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School Commuting in Lisbon: Exploratory Research on Active and Public Transportation Choices

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ABSTRACT

In the past decades, there has been a significant growth in awareness related to the impacts of school commuting in metropolitan areas. The use of public transport and the promotion of active transportation choices among educational communities are key issues for the development of sustainable and efficient cities. This paper explores multiple factors, which range from the socioeconomic sphere to the built environment and safety around schools and also includes variables such as the proximity of the school to public transport stations/stops, the school grade and the school type (i.e., public or private schools). This paper aims to study how all these factors influence two different school commuting choices in Lisbon, Portugal: (1) the choice between active versus motorised travel modes and (2) the choice between public versus private transport modes. The *Hands Up* survey database, which includes 10 different modes for school commuting, was analysed to estimate binomial logistic regression models. The results suggest that school commuting independence happens at younger ages for public school students than for private school students and that a higher socioeconomic status has a negative impact regarding the use of public transport and active commuting to school. The planning of the public transport network is also pivotal since the close proximity of stations/stops of certain commuting modes discourages active commuting to school.

1 | Introduction

According to the United Nations [1], more than half of the World's population live in cities and, by 2050, it is estimated that seven out of ten people will likely live in urban areas. To enable people the access to education, healthcare, employment and other services, it is crucial to have these essential services within a reasonable walking or cycling distance from their houses and to encourage mobility through public transportation. Public transportation can promote efficiency, inclusivity and safety of urban areas. Hence, public transportation can also reduce traffic congestion and pollution. Nevertheless, city governments have a massive task ahead in seeking to promote the availability and use of public transport systems and to promote active commuting choices on peoples' daily routine [1–3].

On a commitment with the United Nations' sustainable development goals, worldwide, there has been an increasing concern to study current transportation choices in urban areas, namely, school commuting (SC), to create policies that can contribute to the development of sustainable cities and communities. SC has a high impact on traffic congestion when it is majorly done using private vehicles, since it is a type of commuting that generates a high concentration of traffic at very particular hours of the day: in the morning, when leaving the children at school, and in the afternoon, when parents get their children from school [4]. This means that there are two major areas in which investments can have a pivotal impact to bring positive contributions to SC and the development of sustainable cities and communities:

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i. The development of '15-Minute Cities', with walkable streets and cycling ways, to promote active commuting to school (ACS).

ii. The expansion and improvement of the public transportation network to promote SC by public transportation.

This study explores two major choices regarding SC: (1) the choice between active and motorised travel modes of transportation and (2) the choice between public and private modes of transportation. Three main explaining factors are considered in this exploratory study, namely, (1) socioeconomic factors; (2) built environment factors and (3) transportation distance factors.

The socioeconomic variables include the students' grade, the type of school (whether it is public or private) and also a socioeconomic status (SES) score classification for each parish. The built environment variables are related to the school area, since the Hands Up survey unfortunately does not gather any information on where the students reside, and therefore, there is no way to take into account the built environment around the zone of residence. The built environment variables are the distance to the closest green area (park or playground), the existence of parking spots near the school and also a safety level variable for each school. Lastly, it was important to include for each school the distance between the school and the station/stops of the different public transportation choices (e.g., bike-sharing system [BSS], bus, subway, train and tram). Therefore, we aim to better understand the influence of the last mile in SC. The last-mile notion is a topic that is gaining more importance in commuting [5, 6] but has not been explored in SC in research.

Having said that, the aim of this study is to understand the influence and effect of all these variables on our two major binary SC choices. Lisbon serves as an excellent case study; as in the last decades, Lisbon has been expanding its public transport networks, implementing cycling infrastructure and the GIRA BSS. However, during workdays, private cars still represent 56.3% of all transportation modes, while an inquiry done by the Lisbon municipality shows that 43.76% choose private car as the most common mode of transportation. These enquiries clearly show that Lisbon is a city that still is highly dependent on transportation by private vehicles.

The outline of the paper is the following: This first section introduces the main research topic of SC and the factors explored in this study. Then, Section 2 provides a more comprehensive literature review on the topic of SC. Section 3 details the methods conducted in this research. Section 4 presents the results, while Section 5 discusses them. Finally, Section 6 presents the main conclusions and points out directions for future research.

2 | Literature Review

2.1 | Factors Influencing SC

The high dependence on private cars is a topic discussed in many studies globally. For example, Black et al. [4] explain that in the UK, car-owning households make nearly double the amount of journeys via private car than a household without a car and that many of these trips are for short journeys that take 2 to 5 min. In fact, this growth in very short car journeys is especially prevalent in SC for home-to-school trips, having grown twice as fast as the average. SC in the morning accounts approximately for 20% of all UK car journeys on weekday rush hour mornings, and more than 50% of these trips cover distances under 1.6 km. Therefore, the paper hypothesises that the transition to ACS correlates with a decrease in localised congestion, since it decreases the high usage of private vehicles for SC. There are already projects being implemented regarding the so-called '15-Minute City', which are residential urban concepts where one can reach every necessary place to fulfil the daily necessities by walking or cycling no more than 15 min. This includes schools, supermarkets, hospitals and fitness gyms, for example. Moreno et al. [7] goes into detail discussing this concept, showing that it may help in having more sustainable and accessible cities with reduced congestion and pollution.

Moreover, many studies discuss the influence of age as a factor in the SC modal choice, since growing older also influences parental perception and their willingness to let their children be more independent and autonomous. An interesting finding comes from McDonald [8] in the United States, which showed that a 1-year increase in age leads to a 0.4% increase in the probability of walking and a 1.4% decrease in the likelihood of being driven to school. This is a first hint to the fact that as students grow older, they become more independent and autonomous regarding their SC modal choice, which in almost all cases means that there is a decrease in the number of students being driven to school. However, the commuting mode that students transition to depends on case to case, since for some studies, there is an increase in active modes, while for others, there is an increase in public transport. For example, in Portugal, Lopes et al. [9] draw interesting conclusions in terms of understanding that highly urbanised areas lead to a decrease of ACS due to the parental fear of traffic and accidents. This leads to children gaining autonomy and independence at a later age and consequently to a high dependence on automobiles. Additionally, Cordovil et al. [10] show that only 21% of primary school students and 45% of secondary school students travel home from school actively and independently. The factor that seems to influence this choice the most is age. Other studies such as Barranco-Ruiz et al. [11] corroborate the findings that age also has an impact on the SC modal choice. Looking at Ecuadorian students, the authors show that ACS is more prevalent among young adolescents (20%) and older adolescents (19.8%) than among children (14.2%), which once again shows that adolescents have more independent mobility than children. Power and Fitzpatrick [12] show in a study performed in the Republic of Ireland that not only is being over 12 years old one of the factors positively associated with ACS, but also while for primary school students, the private car is the most common commuting choice, and for secondary school students, the most common is public transport, which once again points to the fact that the students become more independent as they get older. Loureiro et al. [13] reach the interesting conclusion that ACS in Portugal tends to be higher among older adolescents and among adolescents with stronger family support. The study suggests that age is an important moderator for adolescent ACS in Portugal because older adolescents may have fewer personal safety concerns, since they are less dependent on parents and have greater autonomy, which means that having less parental control contributes significantly to adolescents' decisions about ACS.

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Studies usually consider the SES by analysing household income, built environment or school type, since these factors have an impact on SC modal choice due to the inequities that arise from them. Pinto et al. [14] conduct a systematic review of students aged 10–19, mostly from European countries but also including countries from Asia, Oceania, North America and South America. Their findings point to the fact that adolescents from families with lower income were more likely to adopt ACS than the ones from wealthier families. It is explained that it is not possible to establish a cause and effect for this behaviour but that it is possibly due to the fact that families with lower economic conditions are possibly more likely to have no motorised transport available. Studies such as Van Kaan et al. [15] and Power and Fitzpatrick [12] introduce a so-called SES variable in their models. In the case of Power and Fitzpatrick [12], this variable is based on family affluence scale, while for Van Kaan et al. [15], it is a score variable that ranges from −4 (extremely deprived) to +4 (extremely well-off), and it is based on factors such as mean household income, percentages of households with low income, percentages of residents without paid work and percentages of households with a low educational level on average. Mota et al. [16] also used a SES variable but based on the parents' occupation and education for a study conducted in Aveiro, Portugal, regarding female students from 7th grade to 12th grade. The data showed that students whose parents were in the lowest occupational group were significantly more likely to adopt ACS than those in higher groups and that the association was similar for the fathers' educational level. Additionally, the results showed that a transition from the father's lower occupation status or low education level to middle occupation or education was a predictor of motorised transportation. The data also showed that higher socioeconomic position is associated with higher motorised commuting, which they justify with the possibility of the household having more money availability and car ownership. Xiao et al. [17] compares school travel inequities between students from public and private schools in Shenzhen, China, by running two different models considering SC modes, such as bicycle, bus, car and school bus. The results showed that the trip length and the availability of private vehicles are the most significant factor, leading to motorised travel. Children whose parents do not hold a permanent residence permit to an urban area, who are mostly workers who have a variable work schedule/location, do not have equal eligibility to engage in the public education service system. This leads to these children being forced to go to private schools, which are usually located 1.67 times further away, and consequently creates more constraints and less flexibility on travel mode options, influencing the modal choice towards motorised travel modes. This topic is also explored by Moreno-Monroy et al. [18] in the São Paulo Metropolitan Region. The results show that the provision of public schools spatially is important and impacts young people living in areas with low levels of accessibility the most. If schools are agglomerated in certain areas and there is an absence of a public transport subsidy for SC, the students who experience a substantial increase in travel-to-school times may be forced to change from ACS to motorised travel modes. Consequently, this comes associated with an increase in the monetary spending in SC. Therefore, the most negative effect is felt by students with low-income, which may result in higher drop-out likelihood, decrease in class attendance and an overall worse performance in school. Dias et al. [19] analysed the home-to-school trip modal choice behaviours in Kandy, Sri Lanka, finding that the school type plays a significant role in the choice of school bus and private vehicle and that students from private schools are less likely to use public transport. The results also showed that active modes are not a predominant choice, and this is related to the lack of suitable infrastructures and safety issues.

Finally, the factors regarding the built environment, around the zone of residence and around the school, as well as the distances, are some of the most important factors and are included in many studies regarding the topic of SC. Pizarro et al. [20] show that, for Portuguese students in Oporto, 2 km seems to be the maximum reasonable distance for walking between home and school and that increasing this distance is associated with higher levels of motorised transportation to school. Furthermore, cycling is an uncommon choice for SC in Oporto, and therefore, special attention should be given to this mode of SC especially for distances over 2 km. Mitra [21] also conducted a systematic review, highlighting how the urban environment has an influence on travelling modes. The built environment, which according to Mitra, is characterised by the extent and quality of land use mix, transportation network and urban design features (i.e., aesthetic, physical and functional qualities of buildings and streetscapes) have an influence on the transportation modal choice. It is explained how neighbourhood street design has an impact on safety concerns, since, for example, having the presence of sidewalks enhances the perception of traffic safety, while other characteristics such as four-way streets with high volume of traffic and busy intersections create safety concerns that discourage ACS. It is highlighted how pedestrian comfort and attractiveness of the travel route may encourage active travel. The presence of parks, tree-lined streets, smaller neighbourhood blocks and pedestrian-oriented buildings may have a positive influence on the decision to walk/cycle to school. Mitra et al. [22] studies how the built environment around the school and around the zone of residence influence school travel modal choice of students aged 11–13 years in Toronto, Canada. The results indicate some association between the built environment with both school and home, and a student's likelihood of walking to and from school, having a stronger association for the morning trips. It is highlighted how distance between home and school is the most important factor when deciding whether to walk to school, since a 1-km decrease in the travel distance increases the odds of walking by 0.71–0.72 times. It shows that while for the built environment around the school, the effects on ACS were moderate, for the built environment around the zone of residence, these effects appear to be stronger and to have a larger impact on encouraging walking to school. Another interesting finding regarding the built environment is that, while for adults, one of the most important factors may be land use mix, for a child, this is not the case and, it is more important to guarantee traffic and personal safety. Carlson et al. [23] regard built environment characteristics associated with ACS for students aged 12–15 years and reach the interesting conclusion that residential density around the school and around the residence is both associated with ACS, which means that it may be more effective to target both settings instead of focusing only on one. It is explained that a greater residential density may be a marker of more walking-supportive features, such as pedestrian design and more people on the street that creates a safer social environment. Huertas-Delgado et al. [24] consider a survey completed by parents of

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children enrolled in primary school (aged 9–12 years) and of adolescents enrolled in secondary school (aged 12–16 years) in Granada, Spain, to understand the parental perceptions of barriers to ACS. The results show that many of these barriers are related to the built environment. The most common barriers for the parents of children in primary school were traffic volume and dangerous intersections; while for parents of adolescents in secondary school, the most common were distance to school and dangerous intersections. Other barriers reported by parents include the absence of sidewalks and bike lanes, for example. The study goes further into explaining that dangerous intersections were among the most reported parental barriers to ACS for both children and adolescents and that improving road safety is one of the most important factors to increase ACS. Furthermore, Jardim et al. [25] and Rothman et al. [26] also show that traffic congestion negatively impacts ACS and that factors such as illegal parking, dropping children at the opposite side of the road from schools and dangerously reversing have a major influence on this impact, which once again shows how important the built environment around the school is to avoid these situations. Vitale et al. [27] show that the surrounding of schools has a considerable impact on the modal choice and that decisions on the size and built environment around schools have a significant influence on the school travel mode. In particular, when dealing with schools in rural/suburban areas, this decision may limit children's ACS and aggravates the reliance on travelling by bus. Other studies, such as Rothman et al. [28] and Van Kaan et al. [15], focus more directly on the built environment around the school. Rothman et al. [28] did a pilot study to evaluate the school safety zone and built environment interventions created in 2017 in Toronto, under the City of Toronto's Vision Zero Road Safety Plan. This study aimed to examine the effects of these built environment interventions on driver speeds, ACS and dangerous driving. The results show that a high proportion of drivers were speeding in front of schools, before the interventions about 50% of the drivers were exceeding the speed limit, while approximately 75% exceeded 30 km/h. After the interventions, there was a modest reduction in drivers over the speed limit, reducing from 44% of the drivers to 40%, and there was also a trend of increase in ACS and a reduction in dangerous driving. The authors make it clear that, although implementing reduced speed limit zones near the schools has a positive impact on lowering collision rates, it is not enough since overall there is poor driver compliance, and therefore, it is important to additionally implement other evidence-based built environment interventions, designed to physically slow traffic or to separate pedestrians from drivers. The study reaches the conclusion that the trend towards increased ACS after the implementation of these zones was small but notable. It is explained that it may take a longer period of observation to reach further conclusions regarding this trend but that surveys, performed after the Safe Routes to School infrastructure improvements at schools in California, were implemented, showed that most parents thought that the increase in safety was important to increase ACS. Van Kaan et al. [15] studied the association between the physical environment of primary schools (students aged 5–12) and ACS in the Netherlands. The study has interesting findings regarding the built environment around the school by showing that in their models, the strongest positive correlation between the school neighbourhood environment and ACS of older children was found for aesthetics. This means that the attractiveness of the school neighbourhood may have a direct influence on the SC modal choice. When analysing this finding more in-depth, it showed that it was particularly the presence of a park in the school environment that was associated with ACS. In addition to this, there was a strong positive correlation between local safety and ACS by older students. It is reported by parents that dangerous intersections and the lack of speed limits are the major barriers preventing them from allowing their children to adopt ACS. The study further explains that regarding safety characteristics around a school neighbourhood, there is a certain threshold that is an essential condition for ACS and that once these requirements are fulfilled, the aesthetic features become more important for ACS. It is important to note that the built environment may not only have an impact on a transition to active commuting, but it may also positively influence a transition to public transport. Regarding SC in Lisbon Metropolitan Area (LMA), Queiroz et al. [29] focused on the factors that shift the decision of using private modes in SC towards the use of public transport in SC. This study, with children from Grade 1 to Grade 12, showed that along with the factors related to the frequency and schedules of public transport, the bus network factor is also one of the most impactful on students' choices, which means that a correct planning of the location of public transport stations/stops can positively influence the use of public transport in SC. Finally, school-area walkability and greenness are positively associated with active SC [30], while multinational trend data from 28 countries highlight substantial contextual variability in active commuting patterns, underscoring the need for location-specific determinants to inform policy [31].

2.2 | Research Questions

The goal of the present study is to explore three different research questions (RQ1–RQ3) regarding SC in Lisbon. Firstly, the aim is to understand to what extent school type and school parish SES affect SC choices (RQ1). Secondly, the aim is also to understand at what age, i.e., the school grade, a student gains independence and starts choosing different travel modes (RQ2). Thirdly, the aim is to quantify how the built environment, transportation network and the proximity to transportation stations and/or stops influence the modal choice (RQ3). The findings on these research questions RQ1, RQ2 and RQ3 will be discussed later.

This analysis is crucial to help city planners and policymakers to understand how these different factors impact the choices of active and public modes in SC and to support decisions to promote ACS, to improve public transportation systems, to reduce private vehicle utilisation and carbon emissions; and, ultimately, to create more sustainable and efficient cities.

3 | Data and Methods

3.1 | Databases

Similarly to studies such as Mammen et al. [32] and Vitale et al. [27], a 'hands up' type of survey was conducted to gather the data. In this case, the database contained data regarding the Lisbon municipality, Portugal [33]. The 'Mãos Ao Ar' *(Hands Up)* initiative, promoted by the Lisbon municipality (CML), aims to study how students in Lisbon usually travel to school. To do so, students from the compulsory school system are asked 'How do you normally travel to school?' and then, the teacher counts the

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number of hands that are lifted for each mode and writes it down on the survey sheet. The studies conducted by Lisbon municipality, between 2018 and 2021, have been published in Portuguese and are available on the CML website, as well as the main statistics collected through the surveys. It is important to mention that CML *Hands Up* survey reports mainly have descriptive statistics, and our research questions were not formulated and analysed in CML studies. Thus, this paper provides a new insight into their raw data, which was analysed under a research confidentiality agreement.

To capture Lisbon parishes' SES score, data from the 2015 Social Diagnosis of Lisbon municipality were used [34]. To define proximity to different transportation modes and to classify the school surroundings environment, GIRA BSS map and Google Maps were used. To define school surroundings safety levels, Google Maps and Google Street View Photos were used.

3.2 | Procedures

Implemented for the first time in 2018, the *Hands Up* survey in Lisbon is conducted, annually, in October. It is important to note that the *Hands Up* survey does not follow a sampling method. Their only imposition is to exclude military, professional and artistic schools due to its characteristics that might influence mobility. Other than that, the *Hands Up* initiative talks to all schools in the Lisbon municipality (circa 230 each year) to understand whether the school wants to participate; if it does, the survey is sent to the school; otherwise, the school is not part of the study that year. It is also important to note that the fact that a school decides to participate, it does not mean that every class from that school will participate. Each school decides with the respective class directors if they want to participate or not, which means that for some schools, every school year may be represented, while for others, only some school years may decide to participate. This means that there is total freedom for each school to participate exactly as they want each year.

A strong limitation that this survey has is that it only collects information regarding the SC modal choice but totally disregards any information about the zone of residence of these students, and therefore, there is no way to have a better understanding of the distances that each student must travel to get to school. Even though there is no information regarding these distances, it is important to know that under the Legislative Order 10-B/2021, when students are enrolling in public schools in Portugal, the priority is given to students who reside near the school. On the other hand, for private schools, there is no type of limitation regarding where a student resides and the location of the school that attends.

Due to the *Hands Up* survey data collection characteristics, concerns about data validity and reliability arise. de Wit et al. [35] confirmed the validity and reliability of the *Hands Up* survey in New Zealand by doing a test–retest method for the children's answers and by cross-checking the answers, the children gave with their parents. This study confirmed the validity and reliability of the Hands Up survey by obtaining consistent results (Cronbach's alpha ranging from 0.81 up to 1.00) for almost all commuting modes.

Data from the *Hands Up* survey was integrated with data regarding socioeconomic factors, schools' surrounding built environment safety and school proximity to different transportation modes. More information on these variables is provided in Section 3.4.

3.3 | Participants

The *Hands Up* survey (2018–2021) was addressed to students from the compulsory school system in Lisbon. In Portugal, school is compulsory for children aged between 6 until 18 years old. The compulsory school system is organised into first cycle, second cycle, third cycle (basic education) and high school (secondary education). The first cycle comprehends Grade 1 up until Grade 4, the second cycle includes Grades 5 and 6, the third cycle includes Grades 7, 8 and 9, and the high school consists of Grade 10 up until Grade 12. It should be noted that one or multiple cycles of studies can be taught at the same school. Therefore, a school may not correspond to a single cycle of studies. To understand the size of the compulsory school system in Lisbon, Table 1 presents the total number of students enrolled in each cycle as in December 2021, considering every single school in the Lisbon municipality (includes military, professional and artistic schools).

As mentioned before, not all schools are considered for the *Hands Up* survey, since military, professional and artistic schools have particular characteristics when compared to all other schools and these characteristics may have an effect on the mobility patterns, the *Hands Up* organisation chooses to leave these schools out of the survey. All other schools in Lisbon that are not affected by these particularities are considered eligible for the survey and therefore invited to participate. However, as explained before, it is up to each school to decide whether they want to participate or not. Table 2 presents the number of schools in Lisbon that chose to participate in the survey each year, also distinguishing by the number of public schools and the number of private schools. A column is added to this table with the title 'Total encompassed'. This column refers to all schools that the *Hands Up* organisation considered eligible and invited to participate in the survey for that specific year. Note that for the first year (2018), the number of schools that participated and the number of answers obtained is lower than for the subsequent years but that for the following years, the participation rate is reasonably high, suffering from a slight decrease in 2020 when the COVID-19 pandemic started.

Table 3 shows the number of students that participated in the survey throughout the years (i.e., the number of answers obtained in the survey). As expected, there are always more students from public schools participating than from private schools, since there exist more public schools than private schools in Lisbon. This table not only shows the total number of students that participated each year but also the total number of students from all schools that chose to participate. This way one is able to calculate the participation rate of the students from the schools that agreed to be a part of the *Hands Up* survey for each year. The participation rate is once again reasonably high for every year, except for 2018 which was the first year of implementation. All in all, the total number of answers obtained from the 4 years of implementation of this survey is 140,745.

Table 4 shows the distribution of SC modes in Lisbon. There is a dependence on private vehicles with about 50% of students going to school by automobile, while only 24%–27% choose ACS

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TABLE 1 | Number of students in the compulsory school system in Lisbon by cycle and school sector, 2021 (*N*).

	Public school	Private school	Total
First cycle	13,730	11,330	25,060
Second cycle	8763	5372	14,135
Third cycle	14,586	7462	22,048
Secondary school	19,582	14,706	34,288
Total	56,661	38,870	95,531

Note: Source: DGEEC/ME-MCTES through Pordata.

and 19%–25% use public transport [36]. It is important to note that the *Hands Up* survey does not consider multimodal SC. It is explained to the students that they should choose the mode that is used for the longest on the trip.

3.4 | Mode Availability in Lisbon

Cycling has been growing in popularity in recent years, and although Lisbon is known as the seven hills city, nowadays, it has over 100 km of cycling lanes. The GIRA BSS has been a major influence for this growth. It was officially launched in 2017, and nowadays, it counts with over 100 stations distributed throughout Lisbon, representing a total of over 2000 bicycles at disposal. Regarding public transport, the subway system in Lisbon is divided into four different lines, which contain in total 56 stations and its network extends over 44.5 km. In 2019, the subway served to about 160 million passengers, which decreased to about 85.6 million in 2020, due to the pandemic. There are plans to add further stations to the network until 2025. Regarding the bus and tram network, both are operated by the public transportation company Carris. Carris has a fleet of 745 buses and 48 trams, and its network consists of 97 bus routes and 6 tram routes. In 2019, this network had 139.5 million passengers. Due to the pandemic, this number went down to 79.3 million in 2020, but in 2021, it recovered to 91.2 million. The train network is operated by two different companies, Comboios de Portugal (CP) and Fertagus. CP operates a network of 73 stations in the LMA, of which 18 are in the Lisbon city. Fertagus operates a network of 15 stations in the LMA, of which four are located in Lisbon and share the train stations with the CP train operator.

3.5 | Measures/Variables

3.5.1 | SC Choices

The answers to the *Hands Up* survey: 'How do you normally travel to school?' were recoded for two different comparisons: (i) transportation mode – where the answers were separated into: active modes of transportation, which was represented with Value 1 and motorised modes of transportation, which was represented with Value 0; (ii) transportation type – where the answers were separated into public transport modes, which was represented with value 1, and private transportation modes, which was represented with value 0. It should be noted that ACS choices were considered public transportation choices in the second comparison. It should also be noted that, as mentioned before, the *Hands Up* survey only provides information on the SC modal choice, and therefore, since the *Hands Up survey* covers the whole municipality of Lisbon, and not only a specific zone where one could analyse the built environment for that zone, there is no way of introducing variables, such as the proximity of the school to the students' home or the built environment around the zone of residence, which in past studies have showed added value, as discussed in the literature review.

3.5.2 | School Type

The school type was recoded as a dummy variable: 0 for private school and 1 for public school.

3.5.3 | Parishes' SES

As stated in the literature review, studies such as Van Kaan et al. [15] and Power and Fitzpatrick [12] show that an SES score is a factor that has a significant influence on the SC choice among students. Having this in mind, an SES score variable is added in this study, by quantifying a score to each one of the 24 parishes in Lisbon, which provides an insight on the socioeconomic characterisation of the different parishes.

The implementation of this variable was done by conducting an exploratory factor analysis (EFA), with the RStudio software, and using five social indicators obtained in the Social Diagnosis of Lisbon from 2015–2016 [34]. EFA is a data reduction technique that aims to identify latent factors that explain the patterns of correlations among observed variables. It simplifies complex data by reducing the number of variables into fewer factors, which help understand how these variables are related to each other. Social indicators are statistical measures to quantitatively translate a social concept and inform about a certain aspect of social reality and are used in studies such as Van Kaan et al. [15] to introduce a SES score by analysing social indicators, such as mean household income, percentages of households with low income, percentages of residents without paid work and percentages of households with a low educational level on average. Using Van Kaan et al. [15] as reference and analysing the social indicators that were available in the Social Diagnosis of Lisbon, the following indicators were considered valid to introduce a SES score in this study: (i) early school drop-out rate, (ii) the percentage of food aid programs beneficiaries, (iii) the percentage of

TABLE 2 | Number of schools participating in the Hands Up survey in Lisbon (*n*).

	Public schools (*n*)	Private schools (*n*)	Total participating schools (*n*)	Total encompassed (*N*)	School participation rate (%)
2018	65	20	85	228	37.3
2019	117	71	188	228	82.5
2020	107	52	159	229	69.4
2021	123	56	179	226	79.2

Note: Source: Lisbon Hands Up Survey report—Ref. [33].

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TABLE 3 | Number of answers obtained in the Hands Up survey in Lisbon (*n*).

	Answers obtained from public schools (*n*)	Answers obtained from private schools (*n*)	Total answers obtained from schools that participated (*n*)	Total number of students attending the schools that participated (*N*)	Student participation rate (%)
2018	11,565	4124	15,689	35,068	44.7
2019	31,961	15,180	47,141	55,392	85.1
2020	25,027	14,808	39,835	49,669	80.2
2021	26,318	11,762	38,080	53,616	71.0
Total	94,871	45,874	140,745	193,745	72.6

Note: Source: Lisbon Hands Up Survey report—Ref. [33].

registered unemployed people, (iv) the percentage of families benefiting from social inclusion income and (v) the percentage of people with unemployment benefits. These indicators were chosen since they were the most fit to represent the purchase power of the families in each parish, as families with lower purchase power are more likely to walk to school [14] or to use public transport. As explained previously, by running an EFA using the RStudio software, it is possible to take these five social indicators and reduce them down to one socioeconomic factor that describes the correlation between all variables and represents the SES of a parish. To test the reliability and validity of the EFA approach, two metrics were computed: the Kaiser–Meyer–Olkin (KMO) test, with a meritorious adequacy with KMO = 0.80; and the Cronbach alpha, with a valid value of 0.86. Further information regarding the details and tests on the EFA, the KMO test and Cronbach's alpha, are provided in Appendix A. Appendix Tables A.1, A.2, A.3, A.4, A.5 provide additional statistical validation results supporting the EFA conducted in this study.

The SES score, obtained from the EFA, showed that there are 14 parishes with a positive score and 10 parishes with a negative score, which means that 14 of the 24 parishes in Lisbon are considered to be above average in terms of SES status. The ones with the best scores represent a higher SES, such as São Domingos de Benfica (1.261) and Belém (1.141), while the ones with the worst score represent a lower SES, such as Marvila (−1.646) and Santa Clara (−2.646).

TABLE 4 | School commuting distribution in Lisbon by year (2018–2021) [%].

Mode	2018 (%)	2019 (%)	2020 (%)	2021 (%)
Automobile	42.8	48.6	51.4	48.2
Walking	30.1	23.4	24.2	25.8
Bus	16.6	15.5	13.1	14.1
Subway	5.6	5.1	3.5	4.9
Train	1.5	2.5	2.0	2.2
Cycling	0.8	1.0	1.5	1.5
School bus	0.9	1.3	1.5	1.4
Motorcycle	0.9	1.0	0.8	0.9
Tram	0.2	0.5	0.4	0.4
Other	0.6	1.1	1.6	0.6

Note: Source: Lisbon Hands Up Survey report—Ref. [33].

3.5.4 | Safety Levels Around Schools

Based on the literature review, and studies such as Huertas-Delgado et al. [24] and Rothman et al. [28], the built environment around the school is one of the major factors influencing ACS, since it has a direct influence on parents' perception of safety. Parents report traffic volume and dangerous intersections as the most common barriers, as well as the absence of sidewalks and speeding. Having this in mind, it seemed important to include a safety variable in this study that could describe the safety of the built environment around the school, considering these factors that are reported by the parents as common barriers. Therefore, a 4-point classification for safety levels was defined, which ranges from 0 (worst) to 3 (best). These levels focus on the existence of crosswalks, the existence of traffic signs, the width of the roads and the width of the sidewalks. For example, a school with Safety Level 0 has no traffic signs and no crosswalks, while a school with Safety Level 3 has traffic signs, crosswalks and large roads/sidewalks.

3.5.5 | Proximity of Schools to Green Parks and Playgrounds

To understand decisions behind SC choices, it was important to study and quantify other factors related to the built environment around the school that may influence such decisions. Therefore, taking into account, for example, the findings from Van Kaan et al. [15], it was important to gather information regarding how far away from each school green spaces are, such as public parks or playgrounds, since it is reported that the presence of green spaces is directly associated with ACS.

For each one of the 222 schools included in this study, Google Maps and the Google Maps Street View functionality were used to visualise where the closest green spaces were and to determine the distance to these green spaces.

3.5.6 | Parking Spots

The existence of parking spots is a variable that was also added in an attempt to better describe the built environment around the school. It was recorded as a dummy variable, where 0 represents the inexistence of officially regulated parking spots around the school and 1 represents the existence of officially regulated parking spots around the school. Officially regulated parking spots means that either there is a sign allowing parking in that area or there are drawn lines on the floor, showing that a car can be parked there.

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3.5.7 | Proximity of Schools to Public Transportation

Although there is no way to include the proximity of a students' home to the school due to the limitations of the *Hands Up* survey, when taking into account studies such as Queiroz et al. [29], it seemed relevant to add variables that quantify the proximity of the different public transport commuting modes and the BSS stations to each school, since the availability and proximity of these commuting modes also has an influence on the modal choice. It was assumed that the effects of different transportation modes and their proximity could vary for shorter versus larger distances/proximities. To analyse the different effects that different proximities had, an exploratory statistical procedure was designed. The inclusion of these variables seemed especially important considering that the last-mile commute is a topic that is commonly discussed in papers about commuting, such as Razak [6], but it is not very explored in the case of SC, and therefore, these variables attempt to bring new insights on how accessibility to different public transport modes stations/stops influences the SC choice.

Since bicycle was one of the possible answers in the *Hands Up* survey, and the GIRA BSS has been growing a lot in recent years, the distance to the closest BSS station was also verified via Google Maps and with the help of the official GIRA station map. Due to the yearly growth of the GIRA BSS network, this verification had to be done regarding the year of each *Hands Up* survey study to confirm which stations were actually available at that time. For the cases where there was no information on when a certain station has opened, these stations were not considered, and the next closest one was considered to make sure that a station that did not exist at the time of the survey is not being included.

Although the proximity to the closest stations/stops for the different modes was already known, it was important to create variables that could represent distance thresholds, assuming value 1 if the distance to the school in question was lower than that certain value/threshold. This is important in order to test whether and when the proximity to these stations/stops has an impact on the modal decision. Note that if proximity (in metres) is added, without comparing a spectrum of threshold values, then its effects and complexity on modal decisions would be too simple. Therefore, different generalised linear model (GLM) regressions were estimated. These regressions already included the statistically significant variables, such as distance to green parks, safety level, SES and type of school sector. In addition to these variables, the proximity variable, the binary variable controlling the distance threshold and the interaction term between both were also included. The objective was to determine for each type of station/stop what distance to use as the threshold for this binary variable. To choose the best model specification, it was important to verify two different issues: first the coefficients for both these variables and the interaction term were statistically significant; and secondly, when there were multiple cases for which the first condition was true, the one with the lowest AIC value was chosen as the best model specification. For the comparison between active versus motorised transport modes, the optimal distance thresholds obtained were 1000 m, 700 m, 300 m, 800 m and 700 m, for the BSS Station, subway station, bus top, train station and tram stop, respectively. For the comparison between public versus private transport modes, the optimal distance thresholds obtained were 700, 300, 200, 500 and 1400 m, for the BSS station, subway station, bus top, train station and tram stop, respectively.

3.6 | Statistical Modelling

Descriptive statistics (mean, standard deviation, maximum and minimum) for the variables were calculated. To test active versus motorised travel and public versus private transportation choices, the traditional binomial logistic regression model using the logit link function was used.

GLMs describe the dependence of a dependent variable y_i on a vector of regressors x_i, in which i is the ith of the n sampled observations. This distribution for the dependent variable y_i belongs to the exponential family with a probability density function, which can be described as follows:

$$f(y;\lambda,\phi)=\exp\left(\frac{y.\lambda-b(\lambda)}{\phi}+c(\lambda,\phi)\right), \tag{1}$$

where functions b and c determine which distribution is being used, e.g., Poisson or binomial, ϕ is a dispersion parameter, which is often known and λ is the canonical parameter that depends on the regressors via a linear predictor. This linear predictor η_i is a linear function of regressors given by

$$\eta_i=\beta_0+\beta_1x_{i1}+\beta_2x_{i2}+\ldots+\beta_jx_{ij}. \tag{2}$$

The link function, $g(\cdot)$, converts the expectation of the response variable into the linear predictor, as shown in the following equation:

$$g(\mu_i)=\eta_i=\beta_0+\beta_1x_{i1}+\beta_2x_{i2}+\ldots+\beta_jx_{ij}. \tag{3}$$

Its inverse function, also known as the mean function, can now be expressed as

$$\mu_i=g^{-1}(\eta_i)=g^{-1}\left(\beta_0+\beta_1x_{i1}+\ldots+\beta_jx_{ij}\right). \tag{4}$$

This means that instead of viewing the GLMs as models for the full likelihood as it is shown in equation 1, one can express the GLMs as shown in equations (3) and (4), where one uses a particular distribution family for the estimating functions used for fitting the model. For this study, the link function used was the logit, which has the following link function shown in the following equation:

$$g(\mu_i)=\log_e\left(\frac{\mu_i}{1-\mu_i}\right). \tag{5}$$

Consequently, its inverse function is the following:

$$\mu_i=\frac{1}{1+e^{-\eta_i}}, \tag{6}$$

where μ_i is the expected response value and η_i is the linear predictor.

Logit function is the most commonly used link function in logistic regressions, due to its simplicity in the interpretation of the regression coefficients. It also has the advantage of allowing to represent the odds ratio (OR) in a simple way, making it straightforward to read the outcome.

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3.6.1 | Model Selection

The Akaike information criterion (AIC) was the criterion chosen for model selection. It evaluates how well a model fits the data, without overfitting it, as it adds a penalty term for model complexity. To quantify the AIC, the model's maximum likelihood is estimated ($\widehat{L}$) along with the number of parameters (K). The log-likelihood is applied, and it measures how likely it is to have observed the data sample for a given model.

The AIC value can be calculated using the following equation:

$$\mathrm{AIC} = 2K - 2\cdot\ln(\widehat{L}). \tag{7}$$

When comparing AIC values, the one with the lower value is the better model, because it is low for models with high log-likelihoods, but, as explained before, it penalises more complex models (with many parameters).

McFadden's R^2 is a goodness-of-fit statistic for logistic regression models. It represents the proportion of variance in the dependent variable that is explained by the independent variables and therefore indicates how well a model fits the data. McFadden's R^2 values range from 0 to 1 with higher values indicating a better model fit. In practice, values over 0.4 indicate that a model fits the data very well. The formula for McFadden's R^2 is the following:

$$R^2 = 1 - \frac{\mathrm{loglikelihood}_{\mathrm{model}}}{\mathrm{loglikelihood}_{\mathrm{null}}} = 1 - \frac{\mathrm{residual\,deviance}}{\mathrm{null\,deviance}}, \tag{8}$$

where $\mathrm{loglikelihood}_{\mathrm{model}}$ is the log-likelihood value of the current fitted model and $\mathrm{loglikelihood}_{\mathrm{null}}$ is the log-likelihood value of the null model (model with intercept only). In other words, the residual deviance tells us how well the response variable can be predicted by a model with some predictor variables while the null deviance tells us how well the response variable can be predicted by a model with only an intercept term.

The OR is a statistic that is commonly computed in logistic regression models.

$$P(X) = \frac{1}{1+e^{-\eta_i}} = \frac{1}{1+e^{-(\beta_0+\sum\beta_i x_i)}}, \tag{9}$$

$$\mathrm{OR} = \frac{P(X)}{1-P(X)} = e^{(\beta_0+\sum\beta_i x_i)}. \tag{10}$$

The usage of the OR allows a simpler interpretation of the estimated results and consequentially a better understanding of the associated effects.

Regarding the values obtained for the OR, there are three possible cases: (i) if $\mathrm{OR} = 1$, it indicates that there is no association between the variable and the outcome; (ii) if $\mathrm{OR} > 1$, it indicates that the variable has a positive impact on the occurrence of an event and; and (iii) if $\mathrm{OR} < 1$, it indicates that the variable has a negative impact on the occurrence of an event. The association between the variable and outcome is stronger the further away the value of the OR is from 1.

4 | Results

4.1 | Preliminary Analysis

Two different models were used in this study to analyse the choices behind the 140,745 answers obtained: one that compares active SC versus motorised travel SC and the other that compares public transport SC versus private transport SC. For the first model, active SC (36,968 answers) was represented with value 1, while motorised SC (103,777 answers) was represented with value 0. For the second model, public transport SC (67,628 answers) was represented with value 1, while private transport SC (73,117 answers) was represented with value 0.

Descriptive statistics, such as the mean, the standard deviation, the minimum and the maximum value, were calculated and summarised in Table 5.

4.2 | Analysis of Regression Models

This subsection analyses the results obtained from running the logit binomial regression model using all the variables mentioned before, as well as the interaction terms between some of these variables. Table 6 presents the results obtained for the influence of the explanatory variables for the two different binary decisions of SC modes (active vs. motorised; and public vs. private).

4.2.1 | Model 1 Analysis: Active SC Versus Motorised SC

Analysing the results from Table 6, when comparing active and motorised travel modes, it is possible to notice some trends that were expected beforehand. The closer there is the presence of green spaces next to schools, such as parks and playgrounds, the more probable it is for a child to adopt ACS, which is in accordance with the findings from Van Kaan et al. [15].

Regarding safety levels, one can notice that the higher the safety level is, the more probable it is to opt for ACS. Although this is true, it is important to mention that for a safety level of 2, the maximum value is reached; while for the third level, it stabilises and remains practically the same. This may suggest that there exists a safety threshold that parents deem as the minimum acceptable for them to allow their children to adopt ACS. This finding was also suggested in Van Kaan et al. [15].

The existence of parking spots next to schools influences positively the choice of ACS. Although this may be intuitive at first, it may be explained by two factors: (i) Parents may feel it is safer for their children to travel actively to school, if the cars can park correctly in designated parking and are not stopped on the sidewalk or in the driving ways, since it is less likely to originate accidents, which is aligned with the findings by Jardim et al. [25] and Rothman et al. [26]; and (ii) motorised travel modes encompass not only private modes but also public transportation, which does not rely on these parking spots to be chosen.

One can also see from the results in Table 6 that the better the schools' parish SES score is, the more probable it is for the child to adopt motorised school transportation modes, which may suggest that the better the SES score, the more likely it is for families to have more purchase power and be able for example to own a car, which consequently makes it more likely to adopt motorised travel modes of transportation. This finding is also aligned with Pinto et al. [14].

To have a better understanding on the effects of the school sector and school grade variables, as well as their interaction, Figure 1 plots the estimated effects.

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TABLE 5 | Descriptive statistics (mean, standard deviation, minimum and maximum) of variables.

Variables	Mean	SD	Minimum	Maximum
Prox. BSS station (m)	1711.621	1400.258	5	6500
Prox. subway station (m)	1492.848	1744.555	10	7400
Prox. bus stop (m)	128.597	101.396	5	500
Prox. train station (m)	1781.547	1015.632	200	5700
Prox. Tram stop (m)	3414.836	2655.452	15	10,000
Prox. green spaces (m)	342.008	257.176	5	1500
SES	−0.166	0.956	−1.261	2.646
Active transportation (%)	26.867	20.577	0	100
Motorised transportation (%)	73.133	20.577	0	100
Public transportation (%)	49.883	29.386	0	100
Private transportation (%)	50.117	29.386	0	100
Safety Level 0 (%)	5.021			
Safety Level 1 (%)	19.896			
Safety Level 2 (%)	70.846			
Safety Level 3 (%)	4.237			
Public school (%)	59.912			
Private school (%)	40.088			
Parking spots (%)	85.022			
No parking spots (%)	14.978			

Figure 1 is obtained with the estimated values for the binomial logistic regression. The link function can be expressed by

$$\text{logit}(p) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3, \tag{11}$$

where β_1, β_2 and β_3 are the coefficients associated with the school sector, the grade and their interaction term school sector x grade, respectively. These results show that around Grade 6 for public schools and Grade 7 for private schools are when there is a higher shift towards active modes. Around the transition from Grade 9 to Grade 10, there is a considerable drop for both school sectors, which means an increase in motorised travel modes for public school. It is also interesting to observe that for secondary school, e.g., Grades 10 through 12, the difference between public and private schools fades away, and both school sectors are tending towards the same ACS levels. Using the same equation (11), one can obtain the graphs for the influence of the proximity to stations/stops, which as explained before is an attempt to understand the influence of the last mile in SC, by analysing how the proximity to different public transport modes influences the SC modal choice. In this case, β_1, β_2 and β_3 are the coefficients associated with the proximity variable, the distance threshold variable and their interaction, respectively. It is important to note that for both models, the OR representation does not include the curve from the train and the tram due to the fact that both these modes have low representativity in terms of number of students that use them and therefore the curves for these modes did not

TABLE 6 | Results of explanatory variables for the binomial regression model with logit link function.

	Logit binomial model 1 (active vs. motorised)			Logit binomial model 2 (public vs. private)		
	Estimate	St. error	*p*-value	Estimate	St. error	*p* value
(Intercept)	6.018×10^{-1}	1.879×10^{-1}	0.001	−1.258	8.108×10^{-2}	$< 2 \times 10^{-16}$
Green spaces	-4.898×10^{-4}	3.025×10^{-5}	$< 2 \times 10^{-16}$	1.468×10^{-4}	2.806×10^{-5}	1.680×10^{-7}
Safety Level 1	3.134×10^{-1}	4.497×10^{-2}	3.203×10^{-12}	1.662×10^{-1}	3.761×10^{-2}	9.904×10^{-6}
Safety Level 2	5.487×10^{-1}	4.421×10^{-2}	$< 2 \times 10^{-16}$	1.665×10^{-1}	3.778×10^{-2}	1.053×10^{-5}
Safety Level 3	5.456×10^{-1}	5.354×10^{-2}	$< 2 \times 10^{-16}$	-8.098×10^{-2}	4.692×10^{-2}	0.084
SES	-1.619×10^{-1}	8.074×10^{-3}	$< 2 \times 10^{-16}$	-1.476×10^{-1}	7.876×10^{-3}	$< 2 \times 10^{-16}$
Parking spots	8.413×10^{-2}	2.575×10^{-2}	0.001	1.126×10^{-1}	2.301×10^{-2}	9.940×10^{-7}
AIC		36,339			39,874	
Null deviance		30,868			55,435	
Residual deviance		18,722			21,602	
McFadden's R^2		0.393			0.610	

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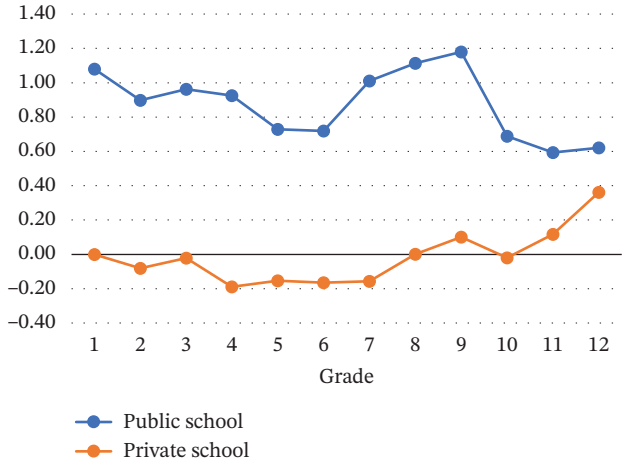


FIGURE 1 | Evolution of the effects of the school sector across school grades for choosing active transportation modes.

allow to reach reliable conclusions and are left for further research. Figure 2 plots the OR values for the effects of the BSS station, subway station and bus stops, depending on the distance.

In Figure 2, one can spot that having a BSS station right next to school makes it 50% more likely for students to adopt ACS (OR = 1.5). Up to around 400 m, the BSS station has a positive influence on children choosing ACS. Regarding the subway and bus, having a subway station or bus stop close to the school makes it 30% and 90% less likely to adopt active modes, respectively.

Since the information gathered about the distance to bus stops showed that the maximum distance to a school is 500 m and that the mean distance is 128 m, one can deduce that this variable always influences negatively the choice of active modes, because these stops are located close to the schools and therefore are always a valid option for a motorised travel mode choice.

4.2.2 | Model 2 Analysis: Public Transport Versus Private Transport in SC

Since walking and cycling were associated as public transportation modes, the proximity to green spaces was expected to influence the decision towards public modes of transportation. However, the results in Table 6 show that the proximity of green spaces to schools, for this case, is not having the expected influence. This may be explained by the fact that the public modes mainly consist of public transport, which do not depend on the existence of these green spaces to be used as the commuting mode, and therefore, the variable mitigates its effect in this comparison.

Regarding safety, for schools that have a safety level as high as 2, it impacts the decision towards a public mode of transportation, while for the highest safety level, the impact favours a private mode. This may once again suggest that Safety Level 2 is regarded as a minimum safety threshold for parents to allow their children to commute to school, without having to drive them to school, and that beyond that safety level, the differences between Level 2 and Level 3 are not significant. Regarding the parking spots, the results show that it does not influence positively the choice of private modes of transportation. This may once again be because of the parents' perception of the safety around the school. When there are designated parking spots, this perception improves, since it is less likely for cars to be stopped in the driving ways or on the sidewalk, which may reduce the fear of accidents and consequently the need to drive their children to school [25, 26, 37–39].

The schools' parish SES score also shows that the better this score is, the more likely it is for a student to choose a private mode of transportation, as suggested by Mota et al. [16] and Pinto et al. [14].

Figure 3 plots the effects of the school sector and school grade variables on choosing public transportation modes, as well as their interaction term.

In this case, Figure 3 shows that from Grade 4 onwards, the trend is almost always towards public modes as children get older, as expected and reported in other studies [9]. Once again, for public schools, the autonomy transition happens at an earlier age, around grade 6/7, while for private schools, it happens around Grade 8/9. It is also important to note that once again around Grade 10, this prevalence of ACS for children in public schools stabilises, while for children in private schools, there is a higher increase in the willingness to adopt public modes after Grade 10. This may be explained by the fact that around this age, teenagers no longer feel the need to be brought to school by private vehicles and start to have preferences towards choosing modes that allow them to go together with friends or to gain the feeling of independence, which is also in accordance with findings from Power and Fitzpatrick [12].Figure 4 plots the influence of the proximity of different stations/stops on the public mode choices, using the ORs.

Although it is harder to interpret the results for this comparison than in Figure 2, as in this case, none of these distances relate to private modes since they are all part of public transportation modes. There are still some aspects that can be analysed, namely, that it is around the distance of 200 m until the distance of 300 m that the location of the subway station has a positive influence when choosing a public mode of transportation.

5 | Discussion

5.1 | RQ1: Schools' Parish SES and School Type

The results show that for the two comparisons done in this study, (i) active modes versus motorised travel modes and (ii) public transport versus private transport, the SES score is a factor that is associated with car dependence in Lisbon. For the first comparison, it influences positively the choice of motorised travel modes, while for the second comparison, it influences positively the choice of private transport instead of public transport. These findings show that the better the socioeconomic conditions are, the more likely it is for parents to own a private vehicle and drive their children to school, which consequently impacts ACS negatively. This is aligned with findings from studies such as Huertas-Delgado et al. [40], Loureiro et al. [13], Mota et al. [16] and Pinto et al. [14].

It should be noted that, in the Portuguese public school system, to promote the proximity of services to the population and to promote ACS, educational laws privilege the assignment of

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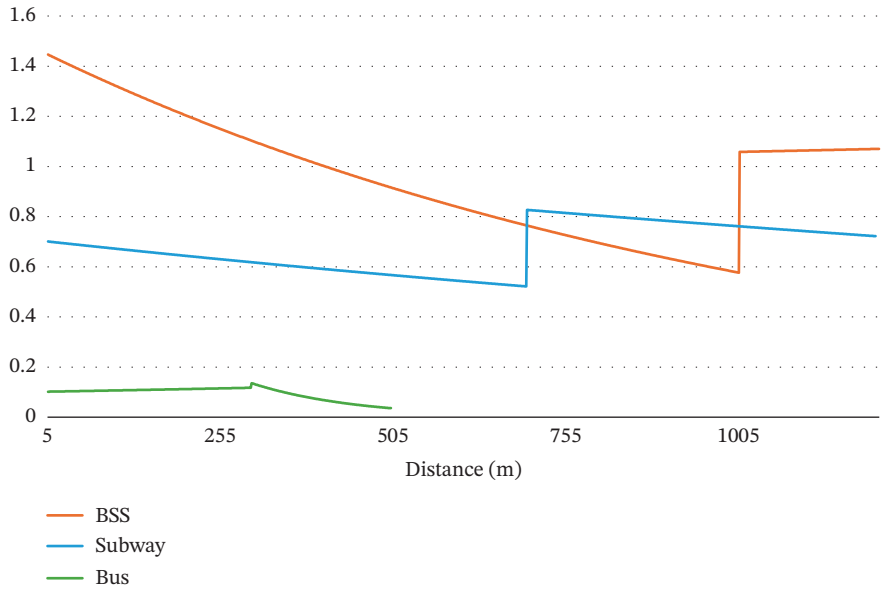


FIGURE 2 | Representation of the odds ratio for the proximity/distance of stations/stops of different transportation modes (bike-sharing system [BSS], subway and bus) in the decision of using active modes in school transportation.

students to a school next to their residence location (Legislative Order n.° 6/2018 published on the 12th of April 2018). Regarding the private school system, schools determine their own criteria of students' enrolment, regardless of the distance from home to school. This notion alone aids in understanding how important the school type is as a factor in SC decisions, and therefore, the assignment of a student to a school near the residential area seems to be an important educational policy to promote ACS and public transportation SC among public schools. In addition to this, it should be noted that private school attendance in Portugal is a parental choice, with an associated cost to be supported by the parents. Therefore, attending a private school also reflects a higher SES since it is harder for households with low income to afford those costs. Having this in mind, the analysis of the results shows that ACS in public schools is significantly higher than in private schools, regardless of the school grade, which is also corroborated by Mota et al. [16]. SC using public transportation is also higher in public schools than in private schools, regardless of the school grade. These findings are aligned with studies such as Corral-Abós et al. [41] and Dias et al. [19], confirming that the school type plays a significant role in the choice between public transport or private transport and that students from private schools are less likely to use public transport.

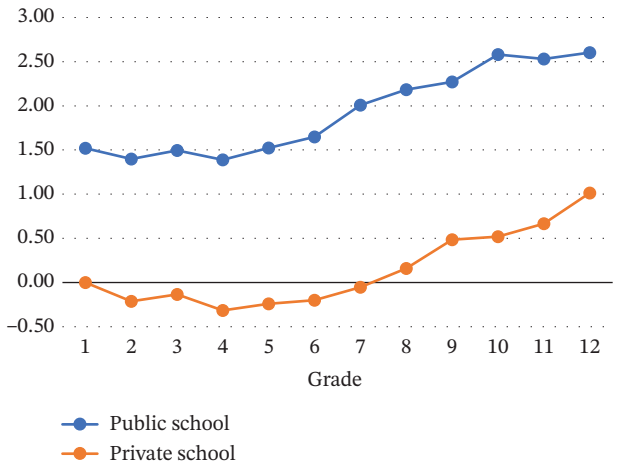


FIGURE 3 | Evolution of the effects of the school sector across school grades for choosing public transportation modes.

5.2 | RQ2: How Age Influences Students' Independence in SC

When analysing the results obtained, one can understand that for both comparisons conducted in this study, the results show that the school grade variable, which is a proxy of the age of the students, is an important factor to reduce car dependence. For both comparisons, the use of active modes and public transport increases, respectively, as students become older, which shows that they gain more independence in their SC choices. These results are in accordance with findings by Cordovil et al. [10], Gálvez-Fernández et al. [42], Loureiro et al. [13] and McDonald [8], which show that age is one of the most important factors for SC independence and that growing older reduces the need for parents to drive their children to school.

Regarding the comparison between ACS and motorised commuting, the results showed that the use of active modes happens at an earlier age for public schools; it is around Grade 6 that there is an increment towards active modes, which shows the first signs of children gaining independence on their SC modal choice, while in private schools, it is around Grade 7. The transition from second cycle to third cycle of studies (ca. 12 years old), as children grow older, seems to be a turning point regarding ACS, which is in line with Cordovil et al. [10], Gálvez-Fernández et al. [42] and Reimers et al. [43]. This difference, regarding ACS on public and private schools, tends to be smaller as students grow older, with a turning point, on both private and public schools, on the transition from Grade 9 to Grade 10 (ca. 15 years old), when students go from the third cycle to secondary school.

Regarding the comparison between public transport and private transport, the results show that the use of public transport grows

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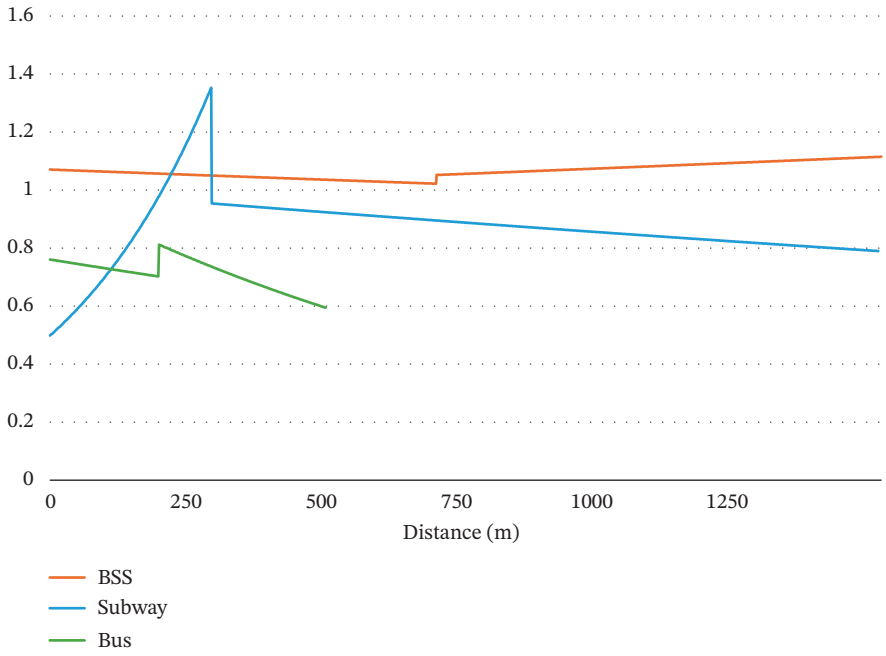


FIGURE 4 | Representation of the odds ratio for the proximity/distance of stations/stops of different transportation modes (bike-sharing system [BSS], subway and bus) in the decision of using public modes in school transportation.

steadily as the students grow older. It is also possible to notice that once again the SC independence seems to happen earlier (sixth to seventh grade) for students at public schools than for students at private schools (eighth to ninth grade). As expected, the results also show that the transition from the third cycle to secondary education is where the changes are most impactful and it is at this age that students adopt public transport as their commuting mode the most, which is in line with Power and Fitzpatrick [12].

One can see from the results that in the transition between cycles of education is where the impacts of age in SC choices are more significant. If, on the one hand, the transition from second to third cycle sees a decline in the use of private vehicles and increase in ACS and public transport modes for both public and private schools, the transition from third cycle to secondary education is more particular. It also has a significant decline of the use of private vehicles. However, for private schools, it is replaced by ACS and public transport, while for public schools, it also has a decrease in ACS but with a much higher transition towards the use of public transport modes. Therefore, it is on these cycle transitions that local public policies to encourage students for ACS and public transportation SC should be targeted and developed, regardless of the school sector.

5.3 | RQ3: Built Environment and Transport Proximity

Regarding safety level around schools, for schools that have a safety level as high as 2, it was shown that it impacts positively the decision towards a public mode of transportation. Moreover, it was observed that the higher the safety level is, the more probable it is to opt for ACS. However, the maximum value is reached at safety level of 2, while for the third level, it stabilises and remains practically the same, which shows that once a certain minimum level of safety is reached, the parents feel comfortable enough to allow their children to choose active/public modes, which is aligned with Van Kaan et al. [15]. Regarding green spaces, the results showed that the closer the green spaces are, such as parks and playgrounds, next to schools, the more probable it is for a child to adopt ACS. These conclusions are in line with research about the impact of the built environment such as Lopes et al. [9], Mitra et al. [22], Mitra [21], Van Kaan et al. [15] and Vitale et al. [27]. Regarding parking spots, the results show that it influences the choice towards active modes, which are aligned with Rothman et al. [26] and Jardim et al. [25], showing that having a safe environment around the school, without cars stopped in the driving ways or on the sidewalk, allows children to adopt ACS.

When it comes to stations' proximity to schools, having a subway station within 200 m up to 300 m has a positive effect when choosing a public mode of transportation. For tram stops, train stations and BSS stations, although when they are close to the schools, their effect on ACS is positive, when about 500–600 m is reached for the location of these stations/stops, their effect decreases significantly.

One can also see from these results that having a BSS station right next to school makes it 50% more likely for students to adopt ACS. Up until almost 500 m, the BSS station has a positive influence on children choosing ACS. These results are in line with Lucas and Andrade [44]. Regarding the subway and bus, having a subway station or bus stop close to the school makes it 30% and 90% less likely to adopt active modes, respectively, which is also in line with findings from Queiroz et al. [29], which show that the bus network (i.e., distribution of the bus stops) is one of the most important factors for students when choosing to use public transport, and with findings from Tilahun et al. [5], which show that in commuting the last-mile issues are often cited as one of the barriers to public transport use.

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The results show that the built environment around schools and stations' proximity has a huge impact on transportation choices. Timperio et al. [45] suggest that, to increase children's ACS, it may be important to create child-friendly communities. Furthermore, it seems to be important to allow children and adolescents not only to have access to the city but also to have the right to make the city different according to their needs and desires [46]. Therefore, for policymakers and city planners, it seems to be vital to listen and consider these stakeholder options, when designing environments and locating transport stations/stops in the close proximity around schools, towards more inclusive and youth-centric mobility systems.

6 | Conclusions

As expected, private vehicles are the most commonly used SC mode in Lisbon and this dependence is especially severe for private school students. For public school students, there is a higher use of public transport and ACS than for private school students. The proximity of schools to green spaces such as parks or playgrounds is positively associated with ACS. The built environment around the school also impacts ACS positively, especially regarding the safety in terms of the existence of traffic signs, crosswalks and large roads/sidewalks. A higher SES status is correlated with the higher probability of owning multiple vehicles; therefore, it impacts negatively ACS and the use of public transport. As commonly reported, age is pivotal for SC mode choice. The results show that for both types of schools (public and private), students gain more independence regarding their SC mode choice as they grow older and consequently, there is more diversity in the used modes at older ages. For private school students, the increase of ACS and use of public transport happens at the end of the third school cycle and is the highest in secondary school. For public school students, this happens at younger ages, around the beginning of the third school cycle. Regarding the proximity of the stations/stops of public transport, there are no conclusive results, but it is possible to understand that the proximity of BSS stations encourages ACS, while the proximity of bus stops and subway stations discourages ACS.

In conclusion, the findings from this exploratory study suggest that the planning of the public transport network must be done in a way that does not discourage ACS. Expanding the BSS network and opening stations close to the schools can have a positive impact on ACS. Since the distance between home and school is generally longer for private school students, there must be special attention for these trips in specific since ACS is less likely, and therefore, a transition to public transport or private school buses could be very beneficial for the reduction in private vehicle use. For public school students, initiatives such as bike trains or having instructors who accompany the students in the bus routes (e.g., the Amarelo initiative from Carris) can help promote ACS and the use of public transport, respectively.

Regarding limitations, this study does not include information regarding demographic variables; therefore, it would be interesting to include information regarding sex, household income and ownership of vehicles in the future. Moreover, it is important to note that while the COVID-19 pandemic had some impacts that could be noticed in the results obtained in the year of 2020, due to the restrictions and lockdowns, it seems that these impacts did not have an everlasting influence in SC decisions since the values in 2021 returned to values that were similar to the ones obtained in 2019 before the pandemic. Finally, SC is far from being completely understood, since it still has many issues associated with it that need better insights and solving in order to transition to more walkable, sustainable, efficient and healthy cities. The fact that there are studies regarding this topic extending to all continents in the world emphasises how car dependence is a serious problem and that a transition to sustainable SC modes such as active modes or public transport is necessary worldwide.

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The authors have nothing to report.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the Municipality of Lisbon. Restrictions apply to the availability of these data, which were used under licence for this study. Data are available from the author(s) with the permission of the Municipality of Lisbon.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Supporting Information.** Appendix Tables A.1, A.2, A.3, A.4, A.5 provide additional statistical validation results supporting the EFA conducted in this study. Specifically, Table A.1 presents the KMO measure of sampling adequacy for each variable and the overall dataset, while Table A.2 reports the internal consistency metrics based on Cronbach's alpha. Table A.3 shows the reliability analysis when individual items are removed, confirming the robustness of the factor structure. Additionally, Tables A.4 and A.5 summarise the interpretation thresholds for KMO values [47] and Cronbach's alpha [48], respectively. These supplementary materials support the adequacy and reliability of the variables used in the EFA (see Appendix Tables A.1–A.5).

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