking configurations, such as S1 and S3, in S3 children must navigate longer distances through high-traffic areas, increasing their exposure to vehicular hazards. whereas a secondary street somewhat shielded S1. Although S2 had more of an organized parking, yet it was clear that it was insufficient to handle peak time, forcing drivers to park nearby or across the street, increasing crossing risks for children Conversely, schools like S4, which feature planned parking areas adjacent to entrances, exhibit more streamlined and organized pedestrian flow, minimizing vehicular-pedestrian conflicts. Schools S5 and S6, which lack planned parking infrastructure, result in chaotic movement patterns, forcing children to cross unpaved or congested zones, further compromising their safety.

3.4 Summary of Results

The evaluation of walkability across the six school sites reveals a wide variation in their performance based on key factors such as greenness, sidewalk conditions, traffic volume, and street crossing features. Each site exhibits distinct strengths and weaknesses, highlighting the complexity of creating a universally walkable urban environment. Below is a detailed "pairwise comparison" of the findings:

Among the top-performing options, S2 stands out with excellent sidewalk conditions, low traffic volume, high street crossing features, and planned parking. However, its disadvantages include relatively low greenness and only moderate street signage. Similarly, S5 excels with good greenness, high street crossing features, and excellent sidewalk conditions. Yet, it is hindered by high traffic volume and unplanned parking. S1 also performs well, with high greenness, good street crossing features, and effective street signage, but it faces notable drawbacks such as poor sidewalk conditions, high traffic volume, and the lack of planned parking.

On the other hand, S4 is among the low-performing options. While it has excellent sidewalk conditions, low traffic volume, and planned parking, it is significantly disadvantaged by very low greenness, poor street crossing features, and the absence of street signage. S3 also struggles despite offering low traffic volume and planned parking; it falls short due to poor greenness, moderate sidewalk conditions, and inadequate street signage. Similarly, S6 shows strengths in greenness and street crossing features but is let down by high traffic volume, poor sidewalk conditions, and unplanned parking.

These findings (demonstrated in Figure 9) underscore the need for targeted improvements tailored to each site's specific weaknesses. For instance, enhancing greenness and street signage could elevate the walkability of lower-performing schools, while addressing issues like traffic volume and unplanned parking could maximize the potential of the top-performing ones. Overall, this analysis provides a foundation for prioritizing urban interventions to foster safer and more accessible pedestrian environments for schoolchildren.

Most schools faced significant issues that negatively impacted their surroundings and accessibility. Poor sidewalk conditions were a common problem, with many schools suffering from many deficiencies, such as uneven surfaces or obstructions. High traffic volume near schools was another frequent issue, posing student safety risks. Additionally, many schools lacked proper parking facilities, with parking often being unplanned or unavailable.

Beyond these primary concerns, most schools also struggled with inadequate greenery, making the environment less inviting and conducive to outdoor activities. The presence of main roads or highways near schools made street crossing challenging, if not impossible, while on a smaller scale, sidewalk continuity was often interrupted. This occurred due to changes in slope near driveways, particularly in apartment-style neighborhoods, or sidewalks occupied by trees and decorative elements. Street signs were generally insufficient, and in many cases, they were absent. Furthermore, street crossing facilities were not always available, further complicating pedestrian access to schools.

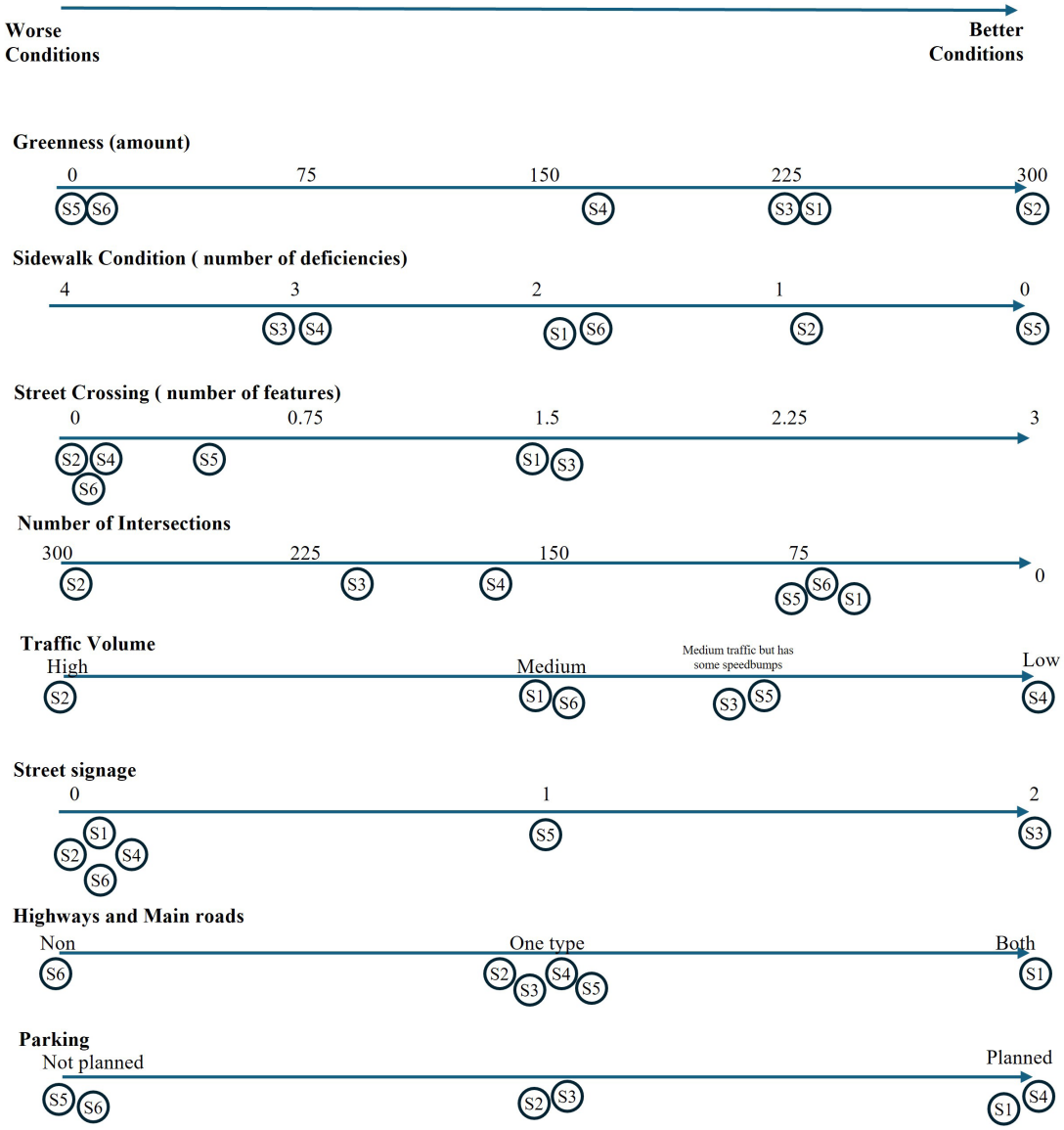

Figure (9). Graphical representation of schools' performance based on the site audit and GIS analysis

4. Discussion

This study provides a comprehensive examination of the factors influencing children's walkability to school in Jeddah, focusing on both the built environment and uncontrollable demographic and socioeconomic factors. The findings from our site audits, GIS analysis, and pedestrian motion studies underscore a complex interplay between urban design, safety concerns, and societal norms that collectively shape the school commute experience.

4.1 Key Results and Implications

The diversity in school types and the socioeconomic characteristics of neighborhoods further highlight disparities in walkability and safety perceptions. Our GIS analysis and pedestrian motion studies revealed significant variations in the quality of the built environment across different types of schools and neighborhoods, suggesting that more affluent areas tend to have better access to safe walking infrastructure. Building on this, our analysis identified several critical barriers to

Table (6). Barriers to walkability in Jeddah's school zones

Factor	Number of Schools Affected	Ratio	Key Observations
Poor sidewalk conditions	5 out of 6	83%	Issues include uneven surfaces, obstructions (e.g., trees, decorations), and slope changes.
Lack of crosswalk markings	3 out of 6	50%	Half of the schools lack visible crosswalk markings, with faded markings in the remaining.
Missing school zone signage	6 out of 6	100%	No schools had proper school zone or speed limit signs.
High traffic volume	4 out of 6	66%	Most schools are located near main roads or highways, posing significant safety risks.
Insufficient greenery	4 out of 6	66%	Only 33% of school zones featured adequate tree coverage to provide shaded walkways.
Unplanned parking spaces	2 out of 6	33%	Two schools had no planned parking areas, increasing pedestrian-vehicle conflict.

walkability in Jeddah's school zones, as summarized in (Table 6) below:

4.2 Integration with Existing Literature

Our findings align with global trends of declining active school transportation, as highlighted by (McDonald et al., 2011; Schoeppe et al., (2016), which emphasize a broader shift towards auto-dependency. This shift is further compounded by deficiencies in the built environment that pose substantial risks to children's safety and deter active commuting. For instance, 66% of school zones in our study exhibited medium traffic volumes, consistent with (Huertas-Delgado et al., 2017), who found traffic density to negatively impact child pedestrian safety. Similarly, the absence of proper crosswalks and traffic calming measures remains a significant barrier, echoing findings by (Torres et al., 2022) that 50% of school zones in the Dominican Republic lacked pedestrian crossings. Moreover, while 33% of Jeddah's school zones have some greenery, increasing shaded walkways could boost walking rates by 20–25%, as shown by (Kweon et al., 2023). Additionally, unplanned parking spaces, observed in 33% of studied schools, exacerbate safety risks, aligning with (González et al., 2020), who demonstrated the hazards of such arrangements in auto-dependent cities. These challenges underscore the multifaceted nature of promoting active commuting, with demographic and socioeconomic factors, as noted by (Al-Qahtani, 2023; McMillan, 2005), further influencing walking behavior. Addressing these issues requires interventions that target both infrastructural and social determinants.

4.3 Policy and Urban Design Implications

Several policy recommendations and urban design interventions are proposed to address the identified challenges. Increasing tree coverage within an 800-meter radius of schools is vital for providing shaded walkways, which could improve comfort in Jeddah's hot climate and boost walkability by up to 25%, as suggested by (Zhao et al., 2022). Sidewalk improvements are essential, including ensuring continuous and stable pathways free from obstructions, safe crossing facilities, and curb ramps. Traffic calming measures, such as speed bumps and pedestrian priority zones near schools, along with traffic lights equipped with pedestrian signals at key intersections, should be implemented to reduce vehicle speeds and enhance safety. Effective parking management is also critical, requiring planned parking areas and designated drop-off zones to minimize vehicular-pedestrian conflicts and streamline traffic during peak hours. Lastly, standardized school zone signage must be implemented across all sites to enhance driver awareness and improve pedestrian safety.

5. Conclusion

This study has identified critical safety and accessibility challenges impacting children's walkability in Jeddah's school zones. Key findings include inadequate pedestrian infrastructure, insufficient crossing facilities, and the absence of essential safety features such as street signage. These deficits pose substantial risks to children's safety and limit their ability to engage in active commuting.

To address these challenges, we recommend prioritizing enhancing shaded green spaces within an 800-meter radius of schools, improving the continuity and condition of sidewalks, and redesigning parking areas to minimize vehicle-pedestrian conflicts. Additionally, implementing clear and consistent school zone signage and measures to reduce traffic speeds near schools will significantly improve walkability and safety for children. These recommendations align directly with the study's findings and offer actionable steps for policymakers and urban planners to create safer, more walkable environments for children.

While this research highlights essential insights, it is not without limitations. For example, the study did not account for gender-specific barriers to walkability, and stakeholder perspectives were not directly incorporated. Future research could address these gaps by including diverse perspectives. Despite these limitations, this research provides a foundation for future initiatives to improve pedestrian safety and urban walkability in automobile-centric cities like Jeddah. By addressing these issues, stakeholders can foster a cultural shift towards sustainable and active transportation, ultimately contributing to the well-being of Jeddah's youngest residents.

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التعامل مع تحديات السلامة والتحديات الحضرية: دراسة لتجارب المشاة للأطفال في المناطق المدرسية بمدينة جدة

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قدم للنشر في ١٨/ ٣/ ١٤٤٦ هـ؛ وقبل للنشر في ٥/ ٧/ ١٤٤٦ هـ.

ملخص البحث. تبحث هذه الدراسة في العوامل التي تؤثر على قدرة الأطفال على المشي في مدينة جدة التي تتمحور حول السيارات، وهو ما يسلط الضوء على الحاجة الملحة إلى البنى التحتية الصديقة للمشاة حول المناطق المدرسية. كانت أهدافنا ثلاثية: إجراء مراجعة شاملة للأدبيات لتحديد العوامل الحاسمة في قابلية المشي، إجراء مسح في جميع أنحاء المجمعات المدرسية في جدة، وتقييم إمكانية المشي للأطفال من خلال عمليات تدقيق الشوارع وتحليل نظم المعلومات الجغرافية وتقييم ديناميكيات تدفق المشاة. تؤكد النتائج التي توصلنا إليها على ضرورة إجراء تحسينات في المناطق المدرسية، وبخاصة في مجالات مرافق العبور، ولافتات الشوارع، وتدابير التحكم في السرعة. ودعت الدراسة إلى زيادة المساحات الخضراء المظللة داخل دائرة نصف قطرها ٨٠٠ متر من المدارس لتعزيز بيئة المشي الأكثر برودة والأكثر جاذبية للأطفال. وتشير الدراسة أيضاً إلى أهمية تصميم أماكن وقوف السيارات في إدارة تجاوز سعة المركبات بشكل فعال، وتقترح إعطاء الأولوية للأرصفة غير المنقطعة، وتقليل التقاطعات لرفع مستوى سلامة المشاة. بشكل قاطع، يقدم بحثنا رؤى أساسية للمخططين وصانعي السياسات الحضريين بهدف خلق بيئة أكثر أماناً وأكثر قابلية للمشي للأطفال في المدن التي تعتمد بشكل كبير على السيارات، مثل جدة.

الكلمات المفتاحية: منطقة المدرسة، إمكانية المشي للأطفال، الاعتماد على السيارات والتصميم الحضري، تحليل نظم المعلومات الجغرافية، سلامة المشاة.