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ARTICLE

Analysing the travel behaviour of older adults: what are the determinants of sustainable mobility?

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Abstract

In recent years, various authorities launched projects that aim to make their cities more age-friendly. Designing age-friendly cities is a complex and context-dependent process that requires clear implementation guidelines for policy makers. As one of the eight domains of age-friendly cities, transportation is a critical component of making our cities more liveable for older adults and their families. This paper contributes to the literature by exploring the travel behaviour of older adults with a focus on the factors that lead to sustainable mobility patterns. Our empirical analysis is based on survey data collected from 1,221 older adults as part of the Age-Friendly Columbus project in Columbus, Ohio in the United States of America. We develop multinomial logistic regression models to investigate the travel mode choices of older adults (auto only, non-auto options only and multimodal (auto and at least one non-auto option)). We include age and built environment characteristics as the key variables, with lifestyle-related factors and socio-demographics as controls in our analysis. We find older respondents were more likely to use autos only compared to younger respondents. Our analysis also reveals significant associations between built environment characteristics and travel mode choices. Interaction effects show that the relationships between built environment characteristics and travel preferences differed by age cohorts among older individuals. The primary contribution of this study is that it provides evidence on what built environmental improvements help to promote sustainable travel among older adults in mid-sized and auto-dependent metropolitan cities. We argue that these improvements contribute to older adults' sustainable mobility, as well as out-of-home activity behaviour, social engagement and individual health. The results of this study may especially benefit non-driver older adults who lack reliable non-auto alternatives for their daily travel.

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Keywords: age-friendly communities; older adults; sustainable mobility; multinomial logistic regression; travel mode choice

Introduction

The world is at the edge of a great demographic shift. The number of persons aged 65 years or older is projected to double by 2050 worldwide (United Nations, 2019). To support governments in making their communities more age-friendly, the World Health Organization (WHO) launched the Global Age-friendly Cities and Communities project. Age-friendliness of a community can be evaluated under eight domains: outdoor spaces and buildings, transportation, housing, social participation, respect and social inclusion, civic participation and employment, communication and information, and community support and health services (WHO, 2007). Impacting all of the domains, transportation is a key element for the wellbeing of older adults (Banister and Bowling, 2004; Adorno *et al.*, 2018). The lack of mobility is associated with an increased rate of social isolation and depression among older adults (Klicnik and Dogra, 2019; Ragland *et al.*, 2019).

As of 2017, the estimated older adult population (65 years and older) in the United States of America (USA) was over 50 million, which is equal to 15.6 per cent of the population (The Administration for Community Living, 2018). Parallel with the ageing trend in the world, this number is projected to exceed 71 million by 2030 (Colby and Ortman, 2015). This means over 20 per cent of the US population will be 65 years and older by 2030. Identifying the mobility needs of the ageing population is a fundamental challenge for policy makers in the USA. Therefore, pro-actively analysing and understanding the complex travel needs of this rapidly growing population segment is imperative.

In the USA, the preferred travel mode among older adults is privately owned vehicles (over 91%) (Shen *et al.*, 2017), which suggests an auto-dependent lifestyle. The share of private vehicle users among adults aged 25–64 years is 90 per cent (Shen *et al.*, 2017) and it varies between 85 and 93 per cent across different cohorts of adults (Dutzik and Inglis, 2014). This is expected considering the auto-oriented urban development in most of the US cities that makes the private automobile a convenient transportation mode for all (McMillan and Lee, 2017). Despite its convenience, reliance on privately owned vehicles can cause community-level challenges such as high levels of traffic congestion, increasing rates of crashes, fatalities and injuries, growth of greenhouse gas emissions, oil dependence, *etc.* (Steg and Gifford, 2005; Black, 2010; Gudmundsson *et al.*, 2016). Car dependency can also cause individual-level challenges for older adults such as loss of mobility due to driving cessation/disabilities (Marottoli *et al.*, 1997; Alsnih and Hensher, 2003; Adorno *et al.*, 2018), driving safety concerns as a result of cognitive/physical impairments, *etc.* (Rosenbloom, 2001; Dumbaugh, 2016; Centers for Disease Control and Prevention, 2020). Sustainable transportation, which refers to accessible, affordable, high quality, multimodal transportation that minimises the environmental and economic costs, is the only viable solution to all these problems (Litman, 1999; Schiller *et al.*, 2010). The promotion of sustainable transportation modes, namely transit, bicycling, and walking as alternatives to auto have the potential to provide positive health outcomes for older adults and help policy

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makers to create a balanced and equitable transportation network for all (Litman, 2002, 2019; Simonsick *et al.*, 2005; Kerr *et al.*, 2012; Cheng *et al.*, 2019*a*). Switching from driving to active travel (*e.g.* walking and bicycling) can result in numerous positive outcomes on physical and mental health of older adults due to the physical activity included and the reductions in pollutants (Frank *et al.*, 2010; Cerin *et al.*, 2017; Yang *et al.*, 2018). Beyond walkable/bikeable distances, transit services may provide travel alternatives to older adults who experience driving cessation or to those living in lower-income households and cannot afford to drive. Emerging evidence also shows that public transit use is associated with health benefits for older adults because of the first- and last-mile connections that require walking (Voss *et al.*, 2016). Provision of a reliable, accessible and affordable transit service, as well as proper infrastructure for walking/bicycling, are critical components of an equitable transportation system for all (WHO, 2002; Adorno *et al.*, 2018; Litman, 2019; Loukaitou-Sideris *et al.*, 2019).

This paper contributes to the literature by analysing the determinants of sustainable mobility among older adults. Specifically, our study responds to the following questions:

(1) What are the built environment characteristics that affect the travel outcomes of older adults?
(2) Are there cohort-specific differences in the associations between built environment characteristics and travel mode choices among older adults?
(3) What can transportation planners do to promote sustainable mobility for older adults?

We employ multinomial logistic regression (MNL) models to analyse the links between travel mode choices, age and built environment while accounting for socio-demographics and lifestyle-related factors. Our focus on age and built environment characteristics is driven by the environmental gerontological perspective, which posits old age as a critical stage in the lifespan that is significantly influenced by the physical environment (Lawton and Nahemow, 1973; Lawton, 1982; Wahl *et al.*, 2012). Previous research on ageing shows that the built environment influences daily mobility, independence, social engagement, physical activity levels and wellbeing among older adults (Cerin *et al.*, 2017; Adorno *et al.*, 2018; Bigonnesse and Chaudhury, 2019; Cao *et al.*, 2019; Li, 2020; Lyu and Forsyth, 2022). Built environment characteristics such as urban density, diversity of land use, walking infrastructure and prevalence of transit stops are facilitators of walking, bicycling and transit use among older adults (Kemperman and Timmermans, 2009; Kerr *et al.*, 2012; Cerin *et al.*, 2013; Figueroa *et al.*, 2014; Chudyk *et al.*, 2015). Due to declines in cognitive and physical capacity as people age, designing pedestrian, bicycling and transit-friendly environments that promote sustainable mobility of older adults is particularly important for relatively older age groups (Marottoli *et al.*, 1997; Mezuk and Rebok, 2008; Schouten *et al.*, 2021). The assessment of the links between travel behaviour and built environment characteristics is even more crucial in auto-dependent North American cities because older residents in these cities face higher risk of mobility disadvantage as they age and experience driving cessation (Adorno *et al.*, 2018; Dabelko-Schoeny *et al.*, 2021). It is important to control for other well-known determinants of travel behaviour, namely socio-demographics and lifestyle-related factors, to examine the true associations between the built environment and mobility of older adults (Schwanen *et al.*, 2001; Rosenbloom, 2009; Chudyk *et al.*, 2015; Cerin *et al.*, 2017; Shrestha *et al.*, 2017; Ulfarsson and Kim, 2019). Consequently, our study controls for factors such as gender, race, employment status, household income, living arrangements, health status and having others available to ask for a ride.

This paper is organised as follows. We first summarise the literature describing the factors influential on travel outcomes of older adults. We then present our study area, data and methods. Next, we demonstrate descriptive statistics and model estimations, and draw from these to inform policy makers about the relevant policies and future research directions. We conclude with potential strategies to enhance sustainable mobility for older adults.

Determinants of older adults' travel behaviour

A significant body of work demonstrates that ageing-related limitations (*e.g.* functional and cognitive impairments, *etc.*) and environmental barriers (*e.g.* spatial segregation, lack of infrastructure, *etc.*) may limit older adults' mobility (Collia *et al.*, 2003; Dumbaugh, 2016; Cerin *et al.*, 2017; Forsyth *et al.*, 2019). Previous research also shows that the lack of mobility is associated with negative health outcomes and, consequently, decreased quality of life for older adults (Marottoli *et al.*, 1997; Fonda *et al.*, 2001; Alsnih and Hensher, 2003; Kerr *et al.*, 2012; Adorno *et al.*, 2018).

Research shows older adults travel less than younger ones (Collia *et al.*, 2003; Szeto *et al.*, 2017; Rahman *et al.*, 2019). However, they are physically more active and drive more than previous generations (Rosenbloom, 2001; Nordbakke and Schwanen, 2015; Wood and Horner, 2019). Given mobility is among the top factors that influence the wellbeing of older adults (Banister and Bowling, 2004; Hjorthol, 2013), the provision of diverse travel options for older adults is crucial. In many Western countries – particularly in the USA – older adults possess auto-oriented travel behaviour and lifestyles (Buehler and Pucher, 2012; Shen *et al.*, 2017). Therefore, driving cessation may significantly increase social isolation and depression levels among older adults (Marottoli *et al.*, 1997; Davey, 2007; Mezuk and Rebok, 2008). Additionally, changing travel behaviours can be challenging for older adults due to their established habits and perceptions (Rosenbloom and Waldorf, 2001; Dill *et al.*, 2014). Recent studies demonstrate that habitual behaviour may be the true determinant of older adults' driving preference and, thus, driving cessation may limit their daily mobility (Mifsud *et al.*, 2017; Caragata, 2021). These issues call for further research that focuses on the promotion of non-auto transportation alternatives for older adults in meeting their transportation needs and challenges.

Previous research shows that the travel outcomes of older adults depend on socio-demographics, lifestyle-related factors and built environment characteristics (Rosenbloom and Waldorf, 2001; Schmöcker *et al.*, 2008; Cao *et al.*, 2010; Van den Berg *et al.*, 2011; Figueroa *et al.*, 2014; Chudyk *et al.*, 2015; Hahn *et al.*, 2016; Böcker *et al.*, 2017; Forsyth *et al.*, 2019; Klicnik and Dogra, 2019; Loukaitou-Sideris *et al.*, 2019; Cheng *et al.*, 2019*b*; Kan *et al.*, 2020). In this section, we present the existing research findings on these three categories.

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Socio-demographics

Socio-demographics are important factors when it comes to older adults and their travel behaviour. Prior studies indicate that age is a significant factor that reduces the travel demand of older adults (Collia *et al.*, 2003; Figueroa *et al.*, 2014). As the risk for cognitive and physical decline increases as people age (Marottoli *et al.*, 1997; Mezuk and Rebok, 2008; Schouten *et al.*, 2021), the decrease in daily trips is expected. Previous research focusing on Europe and Asia shows that ageing older adults drive less and use non-auto alternatives more (Rosenbloom, 2001; Schwanen *et al.*, 2001; Alsnih and Hensher, 2003; Szeto *et al.*, 2017; Cheng *et al.*, 2019*a*). However, studies focusing on auto-dependent geographies such as the USA and Canada show that ageing older adults use autos more and non-auto options such as transit, walking and bicycling less (Hess, 2009; Rosenbloom, 2009; Buehler, 2011; Shen *et al.*, 2017).

Older adults differ in terms of travel needs and preferences depending on their gender and race (Collia *et al.*, 2003; Hess, 2009; Cao *et al.*, 2010; Böcker *et al.*, 2017). Based on previous research, older women drive less and ride transit more than older men (Nobis and Lenz, 2005; Ulfarsson and Kim, 2019). This is because women are less likely to have a driver's licence, and thus rely on alternative modes of transportation more (Metz, 2003; Rosenbloom, 2009; Wacker and Roberto, 2014). Older adults with different racial and ethnic backgrounds show various travel patterns and mode choices. Research shows non-White older adults, *i.e.* Asians, Blacks and Hispanics, are less likely to drive and more likely to use alternative modes such as transit and walking than their White counterparts (Rosenbloom and Waldorf, 2001; Beckman and Goulias, 2008; Ding *et al.*, 2014). Most non-White older adults, especially those who are immigrants, on a low income, *etc.*, are more likely to live in lower-income inner-city neighbourhoods (Loukaitou-Sideris *et al.*, 2019), which suggests that they rely on transit and non-motorised transportation options.

Employment status is another significant determinant that affects travel needs and mode choices of older adults (Schwanen *et al.*, 2001; Hahn *et al.*, 2016). Employed older adults are more likely to be auto users due to their relatively higher income levels (Hjorthol *et al.*, 2010; Shrestha *et al.*, 2017). For many older adults, 'retiring from work' means 'retiring from driving' (Alsnih and Hensher, 2003; Ang *et al.*, 2020). Being employed decreases non-work auto travel among older adults due to limited time availability (Figueroa *et al.*, 2014). Berg *et al.* (2015) argue that even if newly retired people might have an auto-oriented lifestyle, they have very positive attitudes towards walking and bicycling, especially for discretionary travel. Contrary to these findings, Buehler (2011) shows that retirement increases car use among older adults in the USA. Older adults with disabilities are more likely to prefer walking (Schmöcker *et al.*, 2008). Additionally, those who are unable to work are more likely to use transit over autos (Bardaka and Hersey, 2019). Linked with the employment status, household income is found to have significant effects on the travel behaviour of older adults. Previous research shows that retired older adults' household incomes are lower than their younger counterparts (Shrestha *et al.*, 2017), therefore, they are more likely to have limited transportation options due to financial constraints (Novek and Menec, 2014; Lehning *et al.*, 2018;

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Cheng *et al.*, 2019*b*). Older adults with relatively lower disposable incomes are more likely to prefer walking, bicycling and transit as compared to auto (Kim and Ulfarsson, 2004; Böcker *et al.*, 2017; Rahman *et al.*, 2019). According to Schmöcker *et al.* (2008), there is a strong association between mode choice and household income because income level is a significant factor that determines the auto ownership of an individual. All above socio-demographic factors are influential on the travel behaviour of older adults, thus transportation studies need to account for these factors wherever possible.

Lifestyle-related factors

Lifestyle-related factors such as health status and living arrangements (living alone *versus* living with others) are also influential on older adults' travel behaviour (Hess, 2009; Cerin *et al.*, 2017). Better health status is positively associated with out-of-home activity participation, and thus promotes overall travel among older adults (Nordbakke and Schwanen, 2015; Ragland *et al.*, 2019). Mezuk and Rebok (2008) and Chihuri *et al.* (2016) show that worsening health conditions can cause driving cessation and limit older adults' mobility. In other words, those with better health conditions may drive more in the long run. Contrary to this argument, some studies argue better health status can lead to more walking and transit use rather than driving (Naumann *et al.*, 2009; Böcker *et al.*, 2017; Klicnik and Dogra, 2019). It is also important to note that active modes of transportation, such as walking and bicycling, promote positive health outcomes among older adults (Simonsick *et al.*, 2005; Kerr *et al.*, 2012; Cheng *et al.*, 2019*a*).

Living arrangement is another important determinant of travel mode choice among older adults. Those living alone are more likely to walk and use transit as compared to those living with others (Hess, 2009; Chudyk *et al.*, 2015). We want to highlight that the share of older women living alone is higher than older men because they tend to outlive men (Ortman *et al.*, 2014; Reher and Requena, 2018). Hjorthol *et al.* (2010) underline that if a woman is dependent on her husband for travel, the loss of the husband means the loss of the driver and auto travel opportunity, especially among the oldest cohorts. Linked partially with living arrangement, having others to ask for rides is another important factor that affects travel behaviour. Rides given by others are the second most preferred travel mode after driving alone among older adults (Rahman *et al.*, 2016; Ragland *et al.*, 2019). For those with mobility constraints, rides given by others are extremely important (Dumbaugh, 2016). Those who provide rides to older adults may be family members such as spouses, significant others, children and friends (Burkhardt, 1999; Choi *et al.*, 2012). Those living alone without others to ask for rides are prone to crucial mobility limitations (Hess, 2009; Tsai *et al.*, 2013). Therefore, travel behaviour studies need to consider the availability of this option for older adults, especially non-drivers.

Built environment characteristics

A substantial body of literature demonstrates that built environment characteristics are influential on travel behaviour, particularly on non-auto travel such as transit use, bicycling and walking (Handy *et al.*, 2002; Ewing and Cervero, 2010;

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Shrestha *et al.*, 2017; Loukaitou-Sideris *et al.*, 2019). Considering the possible decline of physical/cognitive capacity as people age, the association between built environment and travel behaviour is also important for the mobility and wellbeing of older adults (Nahemow and Lawton, 1973; Lawton, 1989). Therefore, controlling for both objective and perceived built environment measures wherever possible is crucial. It is important to point out that objective measures may not reflect the perspectives of older adults perfectly (Loukaitou-Sideris *et al.*, 2019). In this manner, previous studies using both perceived and objective measures show that inclusion of both would be helpful to capture the true associations between built environment measures and travel behaviour (Cerin *et al.*, 2017).

Previous research shows that built environment characteristics such as residential and commercial density, land-use mix, proximity to open and green spaces, visually appealing and aesthetically pleasing scenery, and quality of pedestrian and bicycling infrastructure are particularly influential on older adults' travel behaviour (Kemperman and Timmermans, 2009; Kerr *et al.*, 2012; Cerin *et al.*, 2013, 2017; Figueroa *et al.*, 2014; Chudyk *et al.*, 2015; Forsyth *et al.*, 2019; Cheng *et al.*, 2019*a*; Kan *et al.*, 2020). Due to health and safety concerns, well-lit sidewalks, safe urban environments and parks, pedestrian countdown timers at crosswalks, and non-slippery pavements for walking are also important facilitators of active transportation amongst older adults (Metz, 2003; Dumbaugh, 2016; Loukaitou-Sideris *et al.*, 2016; Böcker *et al.*, 2017; Ragland *et al.*, 2019). Adkins *et al.* (2017) and Loukaitou-Sideris *et al.* (2019) point out that in neighbourhoods in which safety is a major concern due to high crime rates or disorders, the effects of built environment on travel behaviour can be suppressed. Thus, wherever possible, controlling for the environmental safety measures is important.

It is important to keep in mind that the association between travel behaviour and built environment can be spurious. Individuals with positive attitudes towards specific transportation modes such as walking or bicycling may choose to live in neighbourhoods that meet their travel needs and preferences. Therefore, residential preferences might be the true determinants of travel behaviour rather than neighbourhood built environment for these individuals (Cao *et al.*, 2010). In previous literature, this is defined as residential self-selection (Cao *et al.*, 2009). Controlling for the residential self-selection would provide more accurate estimations on travel behaviour (Adkins *et al.*, 2017).

Transportation service characteristics are influential on older adults' travel preferences. Accessible, affordable, convenient, frequent and reliable transit service provision is important, especially for those who do not own autos and/or cannot drive (Alsnih and Hensher, 2003; WHO, 2007; Novek and Menec, 2014; Dumbaugh, 2016; Szeto *et al.*, 2017; Ragland *et al.*, 2019). The quality of transit infrastructure, such as transit stops with benches and shelters, and the service reliability are particularly important for transit preferences during extreme weather conditions (Shrestha *et al.*, 2017; Klicnik and Dogra, 2019). Considering the importance of the first- and last-mile access issues for transit, high-quality pedestrian infrastructure and prevalence of transit stops are also important for older adults' travel behaviour (Kerr *et al.*, 2012; Cerin *et al.*, 2013). Dill *et al.* (2014) indicate individuals' perceptions about transportation service and infrastructure can influence their mode choices. They argue that perceived quality of service and infrastructure can have mediating

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effects on the relationship between built environment characteristics and travel behaviour. Given that older adults are more likely to experience mobility limitations that may influence their perceptions negatively, it is important to include variables regarding perceived transportation service quality in travel behaviour analyses.

Promoting sustainable mobility among older adults in the USA

Considering the ageing population of the USA, the above-mentioned built environment factors related to infrastructure, design and service characteristics need to be incorporated into the neighbourhood design processes. For that reason, researchers in the field of ageing conducted various empirical studies in recent years to test the potential effects of the built environment on older adults' mobility in US cities. These studies elaborated the impacts of various urban planning concepts such as transit-oriented development[1] and smart growth,[2] and different built environment variables such as building density, land-use mix, transit service quality, street connectivity, quality of sidewalks and proximity to nearest parks on sustainable travel mode choices of older adults (Boschmann and Brady, 2013; Yang *et al.*, 2018; Loukaitou-Sideris *et al.*, 2019; Bai *et al.*, 2021; Schouten *et al.*, 2021). These studies demonstrated that the built environment interventions can significantly influence older adults' travel behaviour, particularly in reducing auto trips and promoting non-auto modes of transportation. Providing non-auto alternatives is crucial in solving the accessibility issues of transportation-disadvantaged communities with limited access to health care, goods, services and social networks, particularly in auto-oriented US cities (Adorno *et al.*, 2018; Lehning *et al.*, 2018; Dabelko-Schoeny *et al.*, 2021).

Based on this understanding, this study focuses on the impacts of various built environment factors and age cohorts of older adults on their travel preferences while controlling for well-known and widely used control variables such as sociodemographics and lifestyle-related factors (for a summary of the factors that influence older adults' travel behaviour, *see* Table 1). Since environmental gerontology literature points out the need for the assessment of individual-level factors together with social and physical environmental components for ageing studies (Lawton and Nahemow, 1973; Wahl *et al.*, 2012), we used a diverse set of variables in our analyses. These variables provide us with the opportunity to examine the true associations between the built environment and sustainable mobility of older adults while controlling for well-known determinants of travel behaviour in later life. Our study presents on-site implementation guidelines for urban planners and decision-makers that are transferable to other cities with similar urban development patterns.

Data and methodology

This study focuses on the travel behaviour of older adults in Columbus, Ohio, in the USA. Central Ohio residents aged 50 years and older make up 31 per cent of the total population (American Community Survey, 2020), and the number of older adults in the region is expected to double in the next 35 years (Mid-Ohio Regional Planning Commission (MORPC), 2017). In order to respond to this demographic change, the authorities launched the Age-Friendly Columbus (AFC) initiative in 2016. Since then, AFC has been working on research projects

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Table 1. Summary table for determinants of older adults' travel behaviour

Determinant type	Determinant name	Source
Socio-demographics	Age	Figueroa *et al.* (2014); Szeto *et al.* (2017); Schouten *et al.* (2021)
	Gender	Rosenbloom (2009); Cao *et al.* (2010); Böcker *et al.* (2017)
	Race	Rosenbloom and Waldorf (2001); Beckman and Goulias (2008); Ding *et al.* (2014)
	Employment status	Buehler (2011); Shrestha *et al.* (2017); Ang *et al.* (2020)
	Household income	Shrestha *et al.* (2017); Lehning *et al.* (2018); Cheng *et al.* (2019*b*)
Lifestyle-related factors	Health status	Nordbakke and Schwanen (2015); Klicnik and Dogra (2019); Ragland *et al.* (2019)
	Living arrangement (living alone *versus* with others)	Hjorthol *et al.* (2010); Ortman *et al.* (2014); Chudyk *et al.* (2015)
	Having others to ask for rides	Tsai *et al.* (2013); Dumbaugh (2016); Ragland *et al.* (2019)
Built environment characteristics	Residential and commercial density	Kemperman and Timmermans (2009); Figueroa *et al.* (2014); Böcker *et al.* (2017)
	Land-use mix	Chudyk *et al.* (2015); Cerin *et al.* (2017); Loukaitou-Sideris *et al.* (2019)
	Proximity to open and green spaces	Kerr *et al.* (2012); Loukaitou-Sideris *et al.* (2016); Yang *et al.* (2018)
	Quality of pedestrian infrastructure	Metz (2003); Kerr *et al.* (2012); Dumbaugh (2016)
	Quality of transit infrastructure	Cerin *et al.* (2013); Forsyth *et al.* (2019); Cheng *et al.* (2019*a*)
	Transportation service characteristics	Alsnih and Hensher (2003); Shrestha *et al.* (2017); Loukaitou-Sideris *et al.* (2019)

and on-site applications that are intended to make the city more liveable for individuals of all ages.

Columbus is the largest metropolitan area in Central Ohio and the 32nd most populous metropolitan area in the nation (Statista, 2021). It has a diverse representation of age groups, cultures and ethnicities. Columbus metropolitan area has a sprawled urban form, a well-connected highway system and a relatively sparse transit network (Wang and Chen, 2015; Vyas *et al.*, 2019). As a major Midwestern city that is more auto-dependent than coastal cities such as New York, San Francisco and Boston, the analysis of the travel behaviour of older adults can offer valuable insights to numerous US cities with a similar urban form and transportation network.

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Data

The primary data for this study were collected by the Center for Community Solutions through engagement with the MORPC as a part of the AFC and Franklin County initiative. Through two surveys conducted in Columbus, Ohio from September to November in 2016, the respondents were asked questions about eight age-friendly domains (MORPC, 2017). The dataset provides 1,221 responses from registered voters aged 50 and older residing in Columbus (stratified by ZIP codes and age groups according to the voter registration list). Age 50 years was selected as the cut-off point because racial and ethnic minorities and those living in poverty experience age-related changes at younger ages than White and/or wealthier counterparts. The same age cut-off point is used by several earlier studies that focus on older adults' travel behaviour (Hess and Russell, 2012; Fordham *et al.*, 2017; Li and Tilahun, 2017). Both surveys provide detailed information on respondents' individual and household characteristics, transportation mode choices and impressions regarding amenities, services, infrastructure and barriers within their neighbourhood.

We linked the AFC survey with the US Environmental Protection Agency's Smart Location Database (SLD) to obtain information about built environment characteristics. SLD is a data product that summarises more than 90 different indicators associated with built environment and location efficiency (for details, *see* US Environmental Protection Agency, 2014). Most of the SLD attributes are available at the census block group (CBG) level; however, since our primary data source is stratified at the ZIP code level, we recalculated all SLD variables at the ZIP code level. In the condition of lack of available built environment data at a finer scale such as CBG or a buffered zone around the participants' home, the use of ZIP codes for the analyses is a common practice in travel behaviour studies (Freeman *et al.*, 2012; Yang *et al.*, 2018; Macleod *et al.*, 2020). The recalculation using ArcGIS software (version 10.6) can be summarised within four steps: (a) using the intersect tool, we calculated intersecting features of each CBG by ZIP codes; (b) using field calculator, we estimated the percentage of area covered by each intersecting feature within the corresponding ZIP code area; (c) using the percentages calculated in the second step, we calculated the normalised values for all SLD variables for each feature within the ZIP code; and (4) using the spatial join operation, we aggregated intersecting features by the corresponding ZIP codes.

The AFC survey respondents were asked about their travel mode choices for running errands, getting medical appointments or attending events. These items were considered the most frequent activities of daily interests. The respondents were allowed to choose multiple options. Based on the respondents' answers to this question, we created three categories to represent individual travel preferences:

(1) Auto user (individual uses the auto option only as a driver and/or as a passenger).
(2) Non-auto user (individual uses only non-auto alternatives such as walking, bicycling, transit, *etc.*).
(3) Multimodal traveller (individual uses both auto – as a driver and/or as a passenger – and at least one non-auto alternative).

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As indicated previously, non-auto options such as walking, bicycling and transit promote positive health outcomes among older adults, minimise environmental and economic costs, and help eliminate isolation issues created by the driving cessation in older ages. Due to these reasons, the multimodal travel preference (indicating that individual uses non-auto transportation modes for some of the trips) and non-auto travel preference (indicating that individual uses solely non-auto transportation modes for travel) can be referred to as more sustainable options as compared to auto-only travel preference. We included three groups of independent variables in our analysis: (a) socio-demographics, (b) lifestyle-related factors, and (c) built environment characteristics. The socio-demographics cover variables such as age, gender, race, household income and employment status. Lifestyle-related factors include health status, living alone and having others available to ask for a ride. Lastly, we included two groups of built environment variables. The first group consists of objective built environment measures, namely retail density, land-use mix and frequency of transit service that come from SLD. The second group includes perceived built environment measures, *i.e.* access to well-maintained and safe parks that are within walking distance of home, access to crosswalks with pedestrian countdown timers that allow enough time to cross, that come from the AFC survey. Also, we tested for additional objective built environment characteristics such as residential density, population density, regional diversity index, *etc.*, and perceived built environment measures such as perceived transit service quality, perceived sidewalk quality, *etc.*, in different stages of the study; however, excluded most of them because they either caused autocorrelation problems or did not provide any interpretive results.

Methodology

We examined the associations between our dependent variable, travel preference, key variables, *i.e.* age and built environment characteristics, and control variables, namely socio-demographics and lifestyle-related factors, using a MNL model (for details, *see* McFadden, 1974; Hausman and McFadden, 1984). MNL is a method employed when you have discrete choices such as transportation mode choice. Therefore, we employ MNL for the multivariate analysis similarly to previous studies focusing on mode choice of older adults (Schwanen *et al.*, 2001; Kim and Ulfarsson, 2004; Buehler, 2011; Böcker *et al.*, 2017).

The MNL employed in this study takes the following functional form:

$$P_{ij} = \frac{\exp\left(S_{ij},\ L_{ij},\ B_{ij}\right)}{\sum_{j=0}^{2} \exp\left(S_{ij},\ L_{ij},\ B_{ij}\right)} \quad \textit{for} \quad j = 0,\ 1,\ 2 \tag{1}$$

where P_{ij} = probability of person i belonging to discrete travel preference category j (0, 1 and 2 refer to auto user, non-auto user and multimodal traveller, respectively); S_{ij} = a vector of individual socio-demographic characteristics such as age, gender, *etc.* of person i; L_{ij} = a vector of lifestyle-related factors such as health status, living arrangement, *etc.* for person i; B_{ij} = a vector of built environment characteristics such as access to well-maintained and safe parks that are within walking distance, land-use mix, *etc.* within neighbourhood of person i.

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We set auto user as the reference category and interpret the coefficients for non-auto user and multimodal traveller as compared to the reference category. We also tested interaction terms between our key variables, built environment characteristics and age, to see whether there are differences across different cohorts of older adults in terms of travel behaviour. A significant number of respondents did not provide complete responses to all questions. We removed those with missing information and examined the sample using univariate and multivariate statistics to identify coding errors and outliers (Tabachnick and Fidell, 2012). The final sample included 689 valid responses. It is important to acknowledge the limitations of using MNL for the analysis. The MNL model assumes that the ratio of probabilities of choosing any two alternatives is independent of the existence of another, the irrelevant alternatives (IIA) assumption (McFadden *et al.*, 1976; Greene, 2018). The IIA assumption is the most serious limitation of MNL models because it may be unrealistic in a number of decision situations (Heinrich and Wenger, 2002; Seo, 2016). MNL models also assume homogeneity in tastes, which implies the effects of an attribute are fixed across a population (Willis, 2014). Lastly, in panel data settings, MNL models assume there is no serial correlation in the error term, which may not hold true in various cases (Morikawa, 1994; Seo, 2016).

Results and discussion

Table 2 presents the descriptive statistics for the dependent variable, key variables (age and built environment characteristics) and control variables. As expected, consistent with the auto-dependency in the USA (Buehler and Pucher, 2012), auto users made up 84 per cent of the sample. The multimodal traveller category which includes individuals who use non-auto modes (bicycles, walking, transit, *etc.*) as well as autos had the second highest share (10%). Lastly, the non-auto users (those who solely use non-auto modes) accounted for 6 per cent of the sample.

Most of the respondents (80%) were within the 50–69 age range, with those aged 60–69 making up the largest share (44%). Twenty per cent of the respondents were aged 70 and above. The survey sample included more women than men (71% *versus* 29%). This is not unexpected. The dominance of women in survey samples is reported in some earlier studies using primary data collected from older adults (Naumann *et al.*, 2009; Ragland *et al.*, 2019). Most of the respondents were White/Caucasian (80%) and almost half of the respondents had more than US $60,000 household income. The median household income in Columbus is US $54,902 (US Census Bureau, 2021), and those who have more than US $60,000 household income have a relatively higher income level. Almost half of the respondents were employed (48%). More than 87 per cent of the participants indicated that their health status is good, very good or excellent. This suggests that for most of the respondents, health status may not be a limitation for walking and bicycling. About one-third of survey respondents lived alone, while 5 per cent did not have others to ask for a ride. This suggests some respondents may not have the option to travel as a passenger, which may reduce their auto use. When it comes to perceived built environment characteristics, 59 per cent of the respondents stated they have access to well-maintained and safe parks, and 55 per cent

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stated they have access to crosswalks with pedestrian countdown timers that allow enough time to cross in their neighbourhood. We included three objective built environment characteristics in the final model, namely retail density, land-use mix[3] and frequency of transit during evening peak.[4] We examined the correlations between all independent variables included in the analysis to rule out multicollinearity. Since all results are modest (all Pearson correlations ≤ 0.51), we proceeded with multivariate analysis (Table 3).

Factors affecting sustainable mobility preferences of older adults

We further examined the effects of independent variables on travel preferences of older adults using MNL models. We also tested for moderation effects through interactions between the key variables to assess differences across different age cohorts. We tested our models for multicollinearity using variance inflation factors (VIFs). Results show the mean VIF value is 1.49 and all individual VIF values are less than 2.86 (lower than the widely used cut-off value of 5.0; Craney and Surles, 2002), which suggests that multicollinearity is not a concern for the model. We also tested all our models for IIA using Hausman–McFadden and Small–Hsiao tests (Hausman and McFadden, 1984; Small and Hsiao, 1985; McFadden, 1987), that are widely used in the literature. The models meet the pre-defined criteria for both tests, which suggest that IIA assumption holds (Long and Freese, 2005). We acknowledge that these tests are sensitive to model parameterisation (Cheng and Long, 2007; Hamre and Buehler, 2014). Based on discrete choice theory and subjective judgement, we decided that all three categories are distinct choice sets for older adults.

We report relative risk ratios (RRR), p-values, and lower and upper bounds of the confidence intervals. RRR refers to the probability of choosing the corresponding outcome category over the probability of choosing the base category for a unit change in the predictor variable. In our models, being an auto user is set as the base category. If RRR is greater than 1 for an explanatory variable, the probability of being in the corresponding outcome category relative to the base outcome category increases as the value of the variable increases. As expected, if the RRR value is less than 1, it refers to otherwise. The results of these models are shown in Table 3.

Controlling for other variables (hereafter this applies to all interpretations), those aged 60–69 were less likely to prefer using non-auto modes as compared to those aged 50–59. This shows the increasing auto-only travel preferences of ageing older adults. This is consistent with the previous literature demonstrating that ageing older adults drive more and use non-auto options less, particularly in auto-dependent geographies like the USA and Canada (Hess, 2009; Rosenbloom, 2009; Shen *et al.*, 2017). We do not find any significant relationship between age and the multimodal traveller category. It is important to note that the cross-sectional structure of our dataset may mask the cohort effects and, thus, the assessment of these findings in a longitudinal design may provide more accurate estimates about the associations between older adults' age and transportation mode choices.

Our results show that most of the built environment characteristics were associated with older adults' mode choices. Having access to well-maintained and

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Table 2. Older adults' characteristics and built environment measures, descriptive statistics

Categories	Variable (person-level)	%	Mean	SD	Minimum	Maximum
Dependent variable	Travel preference:					
	Auto user	83.89				
	Non-auto user	6.24				
	Multimodal traveller (auto + non-auto alternative(s))	9.87				
Socio-demographics	Age:					
	50–59	35.99				
	60–69	44.12				
	70 or more	19.88				
	Gender:					
	Male	28.59				
	Female	71.41				
	Race:					
	White/Caucasian	79.68				
	Non-White	20.32				
	Household income (in US dollars):					
	0–24,999	19.45				
	25,000–59,999	32.80				
	60,000+	47.75				
	Employment status:					
	Employed	48.04				

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	Unemployed/retired and seeking work	11.32
	Retired and not looking for work	30.91
	Disabled and unable to work	9.72
Lifestyle-related factors	Health status:	
	Fair or poor	12.05
	Good, very good or excellent	87.95
	Living alone:	
	Yes	33.09
	No	66.91
	Variable below is the answer to the following question[1]: Do you face any of the barriers listed below when travelling to an appointment, event or community location?	
	Don't have others who can take me:	
	Yes	4.79
	No	95.21
Built environment characteristics	Variables below are the answers to the following question[2]: In your neighbourhood, do you have access to the following?	
	Well-maintained and safe parks that are within walking distance of your home:	
	Yes	58.78
	No or not sure	41.22
	Crosswalks with pedestrian countdown timers that allow enough time to cross:	
	Yes	55.15

(*Continued*)

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Table 2. (*Continued.*)

Categories	Variable (person-level)	%	Mean	SD	Minimum	Maximum
	No or not sure	44.85				
	Retail density		1.01	1.26	0.11	23.80
	Land-use mix		1.66	0.70	0.67	6.41
	Frequency of transit (during evening peak)		291.74	338.92	2.58	1,907.37

Notes:Number of observations = 689. 1. There are other categories in this question that are not included in the final model because either they lack theoretical support or they did not provide any interpretive results. These are 'I can't afford a car or car maintenance', 'I do not drive', 'I can't afford public transportation', 'There is no bus to take me where I need to go', 'Buses are difficult to use and/or unreliable' and 'I don't feel safe walking'. 2. There are other categories in this question that are not included in the final analysis because either they lack theoretical support or they did not provide any interpretive results. These are 'Streets that are visually appealing (trees, flowers, benches and public art make the street a nice place to walk or ride a bike)', 'Well-lit public streets and walkways' and 'Sidewalks that are in good condition'. SD: standard deviation.

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Table 3. Multinomial logistic regression model results

	Model without interaction effect				Model with interaction effect			
	(1) Non-auto user		(2) Multimodal traveller (auto + non-auto alternative(s))		(1) Non-auto user		(2) Multimodal traveller (auto + non-auto alternative(s))	
	RRR (*p*)	95% CIs	RRR (*p*)	95% CIs	RRR (*p*)	95% CIs	RRR (*p*)	95% CIs
Age (Base case: 50–59):								
60–69	**0.37 (0.044)**	**0.14–0.97**	0.81 (0.539)	0.41–1.60	**0.21 (0.048)**	**0.04–0.99**	**0.36 (0.073)**	**0.12–1.10**
70 or more	0.52 (0.335)	0.14–1.96	1.66 (0.248)	0.70–3.92	**0.08 (0.058)**	**0.01–1.09**	0.38 (0.216)	0.08–1.75
Have access to parks within walking distance	1.11 (0.804)	0.48–2.56	**2.95 (0.002)**	**1.49–5.81**	1.07 (0.873)	0.45–2.54	**2.95 (0.002)**	**1.48–5.89**
Have access to crosswalks with countdowns	**4.44 (0.001)**	**1.81–10.87**	**2.05 (0.023)**	**1.10–3.81**	2.10 (0.265)	0.57–7.79	0.82 (0.670)	0.32–2.09
Retail density	0.93 (0.761)	0.58–1.49	0.82 (0.275)	0.57–1.17	0.95 (0.852)	0.57–1.60	0.84 (0.347)	0.59–1.21
Land-use mix	0.92 (0.837)	0.41–2.05	**1.52 (0.061)**	**0.98–2.37**	0.92 (0.849)	0.41–2.08	**1.51 (0.070)**	**0.97–2.36**
Frequency of transit	**1.002 (0.001)**	**1.001–1.003**	**1.001 (0.019)**	**1.0001–1.002**	**1.002 (0.001)**	**1.001–1.003**	**1.001 (0.015)**	**1.0001–1.002**
Age × Crosswalks with countdowns[1] (Base case: 50–59 × Crosswalks with countdowns):								
60–69 × Crosswalks with countdowns	–	–	–	–	2.07 (0.444)	0.32–13.37	3.05 (0.107)	0.79–11.79
70 or more × Crosswalks with countdowns	–	–	–	–	**11.78 (0.070)**	**0.82–169.50**	**8.08 (0.014)**	**1.54–42.50**
Female	**2.86 (0.046)**	**1.02–8.06**	0.74 (0.320)	0.41–1.34	**2.90 (0.046)**	**1.02–8.22**	0.71 (0.263)	0.39–1.30
Race (Base case: White/Caucasian):								
Non-White	1.40 (0.432)	0.60–3.27	1.34 (0.410)	0.67–2.67	1.52 (0.342)	0.64–3.57	1.44 (0.306)	0.72–2.88

(*Continued*)

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Table 3. (*Continued.*)

	Model without interaction effect				Model with interaction effect			
	(1) Non-auto user		(2) Multimodal traveller (auto + non-auto alternative(s))		(1) Non-auto user		(2) Multimodal traveller (auto + non-auto alternative(s))	
	RRR (*p*)	95% CIs	RRR (*p*)	95% CIs	RRR (*p*)	95% CIs	RRR (*p*)	95% CIs
Household income (Base case: 0–24,999):								
25,000–59,999	**0.16 (0.000)**	**0.06–0.43**	**0.34 (0.011)**	**0.15–0.78**	**0.14 (0.000)**	**0.05–0.39**	**0.31 (0.006)**	**0.13–0.72**
60,000+	**0.17 (0.003)**	**0.05–0.54**	**0.48 (0.090)**	**0.20–1.12**	**0.15 (0.002)**	**0.05–0.50**	**0.44 (0.057)**	**0.19–1.03**
Employment status (Base case: Disabled and unable to work):								
Employed	0.58 (0.350)	0.19–1.81	**0.35 (0.035)**	**0.13–0.93**	0.66 (0.482)	0.21–2.10	**0.39 (0.060)**	**0.14–1.04**
Unemployed/retired and seeking work	0.92 (0.898)	0.25–3.40	**0.34 (0.076)**	**0.11–1.12**	1.06 (0.933)	0.28–4.01	0.37 (0.103)	0.11–1.23
Retired and not looking for work	0.74 (0.668)	0.19–2.88	**0.35 (0.056)**	**0.12–1.03**	0.93 (0.920)	0.23–3.73	0.40 (0.102)	0.13–1.20
Health status (Base case: Fair or poor):								
Good, very good or excellent	**0.41 (0.058)**	**0.16–1.03**	0.96 (0.929)	0.40–2.32	**0.41 (0.070)**	**0.16–1.08**	1.02 (0.960)	0.42–2.52
Living alone	**5.26 (0.000)**	**2.14–12.91**	**2.22 (0.012)**	**1.19–4.14**	**5.10 (0.000)**	**2.07–12.58**	**2.20 (0.014)**	**1.18–4.12**
Don't have others who can take me	**4.06 (0.015)**	**1.32–12.47**	2.46 (0.118)	0.80–7.63	**4.32 (0.013)**	**1.37–13.66**	2.61 (0.101)	0.83–8.23
Constant	**0.03 (0.000)**	**0.006–0.18**	**0.07 (0.000)**	**0.02–0.23**	**0.05 (0.001)**	**0.01–0.30**	**0.12 (0.001)**	**0.03–0.43**
Sample size	689				689			
Log likelihood	−285.35				−280.64			
Model χ^2	185.88				195.30			

Notes: The base category is 'auto user'. RRR: relative risk ratio (*i.e.* the odds ratio equivalent in multinomial logit model). CIs: confidence intervals (upper and lower bounds). 1. All variables related to the built environment characteristics are tested for interactions with age. This is the only significant interaction between the key variables.
Significance level: Bold values are significant at the 10 per cent level.

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safe parks that are within walking distance of residential locations increased the likelihood of preferring multimodal travel over the auto-only option. This finding is consistent with the previous literature which demonstrates open and green spaces in the neighbourhood are important facilitators of active travel among older adults (Cerin *et al.*, 2013; Loukaitou-Sideris *et al.*, 2016). Those who have access to crosswalks with countdown timers in their neighbourhood were more likely to be in more sustainable travel categories. This is in parallel with the previous studies that show pedestrian countdown timers are crucial factors that affect older adults' active travel (Metz, 2003; Kerr *et al.*, 2012). Those living in neighbourhoods with higher levels of land-use mix were more likely to be multimodal travellers, which suggests land-use mix is a facilitator of sustainable mobility amongst older adults. The transit service frequency variable had slightly positive associations with both non-auto user and multimodal traveller categories. This indicates those who live in neighbourhoods with higher transit service frequencies were more likely to be in more sustainable travel categories. This is consistent with previous studies linking transit service quality and sustainable mobility among older adults (Alsnih and Hensher, 2003; Szeto *et al.*, 2017; Klicnik and Dogra, 2019).

The findings regarding the control variables are mostly consistent with studies conducted elsewhere. Women were more likely to be non-auto users, as expected (Nobis and Lenz, 2005; Ulfarsson and Kim, 2019). Those with higher household incomes were less likely to prefer multimodal travel and non-auto travel over the auto-only option. This is consistent with the previous literature as presented by Böcker *et al.* (2017), Kim and Ulfarsson (2004) and Schmöcker *et al.* (2008). Those who are not disabled and unable to work were less likely to be multimodal travellers as compared to being auto users. This is consistent with the literature that shows those who are disabled and unable to work are more likely to use non-auto modes of transportation (Schmöcker *et al.*, 2008; Bardaka and Hersey, 2019). Older adults with better health status were more likely to be auto users as compared to being non-auto users. This finding contradicts the previous literature that shows better physical capacity is associated with more non-auto trips (Naumann *et al.*, 2009; Böcker *et al.*, 2017). This might be due to the auto-dependent lifestyle and sprawled urban form in Columbus, Ohio. Some of the previous studies focusing on similar North American cities show similar findings about health status and driving behaviour (Mezuk and Rebok, 2008; Chihuri *et al.*, 2016). Older adults living alone were considerably more likely to prefer multimodal travel and travel with non-auto modes only, as expected. This is consistent with the previous studies that demonstrate living alone is positively associated with non-auto travel (Hess, 2009; Chudyk *et al.*, 2015). Those who do not have others to ask for rides were more likely to be non-auto users. Previous research shows that rides given by others are mostly preferred by older adults who cannot drive (Rahman *et al.*, 2019). Given the auto user category includes auto use as a driver and/or as a passenger, not having anyone to ask for a ride is expected to reduce the probability of being in this category.

Age moderates the associations between built environment and travel preferences

We tested all possible interactions between age and built environment characteristics. The only significant interaction was between age and access to crosswalks with

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pedestrian countdown timers. In this section, we discuss the effect of age and access to crosswalks interaction only since the effects of other variables are consistent with the model without interaction except for the employment variable (*see* Table 3). In the model with interaction, 'unemployed/retired and seeking work' and 'retired and not looking for work' categories of the employment variable were not significantly associated with the multimodal traveller category.

The results of the model with interaction show that among those who have access to crosswalks with pedestrian countdown timers, older adults aged 70 and more were significantly more likely to choose more sustainable travel preferences as compared to those between 50 and 59. This shows that pedestrian countdown timers that allow enough time to cross are particularly important for older adults who are relatively older and more likely to experience physical limitations regarding active travel (Collia *et al*., 2003; Cerin *et al*., 2017). This finding shows that a minor improvement such as the adjustment of crosswalk timers for older adults can significantly increase the active travel preferences of older cohorts. These findings are consistent with the previous studies (Metz, 2003; Kerr *et al*., 2012).

Conclusion and limitations

Our study demonstrates that age and built environment characteristics were associated with sustainable mobility preferences of older adults, controlling for socio-demographics and lifestyle-related factors. We find ageing may not cause a transition from auto to other alternatives, which is consistent with the previous research (*e.g.* Rosenbloom, 2009). Findings regarding age show that ageing older adults were more likely to drive (or ask for rides) as compared to their younger counterparts. The research findings also show that transportation planners and policy makers can promote sustainable mobility by four built environment interventions: by improving park access of older-adult neighbourhoods, by adjusting the timing of pedestrian countdown timers on crosswalks to allow enough time to cross or implementing countdown timers to new intersections, by designing urban environments with higher levels of land-use mix that will increase the diversity of activities and opportunities, and by providing higher-frequency transit services. All of these built environment interventions are imperative for a well-designed and inclusive urban environment for all. They are particularly relevant to cities that are auto-dependent, sprawled and have relatively sparse transit networks because all four interventions contribute to the improvement of built environment and transportation service quality and, consequently, advance non-auto alternatives such as walking, bicycling and transit.

Among these environmental factors, designing urban environments with higher levels of land-use mix, improving access of older adults to parks, and improving transit service frequency require long-term strategies and land-use plans. Taking these policies into account in future planning efforts may help promote sustainable mobility among older adults. Given the upcoming demographic change that will reshape our society, we believe the re-design of our neighbourhoods to meet the needs of the older adults will gain more attention in the future. Therefore, these long-term strategies need to be assessed carefully by planning scholars and practitioners. Our findings regarding the pedestrian countdown timers are considerably

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important in the short term. These easy-to-implement interventions to the intersections might be more effective than transportation planners might think. The interaction of age with the pedestrian countdown timers shows that this intervention is considerably important for people 70 or older with possibly limited physical capabilities. The adjustment of the existing countdown timers to allow more time and/or implementation of countdown timers to new intersections might be a starting point in making the environment more age-friendly given that the other findings may have larger financial implications and require long-term planning.

Our paper builds upon previous studies conducted by environmental gerontological researchers, who underline the need to extend examinations beyond individual level to the social and built environments (Lawton and Nahemow, 1973; Lawton, 1982; Wahl *et al.*, 2012). We argue that built environment improvements contribute not only to older adults' sustainable mobility but also their out-of-home activity behaviour, social engagement, and physical and mental health (Wahl *et al.*, 2012; Cerin *et al.*, 2017; Cao *et al.*, 2019; Lyu and Forsyth, 2022). Age-friendly neighbourhoods are an integral part of independence in later life for older people, and thus they are crucial elements of ageing-in-place policies and practices (Bigonnesse and Chaudhury, 2019). Considering the upcoming demographic change worldwide (United Nations, 2019), we encourage authorities to have a more proactive role in analysing the needs of older adults and preparing environments for their needs.

This research supports other recent studies which demonstrate that creating age-friendly cities requires an in-depth understanding of the perspectives of older adults (Dabelko-Schoeny *et al.*, 2020). A recent comprehensive review of older adults, mobility and living environment literature shows the importance of collaborations between urban planning and other disciplines such as social work and public health, which are traditionally more experienced in working with older adults, to design age-friendly urban environments (Li, 2020). As a multi-disciplinary team consisting of urban planners and social workers, we suggest future studies to expand these connections with other disciplines to understand age-friendliness in more comprehensive ways.

The unique contribution of this study is that it provides specific guidelines on what built environmental factors help to promote sustainable travel among older adults in mid-sized metropolitan cities. Additionally, our study demonstrates that the heterogeneity in the older population calls for specific policies that will address the varying needs of different age cohorts. The findings can assist policy makers in prioritising certain built environment-related improvements to support the mobility of older adults (*e.g.* the adjustment of existing countdown timers). This prioritisation can be particularly helpful for policy makers in solving the mobility issues of relatively older cohorts. The paper also provides insights into the factors that promote the sustainable mobility of older adults. The promotion of sustainable mobility options such as walking, bicycling and transit contributes to positive health outcomes among older adults and help policy makers to develop an equitable transportation system (Kerr *et al.*, 2012; Adorno *et al.*, 2018; Litman, 2019; Loukaitou-Sideris *et al.*, 2019; Cheng *et al.*, 2019*a*). Finally, the findings of this paper can complement existing sustainable transportation policies and help authorities to develop more accessible, affordable and high-quality transportation service provisions for older adults.

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This is one of the few older adult travel behaviour studies using quantitative data collected from a mid-sized metropolitan area in the USA. The policy recommendations that we draw from the data analyses are crucial, especially for non-driver older adults who suffer from the lack of reliable non-auto travel options in these cities. To be prepared for the upcoming demographic change in our society, local policy makers should take a proactive role and prepare the built environment and transportation services for the ageing population's needs. Our results can contribute to these efforts that aim to improve the quality of life for all in our communities. It is important to acknowledge that our recommendations may be more relevant for North American cities that are sprawled and auto-dependent. Similar studies conducted in other cities that have a more compact urban form, well-connected transit network and lower levels of auto-dependency show different results than our study. For example, Buehler (2011) shows that while retired older adults in the USA drive more, their counterparts in Germany drive less compared to those who are not retired. Older adults living in compact cities, such as those in Denmark, Norway, the United Kingdom, the Netherlands and China, with affordable and well-developed transit networks, are less likely to drive and more likely to walk, bicycle and ride transit (Schwanen *et al.*, 2001; Schmöcker *et al.*, 2008; Cerin *et al.*, 2013; Szeto *et al.*, 2017; Cheng *et al.*, 2019*a*). In brief, we can argue that what we can conclude from this study will be more relevant for North American cities with similar urban development patterns, transportation network characteristics and auto-dependency levels.

Our findings provide valuable insights to transportation professionals and decision makers in developing policies that will help to promote sustainable mobility for older adults. We recommend authorities to provide better access to well-maintained and safe parks, adjust pedestrian countdown timers on crosswalks to allow enough time to cross the street, promote higher levels of land-use mix that will provide a more diverse set of services and amenities, and improve the transit service frequency for better service quality. All these interventions can result in many positive outcomes for older adults such as more active travel that will improve physical and mental health, better access to essential services and resources, and more individual independence. These interventions are age-friendly and climate smart, as the promotion of sustainable transportation options such as transit, bicycling and walking helps to overcome numerous community-level challenges such as air pollution, crashes, congestion, *etc*. Lastly, it is important to indicate that having proper infrastructure and environmental elements does not ensure older adults would go out and/or use alternative modes of transportation. Therefore, in addition to the improvements in built environment, local governments need to introduce programmes that will promote older adults' out-of-home physical activities and non-auto travel (Dill *et al.*, 2014; Loukaitou-Sideris *et al.*, 2016).

We want to highlight that the results should be viewed in the light of the sampling limitations of our study. Our final sample is predominantly White/Caucasian, female and auto users. Additionally, those who are relatively older (70 and more) make up only 20 per cent of the final sample. Previous studies show that being White and having access to a private automobile increases car use among older adults (Beckman and Goulias, 2008; Schmöcker *et al.*, 2008; Ding *et al.*, 2014; Shrestha *et al.*, 2017). On the other hand, older women drive less than older men (Shen *et al.*, 2017; Ulfarsson and Kim, 2019). Lastly, studies conducted in North American cities

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demonstrate that ageing older adults drive more than their younger counterparts (Rosenbloom, 2009; Buehler, 2011). Considering the impacts of these factors on older adults' travel behaviour and the composition of our study sample, our findings should be interpreted with caution. While we acknowledge the sampling limitations of our study, we also note that our findings regarding older adults' travel preferences are consistent with other studies using different age cut-off points (*e.g.* 60 or 65) with samples that are more evenly distributed across gender, race, *etc.* (Schmöcker *et al.*, 2008; Hess, 2009; Buehler, 2011; Shen *et al.*, 2017; Ulfarsson and Kim, 2019).

We acknowledge that there are several limitations to our study. This study does not account for travel attitudes, habits and residential self-selection that are found to be mediating the relationship between the built environment and travel behaviour (Cao *et al.*, 2009, 2010; Dill *et al.*, 2014; Adkins *et al.*, 2017; Cerin *et al.*, 2017) due to data limitations. As identified by previous studies, modal choice by older adults may be strongly influenced by habitual practice (Rosenbloom and Waldorf, 2001; Dill *et al.*, 2014; Mifsud *et al.*, 2017; Caragata, 2021). Additionally, older adults' habits and travel-related attitudes may cause them to reside in certain neighbourhoods (Cao *et al.*, 2010), and the residential location might be one of the primary determinants of modal choice. Considering their mediating effects on older adults' travel behaviour, we encourage future research to include these variables in the analysis. Second, we used a cross-sectional dataset that can mask cohort effects and behavioural variations based on socio-economic factors affecting specific groups (Blumenberg and Smart, 2010). The assessment of these long-term effects calls for longitudinal approaches for more accurate and robust estimations (Cao *et al.*, 2009; Figueroa *et al.*, 2014). Third, we used ZIP code-level built environment variables due to the data limitations. We acknowledge that built environment data at a finer scale such as CBG can capture the variability in the relationship between spatial characteristics and travel behaviour more accurately. Therefore, we encourage future empirical studies to test our findings with finer-scale built environment data. Fourth, since the majority of survey respondents were registered voters, the results may not be representative of the travel behaviour of non-registered voters (*e.g.* immigrants, refugees and non-citizens), who make up over 10 per cent of the Columbus metropolitan area population (VERA Institute of Justice, 2017). Additionally, we acknowledge that the effects of the built environment on travel mode choice may vary between individuals based on their demographics (income level, race, *etc.*). While we did not find any significant associations between these two, we encourage future research to explore the variation of built environment impacts across individuals with different demographic characteristics. Lastly, our dataset is limited in terms of the environmental safety perceptions of older adults. Considering previous studies claim that there is a significant association between perceived environmental safety and non-motorised travel for older adults (Loukaitou-Sideris *et al.*, 2016, 2019; Adkins *et al.*, 2017), we suggest further studies to take safety factors into account.

Conflict of interest. The authors declare no conflicts of interest.

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Notes

1 Transit-oriented development is an urban development approach that includes a mix of commercial, residential, office and entertainment centred around transit stations (Federal Transit Administration, 2019).
2 According to the definition of the American Planning Association (2012), smart growth can be defined as an urban development approach 'which supports choice and opportunity by promoting efficient and sustainable land development, incorporates redevelopment patterns that optimise prior infrastructure investments, and consumes less land that is otherwise available for agriculture, open space, natural systems, and rural lifestyles'.
3 Land-use mix refers to the employment mix (entropy). It uses eight employment categories to calculate the employment mix (entropy). These categories are retail, office, service, industrial, entertainment, education, health care and public administration.
4 Transit service frequency during evening peak refers to the aggregate frequency of transit service within 0.25 miles of block group boundary per hour during evening peak period.

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