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Transportation technologies, sharing economy, and teleactivities: Implications for built environment and travel

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ABSTRACT

This paper reviews how teleactivities, the sharing economy, and emerging transportation technologies – components of what we could call the "App City" – may influence travel behavior and the built environment. Findings suggest that teleactivities may substitute some trips but generate others. Telework and teleconferencing may reduce total travel. Findings on the sharing economy suggest that accommodation sharing increases long-distance travel; bikesharing is conducive to more active travel and lower car use; carsharing may reduce private car use and ownership; ridesourcing (ridehailing) may increase vehicle miles traveled; while the implications of e-scooter sharing, ridesharing, and Mobility as a Service are context-dependent. Findings on emerging transportation technologies suggest that private autonomous vehicles and urban air mobility may increase total travel, whereas autonomous buses may lead to reduced car use. Implications of App Cities for the built environment include new transport systems and land use changes due to behavioral changes.

1. Introduction

The rapid developments in information and communications technology (ICT) and the use of mobile or computer online applications (apps) are enabling the widespread adoption of teleactivities, the exponential rise of the sharing economy, and the emergence of new transportation technologies (Gössling, 2018; Levinson & Krizek, 2017; Lyons, Mokhtarian, Dijst, & Böcker, 2018). Contemporary cities have started to accommodate, to different degrees, these three elements: teleactivities, sharing economy, and emerging transportation technologies. Teleactivities such as teleworking and online shopping are becoming mainstream in many societies. The Coronavirus disease (COVID-19) outbreak in 2019–2020 provided an additional strong boost to the widespread global application of teleactivities (Wijesooriya, Mishra, Brand, & Rubin, 2020). Shared mobility options such as sharing of bikes, electric scooters, or cars were making their appearance in more and more cities before the COVID-19 crisis occurred. Emerging transportation technologies including autonomous vehicles, drones, and robots are being tested or already being used in certain cases. Drones have also been used during COVID-19 for purposes such as surveillance and delivery of supplies.

The current dominant trends in transport and land use literature highlight the potential of these app-enabled developments for changing travel behavior and the built environment (Pawlak et al., 2019). Although research on these topics has been growing rapidly, a holistic understanding of how app-enabled teleactivities, the sharing economy, and emerging transportation technologies could potentially influence travel and the built environment is lacking in existing literature. A synthesis of relevant literature is important in

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order to gain insights into how human settlements and life in them are changing and how they are expected to change in the future. This knowledge will offer useful foundations for future research in these fields. It can also provide input to urban governance and planning aiming to proactively steer digitalization and new mobility options toward desired outcomes.

This paper attempts to address this gap by synthesizing the significant trends occurring in transportation and land use due to app-enabled developments. It presents a synthesis of literature on the potential influences of teleactivities, the sharing economy, and emerging transportation technologies on travel behavior and the built environment. The paper examines two research questions: (1) What might be the implications of teleactivities, sharing economy, and emerging transportation technologies for travel behavior? (2) What might be the implications of teleactivities, sharing economy, and emerging transportation technologies for the built environment? Teleactivities reviewed in the paper are: telecommuting (telework), online shopping, online education, teleconferencing, teleleisure, telehealth, and online social networking. Sharing economy options reviewed in the paper are: accommodation sharing and shared mobility including carsharing, ridesharing, ridesourcing (ridehailing), bikesharing, e-scooter sharing, and Mobility as a Service. Emerging transportation technologies reviewed in the paper are: autonomous vehicles, delivery drones, delivery robots, and urban air mobility. Implications for travel behavior will be examined mainly in terms of changes in modal shares, travel distances, trip purposes, and trip frequencies. Implications for the built environment will be examined in terms of changes in location choices, land uses, and transport systems.

Our review includes a qualitative interpretation of existing evidence and theoretical reflections. The scope of the review is broad; therefore, we do not aim to provide an exhaustive review for each element covered in the paper, but rather a synthesis of literature (see Appendix for more details). Around 200 studies were reviewed. We provide an overview of the state of knowledge by presenting and critically interpreting empirical evidence, reflecting on causal mechanisms, reflecting on the research questions at a conceptual level when empirical evidence is missing, identifying gaps and limitations, and presenting recommendations for future research.

The synthesis of literature has led to the introduction of a new concept: the "App City", a concept we use as an umbrella term to describe the emerging trends that we have identified. To facilitate structuring the literature review, discussing the review as a whole, and enhancing readability, we introduce the App City concept at an early stage here. App City will be defined as the city where residents and visitors may use apps to perform teleactivities, participate in the sharing economy, and engage in emerging transportation technologies. These three components of App Cities have three common characteristics. They: (a) are enabled by the use of online apps by end-users (residents and visitors), (b) are strongly interconnected and influence each other, and (c) may significantly influence both the built environment and travel behavior. Other technological developments and ongoing digitalization also rapidly change the built environment and society, but we identify those three in particular as the most significant ones in relation to understanding ongoing and near-future changes in land use and transport. It also has to be acknowledged that the three components of App City are not only present in cities but also in smaller human settlements. However, we use the term App City for reasons of simplicity, and also because several of these developments are more prominent in cities (e.g. teleworking, bikesharing, ridesourcing, e-scooter sharing, Mobility as a Service) than in rural areas.

The paper is structured as follows. Section 2 presents basic theoretical background on teleactivities, the sharing economy, and emerging transportation technologies and a conceptual model that represents their links to travel behavior and the built environment. Sections 3–5 present a literature review of the implications of teleactivities, sharing economy, and emerging transportation technologies for travel behavior and the built environment. Section 3 focuses on teleactivities, Section 4 focuses on the sharing economy, and Section 5 focuses on emerging transportation technologies. Section 6 presents a summary of findings, a discussion, and an agenda for future research.

2. Background

The literature review is organized around three major areas: teleactivities, the sharing economy, and emerging transportation technologies. These three areas are based on the use of ICT and mobile or computer apps and are contributing to changes in people's travel behavior and transformations of the built environment (Banister & Stead, 2004; Batty, 2020; Gössling, 2018; Kwan, 2007; Levinson & Krizek, 2017; Line, Jain, & Lyons, 2011; Lyons et al., 2018; Newton, 2012; van Wee, Geurs, & Chorus, 2013; Yousefi & Dadashpoor, 2019).

Teleactivities, the sharing economy, and emerging transportation technologies – components of what we call "App City" in this paper – are all interconnected. Teleactivities are linked with shared mobility because sharing (cars, bikes, rides, e-scooters) is much easier with ICT-enabled teleactivities (information provision, reservations, paying, insuring) than without. And if shared mobility becomes the standard, this would further stimulate teleactivities, such as online shopping. For example, if people replace private car ownership with carsharing, for each trip the threshold to start driving becomes larger. Booking, walking to find the car, and paying may make each shared car trip slightly less convenient than personal car use, thereby triggering a shift towards teleactivities, such as online shopping, as opposed to driving to a shop. The sharing economy and emerging transportation technologies are also linked: autonomous vehicles, drones, robots, and urban air mobility options might be shared in the future and merged into what could be called "future shared mobility", because sharing reduces the costs of these mobility options. Smart mobility may facilitate teleactivities. For example, autonomous driving is linked with teleactivities since people are allowed to multitask while traveling – they are enabled to both travel and perform online activities (e.g. teleconferencing, teleleisure, telework) instead of simply driving. Accommodation sharing is facilitated by the teleactivity of online booking. In addition, if people would substitute activities for teleactivities, they might increase travel for other purposes, including recreation making use of accommodation sharing, as made explicit by the concept of constant travel time budgets – see Section 3.1.

Our literature review is based on the conceptual model as visualized in Fig. 1. The remainder of the paper will attempt to shed light on the state of knowledge on teleactivities, the sharing economy, and emerging transportation technologies and their relation to travel behavior and the built environment. The knowledge provided in this paper aims to provide the background for future research and discussion on the potential societal and environmental outcomes of App Cities.

3. Teleactivities

Several activities that have traditionally occurred in the physical world are now occurring in the virtual world, enabled by ICT. Activities including working, shopping, learning, recreation, networking, socializing, and making new acquaintances are often happening online via ICT. Activities that occur remotely – nowadays usually via ICT – are called teleactivities. Teleactivity is not a synonym for online activity, but several online activities – e.g. online shopping and online education – are nowadays occurring remotely without being physically present in "brick and mortar" facilities. Therefore, online activities such as online shopping and online education can be considered teleactivities. The employment of teleactivities has been accelerated dramatically due to COVID-19 (Wijesooriya et al., 2020).

ICT-enabled teleactivities are allowing easier access to people, goods, and information. By allowing easier access to people, goods, and information, teleactivities in turn affect behavior and the built environment (Andreev, Salomon, & Pliskin, 2010; Yousefi & Dadashpoor, 2019). According to Circella and Mokhtarian (2017), ICT and teleactivities may influence travel and the built environment in several ways such as by influencing the location of residences and businesses, vehicle ownership and travel mode choices, and eventually the spatial forms of cities. ICT-enabled teleactivities also offer a wide range of options for multi-tasking, especially while traveling (Kenyon & Lyons, 2007; Pawlak, 2020). People are able to perform more than two activities at the same time; for example, travel and telework, travel and socialize online, and travel and perform educational or recreational activities.

The mechanisms through which teleactivities are linked to human behavior, and most notably travel behavior, are classified by previous studies (Andreev et al., 2010; Mokhtarian, Salomon, & Handy, 2006; Salomon, 1986) as: (a) substitution – replacement of a traditional activity by a virtual activity leading to a decrease in travel), (b) complementarity – a traditional activity is supplemented by a virtual one leading to an increase in travel, (c) modification – ICT changes the ways in which an activity occurs potentially affecting travel behavior, (d) neutrality – no change occurs in activities and travel due to ICT. The impacts of ICT-enabled teleactivities on travel behavior often include combinations of these mechanisms, and this makes them complex and difficult to quantify (Gössling, 2018).

Teleactivities may lead to changes in the built environment in two ways: by increasing accessibility to some activities and services thus enabling living in or relocating to more remote areas and favoring the expansion of urban areas; and by replacing activities that have been traditionally occurring in conventional stores and facilities thus reducing the need for such stores and facilities. More specifically, (a) teleactivities increase virtual accessibility, flexibility, and reduce geographical restrictions, and thus may provide opportunities for the relocation of households or workplaces to more remote areas (Moriset, 2003). Thereby, they could potentially be encouraging urban expansion and decentralization (Yousefi & Dadashpoor, 2019). However, it should be noted spatial development mostly depends not on the technologies themselves, but on political intentions, spatial planning policies, and how technologies will be utilized to reach certain goals (Lyons et al., 2018). (b) By providing virtual access to a wide range of activities and products, teleactivities may have a substitution effect on some traditional activities that occur in "brick and mortar" stores and facilities (Circella & Mokhtarian, 2017). Thereby, demand for such stores and facilities becomes lower and they eventually start to become scarcer or even disappear (Lyons et al., 2018).

The following subsections review different teleactivities – telecommuting, online shopping, online education, and other teleactivities including teleconferencing, teleleisure, telehealth, and online social networking – and how these relate to travel behavior and

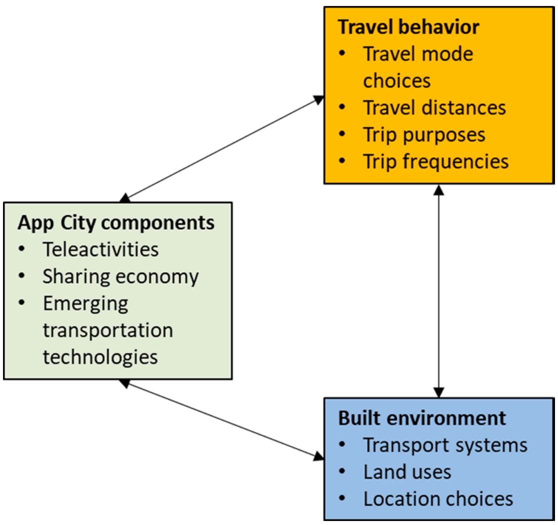

Fig. 1. Conceptual model linking App City components to travel behavior and the built environment.

the built environment (see also Table 1 for an overview).

3.1. Telecommuting

Telecommuting – also called telework or teleworking – is the possibility of not traveling to the main workplace on a regular basis and working from another location (Pratt, 2000). Using digital devices and the internet, telecommuters may work from home but also in several other places such as co-working spaces, coffee shops, and libraries (Di Marino et al., 2018). Telecommuters may work mainly from distance or may have the flexibility to travel to work sporadically (Hill et al., 2003). Telecommuting has been expanding largely due to ICT and especially in larger urban regions (Vilhelmson & Thulin, 2016). COVID-19 made telecommuting a necessity for several job sectors, and this might lead to changes in attitudes towards flexible and remote working. The adoption of telecommuting depends on the nature of the job and the working arrangements and work culture, while it is associated with personal characteristics such as age and education (de Graaff & Rietveld, 2007). It also depends on managers' trust and control as well as individual and household work–life balance issues (Vilhelmson & Thulin, 2016). Telecommuting may have positive impacts on labor productivity, especially for workers with long commutes times (Kazekami, 2020). Telecommuting may have small but mainly beneficial effects on perceived

Table 1
Summary of how teleactivities may influence travel behavior and the built environment.

Teleactivities	Travel behavior	Built environment	Source
Telecommuting / telework	• Can reduce overall distance traveled for commuting • But may also induce additional non-work travel	• Appearance of new spaces and stores such as co-working spaces and telework-friendly coffeeshops • Potential to allow residing or working in remote areas thus favoring decentralization or urban expansion, but this mainly depends on spatial policies	Andreev et al. (2010); Choo et al. (2005); de Graaff and Rietveld (2007); He and Hu (2015); Helminen and Ristimäki (2007); Kim (2017); Kim et al. (2012); Ory and Mokhtarian (2006); Pérez Pérez (2004); Tayyaran and Khan (2003); Tayyaran et al. (2003); Yousefi and Dadashpoor (2019); Zhu (2012)
Online shopping/ e-shopping	• Does not fully replace store shopping • Linked to additional shopping activity and more shopping trips • May replace out-of-home leisure activities	• Several types of "brick and mortar" stores and facilities are decreasing in number, are disappearing, or have disappeared (e.g. bookstores, travel agencies, bank branches) • By offering increased accessibility, online shopping may allow residing in remote areas thus favoring decentralization or urban expansion, but this mainly depends on spatial policies	Andreev et al. (2010); Cao et al. (2013); Cao et al. (2010); Cao et al. (2012); Circella and Mokhtarian (2017); Ding and Lu (2017); Farag et al. (2006); Ferrell (2004); Freathy and Calderwood (2013); Lee et al. (2017); Lyons et al. (2018); Mokhtarian (2004); Mokhtarian et al. (2006); Rotem-Mindali and Salomon (2007); Zhen et al. (2016); Zhen et al. (2018); Zhou and Wang (2014)
Online education	• Reduces travel for education • May have complementary rebound effects on travel by saving time for other types of travel	• No clear implications yet	Herring and Roy (2002); Roy et al. (2008); Wang and Lindsey (2019)
Teleconferencing	• Reduces travel for meetings	• No clear implications yet	Denstadli (2004); Geitmann (2020); Guerin (2017); Høyer and Næss (2001)
Teleleisure	• May replace travel for certain leisure activities • May have complementary rebound effects by saving time for other types of travel	• Several types of "brick and mortar" stores and facilities are decreasing in number, are disappearing, or have disappeared (e.g. music stores, cinemas)	Aguiléra et al. (2012); Andreev et al. (2010); Mokhtarian et al. (2006); Wang and Law (2007)
Telehealth	• Reduces travel to access health services • May have complementary rebound effects by saving time for other types of travel	• No clear implications yet	Dorsey and Topol (2016); Holmner et al. (2014); and authors' elaborations
Online social networking	• May replace travel for certain social activities • May have complementary rebound effects by saving time for other types of travel • May generate opportunities for additional travel for face-to-face socializing	• No clear implications yet	Jamal and Habib (2020); Rosenfeld et al. (2019); and authors' elaborations

autonomy and work-life balance, while it may improve outcomes including job satisfaction, performance, turnover intent, and role stress (Gajendran & Harrison, 2007). A risk with telecommuting is professional isolation which may negatively affect job performance (Golden et al., 2008).

Telecommuting may reduce work-related travel as compared to typical commute since the worker does not travel to the main workplace on a regular basis. Therefore, telecommuting has the potential to reduce overall travel demand, transport emissions, and air pollution, and to relieve transport infrastructure (Pérez Pérez, 2004). However, studies on telecommuting and travel behavior report mixed results. On the one hand, a study in Finland found that telecommuting is associated with reduced overall distance traveled for commuting (Helminen & Ristimäki, 2007), and a time-series study from the USA reported that telecommuting is linked to a reduction in annual total distance traveled – including work and non-work trips – of 0.8% or less (Choo et al., 2005). On the other hand, although there are several studies reporting substitution effects of telecommuting (Andreev et al., 2010), there are recent studies reporting complementary effects or non-significant effects. Zhu (2012) suggested that telecommuting has a complementary effect on travel, since it was found to be associated with travels longer in distance and duration both for total work trips and total non-work trips. Another study from Chicago, USA found that telecommuting was associated with a lower number of commute trips (as expected), but a higher number of non-work trips (He & Hu, 2015). A study from the Netherlands found no significant difference in the total commuting distance traveled between telecommuters and non-telecommuters (Gubins et al., 2019).

On the one hand, these mixed results could be attributed to the individual differences between telecommuters and non-telecommuters and not to a complementary effect of telecommuting on travel. First, telecommuters may travel longer distances to arrive at the main workplace (on days that they travel to their main workplace) than non-telecommuters. In Finland, for example, the commuting distance per trip was 3.9 km longer on average for telecommuters than that of non-telecommuters (Helminen & Ristimäki, 2007). A long commuting trip is one of the main motives for choosing to telecommute (Helminen & Ristimäki, 2007), while the opposite could also be the case: the possibility of telecommuting could increase the willingness to accept a longer commute (De Vos et al., 2019). Therefore, even if telecommuters skip some trips to work, their longer commute distance per trip may be responsible for balancing the difference for the total commuting distance between telecommuters and non-telecommuters. The total commuting distance covered by telecommuters will also depend on the definition of telecommuting status, how often they work remotely, and from where they work remotely. Second, if telecommuters are indeed inclined to make a higher number of non-work trips (He & Hu, 2015), due to personal attitudes and not telecommuting itself (He & Hu, 2015; Lyons et al., 2018), then their non-work travel distance would be longer than that of non-telecommuters, also adding up to the total distance traveled.

On the other hand, there might be indeed a complementary effect of telecommuting on travel. If people could save travel time because of ICT use, this does not mean they actually will do so. An influential theory explaining why is the theory of "constant travel time budgets" (Mokhtarian & Chen, 2004): measured over a large group of people, such as a country, the average time spent on travel is fairly constant at about 60–75 min per person per day. Less time needed for travel, because of ICT or a faster transport system, therefore does not lead to less time spent traveling. People may adapt their trip destination and sometimes also residential choices and trip frequencies. It is possible that telecommuting may have indirect impacts on travel via three mechanisms (Helminen & Ristimäki, 2007). First, by replacing some commute trips, it may provide time and flexibility for additional non-work trips such as trips for maintenance of the household, picking up kids, or other out-of-home activities (He & Hu, 2015; Kim, 2017). Second, by providing the possibility of less frequent commuting, telecommuting may encourage residential relocation to more remote areas (Tayyaran & Khan, 2003; Tayyaran et al., 2003) and the adoption of lifestyles that involve longer travel distances (Zhu, 2012). A third option is that people change their workplace. For example, they might accept a job further away from their residential location because they have to travel to work less frequently.

Therefore, although telecommuting has the potential to reduce travel distances for commuting (Andreev et al., 2010), it seems that at the same time it may generate additional vehicle miles traveled by encouraging more non-work trips or the relocation to more remote areas. Comparing telecommuters versus non-telecommuters, as done by most existing studies, (instead of studying the same individuals before and after adopting telecommuting) makes it difficult to disentangle the possible effects of the above-mentioned mechanisms. In addition, all these various mechanisms may play out differently in different contexts with different working cultures, work regulations, or societal norms.

The impact of telecommuting on the built environment takes mainly two forms: firstly, emerging spaces and working environments for telecommuters and, secondly, possible expansion of urban areas. Telecommuting enables people to work remotely by increasing virtual accessibility and flexibility and reducing geographical restrictions (Moriset, 2003), thus potentially encouraging urban expansion and decentralization (Yousefi & Dadashpoor, 2019). New types of spaces have emerged to accommodate this demand such as co-working spaces or telework-friendly coffee shops. Telecommuters are more likely to live on the outskirts of cities or in remote areas (Kim et al., 2012). Some scholars have argued that telecommuting could facilitate living further away from work and this could therefore encourage urban expansion (Tayyaran & Khan, 2003; Tayyaran et al., 2003), while others reject the possibility of such a causal relationship (Kim et al., 2012; Ory & Mokhtarian, 2006). Although it seems that telecommuting, and ICT in general, may provide opportunities for the relocation of households or workplaces to more remote areas, spatial development mainly depends on political intentions, spatial planning policies, and how technologies will be utilized to reach certain goals (Lyons et al., 2018).

3.2. Online shopping

Online shopping – also called e-shopping – is a type of electronic commerce where one can buy products from a seller over the internet. Online shopping popularity is increasing rapidly, and it now occupies a large share of the total commercial activity in many countries. Online shopping is conducive to the "dematerialization" of certain categories of goods and the emergence of "bricks and clicks" forms of businesses (Circella & Mokhtarian, 2017). A wide range of products are nowadays bought online replacing conventional commerce: newspapers, music, games, electronics, furniture, clothes, meals, groceries, vacation packages, tickets, and bank products (Freathy & Calderwood, 2013; Pawlak et al., 2019). Online shopping is also combined with app-based ridehailing-type services in the form of on-demand, app-based delivery of goods, groceries, and meals (Li et al., 2020; Xi et al., 2020). This type of online shopping is becoming central to life in several urban areas and has been boosted during COVID-19 (Alaimo et al., 2020). Online shopping increases options for shopping, possibly inducing additional shopping activity. Online shoppers tend to be more frequently residing in urban areas since urban residents often have higher computer literacy and greater access to the internet (Cao et al., 2013). However, online shopping is especially important for residents in locations with low accessibility to stores such as rural areas, islands, and exurban areas (Cao et al., 2013; Freathy & Calderwood, 2013).

Online shopping appears to have a complementary effect on in-store shopping according to a review of relevant studies (Andreev et al., 2010). This means that, for the most part, online shopping does not substitute traditional shopping, but induces additional shopping activity by offering a wide range of shopping possibilities at great convenience and generates additional trips to "brick and mortar" shops for physically checking products before buying (Mokhtarian, 2004; Rotem-Mindali & Salomon, 2007). Online buyers are found to make more trips to "brick and mortar" shops than non-online buyers (Cao et al., 2010; Cao et al., 2012; Ding & Lu, 2017; Farag et al., 2006; Ferrell, 2004; Lee et al., 2017; et al., 2016; Zhou & Wang, 2014). These results hold also when accounting for confounding factors such as shopping attitudes (Cao et al., 2010; Lee et al., 2017; Zhen et al., 2016), however further research is necessary to claim a causal link from online shopping to in-store shopping trips and fully understand the pathways between them (Lee et al., 2017). Contrary to most previous studies, Xi et al. (2018) find that store shopping may increase online shopping and not the other way around. Another link between online shopping and travel behavior was found to be a negative association between online buying and the frequency of leisure activities (Ding & Lu, 2017), suggesting that online shopping may replace traditional leisure activities and out-of-home trips (Ding & Lu, 2017; Mokhtarian et al., 2006).

Online shopping, combined with the digitalization of a wide range of products, may lead to changes in the built environment and specifically in commercial land uses. Several types of "brick and mortar" stores are likely to become scarcer due to online shopping taking over their market share (Circella & Mokhtarian, 2017; Lyons et al., 2018). Examples of such stores include music stores, software-selling stores, travel agencies, bookstores, video clubs, and bank branches. The impact of online shopping on transport infrastructure has not been explored much. For the moment, it seems to be small but it has been suggested that it may grow in the future (Zhen et al., 2016). The increased demand for online shopping may lead to more delivery vehicles in the central parts of cities, possibly resulting in increased traffic congestion and emissions if unregulated (World Economic Forum, 2020). To get a better understanding of how online shopping may influence travel, analysis of emerging travel patterns due to online shopping should include growing and more complex patterns of delivery traffic. Online shopping can improve shopping accessibility in low-density areas where conventional, "brick and mortar" stores are less accessible (Zhen et al., 2018), so it could, in theory, favor urban expansion and decentralization. But as noted for telecommuting, spatial structure mostly depends on policy goals and spatial policies rather than the technology itself.

3.3. Online education

Online education is a form of education in which students may partially or completely replace physical presence at an educational facility with learning activities via the internet. Similar terms include distance learning, tele-education, distance education, online learning, and e-learning. Online education can be formal or informal. Formal online education involves formal online courses or even degrees offered by educational institutions, while informal online education may involve self-learning using resources from the internet such as videos, e-books, articles, and wiki sources. A combination of traditional and online education, called blended learning, is common nowadays (Xanthidis et al., 2016). Online education can provide easier access to learning as it usually involves lower costs and flexible schedules and environments. Online education thus provides access to learning for diverse groups of the population including poorer people in places where education is not free, people with mobility difficulties, people residing in remote places, people who live in places with limited or no educational opportunities, people who do not want to or cannot relocate to study, people who work or have other commitments, and parents with young children. Online education is also an important tool for continuous learning throughout professional life (Harun, 2001). According to some studies, attending courses online seems to result in similar learning outcomes in terms of skills and grades compared with traditional classroom learning at least for certain topics (McCutcheon et al., 2015; Summers et al., 2005). However, other studies point to lower outcomes for online learning students (Hurlbut, 2018; Xu & Jaggars, 2013). Satisfaction with the course may be lower for online students than for traditional classroom students (Summers et al., 2005), possibly due to the different sense of social presence and connectedness with other students (Bulu, 2012). Lack of computer skills or lack of access to ICT are barriers to online education. Moreover, although a wide range of topics can be taught online, there are courses that require a physical presence in the form of lab work or clinical work.

Online education reduces or eliminates travel to classrooms, and therefore seems to have a substitution effect on travel. In fact, studies have shown that courses taught online involve significant reductions in personal travel and relevant transport emissions compared with classroom-based courses (Herring & Roy, 2002; Roy et al., 2008). It is possible however that online education may also have rebound effects on travel (Wang & Law, 2007). Time or money saved with online education may be spent on traveling for other purposes including work, household duties, and leisure. Students chose a more remote school and continue to reside at their existing location, or they may choose not to move to a residential location near their school because of online education opportunities. Such potential complementary effects of online education on personal travel have been underexplored in existing research.

To our knowledge, no significant impact of online education on the built environment has been reported in academic research.

Online education could potentially result in changes in transport infrastructure and land use. Reductions in travel to the classroom and changes in travel patterns throughout the day due to rebound effects could result in changing transport demands. Increasing demands for online education could also lead to decreasing demands for school building size. However, all these impacts are still relatively small. By allowing people to study without changing their place of residence and relocating closer to education facilities, online education could potentially influence land use and spatial development.

3.4. Other teleactivities (teleconferencing, teleleisure, telehealth, online social networking)

Other teleactivities include teleconferencing, teleleisure, telehealth, and online social networking. Teleconferencing is the live exchange of information and live communication between two or more people from distance. ICT enables teleconferencing with various platforms of videoconferencing via the internet. ICT-enabled teleconferencing replaces in-person meetings with online meetings, and also allows the online delivery of seminars and remote attendance at scientific conferences. This was particularly highlighted during COVID-19 travel restrictions (Geitmann, 2020). Teleleisure is ICT-enabled leisure. Teleleisure activities replace traditional leisure activities. Examples of teleleisure activities include online gaming, online television, online streaming of movies and series, and listening to music online (Lobato, 2019). Telehealth or telemedicine is the ICT-enabled access to services and information related to health. Examples include video consultation between patient and doctor, online psychotherapy, video conference between clinicians, and online exchange of test results (Dorsey & Topol, 2016). The accelerated adoption of telehealth, which has been boosted by COVID-19, has shown that telehealth, especially if used proactively rather than reactively, may generate important health benefits, assist with the everyday and emergency challenges in healthcare, and reduce socio-spatial inequities related to health (Dorsey & Topol, 2016; Smith et al., 2020). Online social networking is the development and maintenance of social relationships and social networks via platforms on the internet. Online social networking can be used for linking professionals, for socializing with or finding existing friends and acquaintances, for making new friends, for finding a new partner or intimate relationship, or for communicating with people who share common interests or ideas. Socializing via apps and websites has been replacing traditional ways of meeting people (Rosenfeld et al., 2019). It may have positive implications for well-being when used carefully but may also lead to addictions, stress, and distraction (Tarafdar et al., 2020; Wenninger et al., 2019).

Teleconferencing replaces face-to-face meetings and can thus eliminate trips to other locations. Teleconferencing could result in a reduction in car and air travel (Denstadli, 2004; Guerin, 2017). With the widespread development of ICT, travel to conferences can now be replaced by online activities such as online education and information sharing, teleconferencing, and online social networking (Geitmann, 2020; Høyer & Næss, 2001). Similarly, telehealth in the form of online meetings with the doctor can replace face-to-face appointments and thus reduce personal travel and related carbon emissions (Holmner et al., 2014). Teleleisure replaces some leisure activities that were typically performed out of home with in-home leisure (Varghese & Jana, 2019). The time saved through ICT use for teleleisure and possibly telehealth may encourage additional personal travel, thus having a complementary effect on travel (Aguiléra et al., 2012; Andreev et al., 2010; Mokhtarian et al., 2006; Wang & Law, 2007). Online social networking may replace travel for some traditional social activities but could also have a complementary effect on travel (Jamal & Habib, 2020) by generating opportunities for additional travel for face-to-face socializing. Although teleleisure, telehealth, and online social networking may have complementary effects on travel, teleconferencing during work probably has a substitution effect since it is a mandatory activity. Travel for meeting people for work purposes is likely to be replaced by work at the workplace or even by telework. These typically require travel of shorter distance or no travel at all. Overall, the relationships between these teleactivities and travel have been understudied and are difficult to quantify (Andreev et al., 2010; Ettema, 2018; Gössling, 2018).

Similarly to online shopping, teleleisure reduces the use of "brick and mortar" shops and facilities. For example, online streaming of movies and services eventually may reduce visits to movie theaters and video clubs, resulting in a reduction of movie theaters and the disappearance of video clubs. Similar replacement impacts are observed for listening to music online and record shops. The other teleactivities such as teleconferencing, telehealth, and online social networking have not been linked to significant changes in land uses or transport infrastructure, although, theoretically, the increased accessibility that they offer may encourage residing in remote locations and thus favor decentralization and urban sprawl.

4. Sharing economy

Humans have been sharing materials and services with others long before ICT-based sharing options became available. However, in recent years, the sharing economy has been developing dramatically due to the widespread use of ICT (Botsman & Rogers, 2010; Gansky, 2010; Harris & Gorenflo, 2012). The current trends in the sharing economy have been criticized for losing the sense of actual "sharing" because of the mediating, for-profit role of companies such as Uber and Airbnb (Eckhardt & Bardhi, 2015). Bicycles, cars, car trips, electric scooters, and homes are now shared or, more accurately, rented between users and suppliers. In many cases, the supplier is a private company that owns a fleet of vehicles, homes, bikes, or e-scooters and rents them with the help of online apps. This business model resembles the business models of more traditional rental companies, contrasting with sharing between individuals. Therefore, whether this business model should be considered a form of the sharing economy is open to debate. In this review, we include all different types of business models under the category of "sharing economy" for reasons of simplicity.

Shared mobility (such as bikesharing, carsharing, ridesharing, e-scooter sharing) and accommodation sharing (e.g. Airbnb) are among the most commonly used forms of sharing economy (Dogru et al., 2020; Machado et al., 2018; Standing et al., 2019). In addition to shared mobility and accommodation sharing, there are also other forms of the sharing economy such as garden sharing or task sharing. These are not examined in the paper as they have smaller impacts on travel behavior and the built environment.

Table 2
Summary of how the sharing economy may influence travel behavior and the built environment.

Sharing economy	Travel behavior	Built environment	Source
Accommodation sharing	• By displacing residents to less central locations, it could induce increased travel distances • May induce additional long-distance travel for tourism and business • Extra income provided by rental accommodation sharing could incentivize those who rent their room or dwelling to engage in more frequent long-distance trips or holidays to destinations that are further away	• Changes dwelling and building uses • May result in changes in transport infrastructure and facilities and services • New buildings for accommodation sharing purposes resulting in densification or urban expansion • Induced long-distance travelers in the city by accommodation sharing will also require the expansion of existing transport infrastructure and additional facilities and services	Lyons et al. (2018); Tussyadiah and Pesonen (2015); and authors' elaborations
Carsharing	• Could reduce private car use and private car ownership • Could reduce vehicle miles traveled • If not intended to replace regular use of private cars, it could lead to increased walking, cycling, and use of public transport	• Could reduce space for car parking • Could free up urban space by reducing demands for car driving and parking • New land uses may replace infrastructure for private cars • Infrastructure for walking, cycling, and public transport may need to be expanded due to increased needs	Kent (2014); Kent and Dowling (2013, 2016); Litman (2000); Martin and Shaheen (2011); Martin et al. (2010); Rotaris and Danielis (2018); Sioui et al. (2013); Stillwater et al. (2009)
Ridesharing (carpooling, vanpooling)	• May increase the mobility of low-income workers, singles, and women • Mainly replaces the use of public transport • Increases occupancy rate in cars and provides an alternative option to owning a second car • May lead to lower demand for public transport that would, in turn, generate more car use and car ownership	• No clear implications yet	Chan and Shaheen (2012); Lyons et al. (2018); Shaheen et al., 2016a; Shaheen and Cohen (2019); Shaheen et al. (2019)
Ridesourcing / ridehailing	• Replaces traditional taxi, but also public transport and the private car • May induce additional travel and result in additional vehicle miles traveled	• Could result in more cars traveling in the streets and increased congestion • Could reduce car parking demand by replacing personal driving	Alemi et al. (2018); Brown (2020); Erhardt et al. (2019); Henao and Marshall (2019a, 2019b); Jiao et al. (2020); Jin et al. (2018); Mohamed et al. (2019); Rayle et al. (2016); Shaheen and Cohen (2019); Tirachini (2020); Tirachini and del Río (2019)
Bikesharing	• Can increase cycling modal share • Can replace use of public transport. walking, and car use • Increases total active travel	• Requires bikesharing infrastructure, conventional bicycle infrastructure, mixed-use built environment • Can lead to reduced congestion and free space from reduced car use	Castro et al. (2019); Duran-Rodas et al. (2019); Fishman (2016); Fishman and Cherry (2016); Fishman et al. (2013, 2014, 2015); Fyhri and Fearnley (2015); Guidon et al. (2019); Jia and Fu (2019); Shaheen et al. (2010); Wang and Lindsey (2019); Zhuang et al. (2019)
E-scooter sharing	• In compact, walkable, cyclable, and transit-oriented contexts: e-scooters mainly replace active travel and public transport • In more car-oriented contexts: e-scooters seem to replace a high percentage of car travel, but also active travel and public transport • Can be used to complement public transport and active travel modes as a "first-last mile" mobility option	• E-scooters are now integrated into the built environment as they can be found on sidewalks, streets, and other public spaces • If used to facilitate public transport and active travel and reduce car use, e-scooters could contribute to freeing up spaces occupied by cars and car infrastructure	Fearnley et al. (2020); Gössling (2020); Hollingsworth et al. (2019); James et al. (2019); McKenzie (2019)
Mobility as a Service (MaaS)	• Potential for reduction in private car ownership and car use if	• If goals and policies aim for sustainable mobility, MaaS can contribute to a reduction in street	Hensher (2017); Moscholidou and Pangbourne (2019); Pangbourne et al. (2019); Sochor et al. (2018); Utriainen

(continued on next page)

Table 2 (*continued*)

Sharing economy	Travel behavior	Built environment	Source
	accompanied by appropriate goals and policies • Risk of increased car use and traffic if unregulated	space for cars and reduction in space used for car parking, freeing up space for other land uses, and increasing demands for infrastructure for walking, cycling, and public transport. • In that case, MaaS could be in line with urbanization and compact city policies. • If unregulated, it could favor decentralization and urban expansion by facilitating mobility in more remote areas.	and Pöllänen (2018); Wong et al. (2019)

Accommodation sharing – also called home sharing – is the shared use of different types of accommodation. It is nowadays enabled by online platforms like Airbnb. Accommodation sharing may influence how people travel but it mainly does so on a larger scale. By offering an alternative, and at times cheaper, form of short-term accommodation, accommodation sharing may induce extra travel for tourism or business purposes, thereby having a complementary effect on total travel (Tussyadiah & Pesonen, 2015). Accommodation sharing is also changing the housing domain. Short-term rental of empty rooms or apartments can result either in higher building occupancy or in empty housing during low tourist season when dwellings are used only for tourism and not for living. On the other hand, as tourism expands, new buildings are being developed so that they can be used for accommodation sharing purposes.

Shared mobility is the shared use of a transportation mode that "enables users to gain short-term access to transportation modes on an as-needed basis" (Shaheen et al., 2016b, p. 77). Shared mobility is nowadays facilitated by ICT and apps (Gössling, 2018). It includes various forms of carsharing, bikesharing, ridesharing (carpooling and vanpooling), ridesourcing (on-demand ride services), and e-scooter sharing. Another concept that is relevant to shared mobility is that of "smart mobility". Smart mobility mainly refers to urban mobility that is enabled by ICT (Battarra et al., 2018; Lyons, 2018; Uteng et al., 2020). Therefore, smart mobility includes ICT-enabled shared mobility such as bikesharing and carsharing, but also emerging transportation technologies (reviewed in Section 5). Shared mobility may influence travel behavior in similar ways as teleactivities: substitution, complementary, modification, and neutrality. Moreover, by increasing accessibility and altering mobility options, shared mobility could potentially influence transport systems, land use, and location choices.

The following subsections review accommodation sharing and shared mobility, and how these relate to travel behavior and the built environment (see also Table 2 for an overview). The shared mobility subsection is divided into further subsections: carsharing, ridesharing, ridesourcing, bikesharing, e-scooter sharing, and Mobility as a Service.

4.1. Accommodation sharing

Accommodation sharing or home sharing is the concept of offering short-term stays in homes via online platforms. Accommodation sharing platforms can be classified into free, reciprocal, and rental (Voytenko Palgan et al., 2017). The most popular platform nowadays is offered by the short-term rental organization Airbnb. Accommodation sharing has been increasingly used (Dogru et al., 2020), and has consequently received praise but also fierce criticism. Positive aspects of accommodation sharing could be considered the potential for more efficient use of buildings, the extra income offered to residents who are renting their spaces, the exchange of cultures and experiences, the offer of a different type of accommodation experience, and the regeneration of buildings or neighborhoods in decline (Balampanidis et al., 2019; Guttentag, 2019). The other side of the coin, however, points to dramatic increases in rents especially in the case of very touristic cities and neighborhoods, displacement of residents and especially those of lower income, limited availability of dwellings for long-term rent when a short-term rental is more profitable, unfair competition with hotel businesses, nuisance for neighbors, and disruption of local social cohesion (Gurran & Phibbs, 2017; Guttentag, 2019). To mitigate the negative implications of accommodation sharing, several cities are forcing regulations and restrictions.

Although accommodation sharing does not appear to have direct impacts on the travel behavior of residents at a local level, it may influence local travel behavior indirectly. By displacing residents to less central locations, it could lead to increased travel distances at a city level (Lyons et al., 2018). Accommodation sharing also seems to have impacts on long-distance travel. It may induce additional long-distance travel for tourism and business (Tussyadiah & Pesonen, 2015). Accommodation sharing contributes to increased long-distance travel by offering more attractive prices, by covering alternative accommodation needs and sometimes a more personal and interactive experience, and by offering a wider variety of locations and accommodation types (Tussyadiah & Pesonen, 2015). Moreover, the extra income provided by rental accommodation sharing could incentivize those who rent their room or dwelling to engage in more frequent long-distance trips or holidays in destinations that are further away (Lyons et al., 2018).

Accommodation sharing could have the following implications for the urban built environment. First, for the case when the one who rents out a room or dwelling is the one who resides in the dwelling, accommodation sharing results in more efficient dwelling and building use. This would increase demands in transport infrastructure and local facilities and services, potentially inducing the expansion of transport infrastructure and the appearance of extra facilities and services. Second, when dwellings are used only for tourism and not for living, accommodation sharing may result in empty housing during the low tourist season. Third, new buildings may be developed for accommodation sharing purposes resulting in densification or urban expansion. Fourth, accommodation sharing may lead to changes in residential choice and land use, since residents may choose or be forced to relocate. Fifth, long-distance travelers who visit the city (partially) attracted by accommodation sharing will also induce the expansion of existing transport infrastructure and the appearance of new facilities and services.

4.2. Shared mobility

4.2.1. Carsharing

Carsharing is a mobility option that allows the rental of shared cars, thereby having the potential to substitute use and ownership of private cars. The renting body could be a business, individual (peer-to-peer carsharing), or cooperative (Hampshire & Gaites, 2011). The aim of carsharing is that vehicles can be easily found parked in residential neighborhoods. They can nowadays be accessed using an app. Because of the easy access provided by smartphones and mobile internet (Ferrero et al., 2018), the use of carsharing is increasing and expanding, and thus carsharing is becoming a mainstream transport mode (Shaheen & Cohen, 2013). Due to its lower fixed costs, carsharing is a viable alternative to sporadic car users residing in urban areas, and this may incentivize urban residents to use other travel modes to a larger extent and reduce the use of the car (Litman, 2000). Carsharing could be integrated with Mobility as a Service and vehicle automation (Shaheen et al., 2019).

By providing an alternative to the private car, carsharing can reduce private car use (Sioui et al., 2013) and private car ownership (Kent, 2014; Martin & Shaheen, 2011; Martin et al., 2010). Due to the reduced private car ownership, carsharing may promote the use of environmentally friendly transport modes. Indeed, a review of relevant studies shows that carsharing can increase walking and cycling, and promote the use of public transport, while it may reduce vehicle miles traveled (Kent, 2014). For carsharing to promote sustainable mobility, it should be just complementary to more environmentally friendly travel modes such as walking, cycling, and public transport. It should not be used as a main transport mode, except for special cases. To be successful in replacing private car ownership and contribute to sustainable mobility, carsharing typically requires a dense, mixed-use built environment where walking, cycling, and public transport options are readily available (Kent & Dowling, 2013). However, there could also be a demand for carsharing in small towns and rural areas where private car ownership is usually higher, parking is more readily available and other transport options are limited (Rotaris & Danielis, 2018). The use of carsharing in small towns and rural areas was found to be more frequent among students and unemployed people, groups that may not have access to a private vehicle (Rotaris & Danielis, 2018).

Carsharing may cause changes in the built environment but these are not yet completely understood (Stillwater et al., 2009). Although parking spaces for carsharing are required (Kent & Dowling, 2013), overall carsharing can help reducing parking space required (Kent & Dowling, 2016) due to the reduced ownership of private cars (Kent, 2014; Martin & Shaheen, 2011; Martin et al., 2010). Reduced car use and increases in walking, cycling, and use of public transport (Kent, 2014; Sioui et al., 2013) can lead to reduced congestion and freed up spaces previously used for car travel and parking. Increased use of active travel and public transport may require the expansion of city infrastructure for walking, cycling, and public transport. Free space provided by a reduction in parking spaces and lower needs in road capacity for cars, could be used for other land uses including open public space as well as residential and commercial land uses.

4.2.2. Ridesharing

Ridesharing is a concept that includes carpooling and vanpooling (Chan & Shaheen, 2012), and involves sharing a car or van with other riders who travel to a similar destination (Shaheen & Cohen, 2019). It should not be confused with ridesourcing (e.g. Uber), which is an informal form of taxi where a passenger hires a personal car and driver to travel to a destination. Ridesharing has been traditionally done informally through social networks. Informal ridesharing examples are: a couple sharing a car to travel to work or two neighbors sharing a ride. ICT developments are now linked to the use of ridesharing. Ridesharing can now be performed between individuals who had not previously known each other using online platforms.

The exact impacts of ridesharing on travel behavior in cities are difficult to examine and research evidence remains inconclusive. Shaheen and Cohen (2019) reviewed existing studies and found that ridesharing may increase the mobility of groups with lower access to cars including low-income workers, singles, and women. In addition, they conclude that by increasing vehicle occupancy, ridesharing may also lead to reductions in vehicle miles traveled, energy consumption and emissions, and parking requirements. However, a study on carpooling found that most carpool riders were previous users of public transport (Shaheen et al., 2016a). This suggests that ridesharing mainly replaces the use of public transport. Therefore, ridesharing seems to increase the occupancy rate in cars and provide an alternative option to owning a second car (Lyons et al., 2018), but it could have a negative rebound effect on the use of public transport. This would lead to lower public transport demand that would in turn generate more car use and car ownership. To contribute to reduced total travel distances and reduced emissions, it seems that ridesharing needs to be used sporadically or solely when driving is the only option. Therefore, to contribute to sustainable mobility, it needs to be used in combination with regulations restricting car use, while promoting walking, cycling, and public transport.

4.2.3. Ridesourcing

Ridesourcing or ridehailing is an app-based, on-demand ride service such as Uber and Lyft (Rayle et al., 2016). Pooled variants of ridesourcing include ridesplitting, taxi sharing, and microtransit (Shaheen & Cohen, 2019). Residents of dense, mixed land use, and lower-income neighborhoods tend to use ridesharing more than residents of other types of neighborhoods, based on research in

California, USA (Alemi et al., 2018; Brown, 2020). Predictors of ridesourcing use may include technology-embracement, pro-environmental attitudes, variety-seeking attitudes, high education, frequent long-distance travel, and previous taxi and carsharing usage (Alemi et al., 2018). Pooled ridesourcing services may increase in the future as ridesourcing companies aim to increase their market shares and profits (Sperling, 2018). To increase sharing in ridesourcing services, (Brown, 2020) suggests that companies and cities should attract non-users, by offering improved pricing, among others. Societal benefits of ridehailing include comfort and security of passengers, increased mobility for car-free households and people with physical and cognitive limitations, and efficiency in rider-driver matching (Tirachini, 2020).

Ridesourcing replaces traditional taxi, but also public transport and the private car (Rayle et al., 2016; Tirachini & del Río, 2019; Young & Farber, 2019). Ridesourcing replacing public transport and active travel constitutes a risk for sustainable mobility (Brown, 2020). Ridesourcing usage is associated with a higher amount of trips (Jiao et al., 2020). This finding could be explained by the fact ridesourcing increases mobility due to the combination of on-demand service with lower costs. However, the finding could also be attributed to the characteristics of the ridesourcing users: technology-inclined individuals who tend to make more trips. A study from Denver, USA found that ridesourcing adds a significant amount of vehicle miles traveled to the system when accounting for traveling without a passenger (deadheading), induced travel, and substitution of more sustainable travel modes (Henao & Marshall, 2019a). A systematic review of literature indicates that ridesourcing should not be expected to reduce the ownership of private cars and that environmental impacts are still unclear (Jin et al., 2018). Findings from another literature review suggest that ridesourcing's substitution effect on public transport has increased motorized traffic and congestion, with possible negative impacts on the environment and energy consumption (Tirachini, 2020). Ridesourcing companies, such as Uber and Lyft, were found to the most important contributor to the increasing traffic congestion in San Francisco, USA (Erhardt et al., 2019). A positive environmental aspect of ridesourcing is that by replacing personal driving, it may reduce car parking demand in cities (Henao & Marshall, 2019b; Tirachini, 2020), freeing up space for other land uses. Policies and regulatory frameworks are expected to determine the influence of ridesourcing on travel and the built environment (Mohamed et al., 2019).

4.2.4. Bikesharing

Bikesharing aims to offer easy and affordable access to shared bicycles within urban areas. Bikeshare programs provide several benefits including flexible mobility, reduced greenhouse gas emissions, affordability, reduced congestion, reduced air pollution, health benefits from active travel, and a solution to the "first-last mile" issue associated with the use of public transport (Shaheen et al., 2010). The widespread use of ICT now allows the use of automated bikesharing stations as well as dockless bikesharing systems through mobile apps. Bikesharing has grown rapidly in recent years and more and more cities worldwide have been employing bikesharing systems (Fishman, 2016). Bikesharing has become a mainstream travel mode in several cities where residents use it to travel to work or to leisure activities (Fishman et al., 2013).

Empirical studies on bikesharing and travel behavior show that bikesharing has a substitution effect on public transport and walking as it mostly replaces trips previously made by these travel modes (Fishman, 2016; Fishman et al., 2013). At the same time, the adoption of bikesharing has been found to reduce car use – but to a smaller degree compared to the reduction in the use of public transport and walking (Fishman et al., 2013; Fishman et al., 2014). The adoption of dockless bikesharing has been linked to an increase in the proportion of cyclists and further reductions in car use (Jia & Fu, 2019). Overall, bikesharing increases levels of active travel by substituting sedentary modes of transport (Fishman et al., 2015). Bikesharing was found not to be associated with the number of trips made (Jiao et al., 2020) suggesting that it mainly has a substituting effect.

Using electric bicycles (e-bikes) in bicycle sharing programs is a new addition to urban transportation with the potential to change travel behavior in cities (Guidon et al., 2019). E-bike sharing might be preferable in specific topographies, for specific individuals, and for longer trips. E-bike sharing may be a new mobility option for older adults and other groups that would otherwise not have chosen biking as an option. It offers improved mobility to those not being able to bike without a motor. Electric bicycles can increase the amount of cycling by replacing sedentary transport modes (Fishman & Cherry, 2016; Fyhri & Fearnley, 2015). Using e-bikes can lead to important increases in physical activity when replacing car use or public transport, while net losses in physical activity for those switching from conventional cycling are usually small due to increases in overall travel distance (Castro et al., 2019).

Successful bikesharing programs require a dense, mixed-use built environment with high access to facilities and services, public spaces, and tourist attractions (Duran-Rodas et al., 2019; Wang & Lindsey, 2019). Efficient bikesharing infrastructure (e.g. docks), management, and maintenance together with an expansion in conventional cycling infrastructure (e.g. cycle lanes, bike parking) are also necessary to respond to increases in bike transport demand (Guidon et al., 2019; Shaheen et al., 2010; Zhuang et al., 2019). Increased use of bicycles and reductions in car use can lead to reduced congestion from car traffic. Some new land uses may be generated from this substitution effect which would be connected to a reduced need for road capacity and car parking.

4.2.5. E-scooter sharing

E-scooter sharing is the short-term rental of electric scooters (e-scooters) in cities. E-scooters are typically dockless and they are more commonly found in denser cities or denser parts of a city (Jiao & Bai, 2020), within geo-fenced urban areas. E-scooters are accessed with a smartphone app. E-scooter sharing made a sudden appearance in cities worldwide in 2017, and since then, the use of scooters has rapidly increased. They are considered a first- and last-mile mobility option and one of the most common forms of micro-mobility (McKenzie, 2019). For distances that are not too long, they can be used as a main travel mode instead of a "first-last mile" mode. E-scooters are associated with safety concerns and blocked sidewalks due to lack of regulation (Aizpuru et al., 2019; Allem & Majmundar, 2019; Gössling, 2020; James et al., 2019; Rahim Taleqani et al., 2019). Preliminary assessments indicate that e-scooters are about ten times more likely to get involved in an accident compared with bicycles (Fearnley et al., 2020). E-scooters are also linked to environmental concerns due to the energy and materials used for their manufacturing combined with their short life cycle, but also due to energy and emissions arising from transporting the e-scooters to charging stations (Hollingsworth et al., 2019).

The impacts of e-scooters on travel behavior and the built environment are not clear yet since their use is very recent, and knowledge is still not mature enough to draw conclusions. Early studies indicate that the use of the e-scooter and its effects on travel behavior largely depend on the urban form, public transportation systems, and regulations on land use and transport. A recent in-depth study from Oslo, Norway, showed that e-scooters are mainly found in central, and usually denser, parts of the city and central intersections, and that they are typically used for “first-last mile” trips to work or education (Fearnley et al., 2020). The usage of e-scooters mainly replaced walking and to a smaller extent public transport, and more than half of the trips were made as part of a multimodal combination with other travel modes such as walking, metro, and bus (Fearnley et al., 2020). Studies from the United States report quite different results. A study from Washington, DC suggests that e-scooter sharing seems to be primarily used for recreation, leisure, and tourism activities and not for commuting, contrasting with bikesharing which is also used for commuting (McKenzie, 2019). Another study from Rosslyn, Virginia in the United States reported that the usage of e-scooters mainly replaced ridesourcing or taxi and walking, but also cycling, bus, and private car (James et al., 2019). This finding suggests that e-scooters can replace both motorized travel and active travel modes. Altogether, these early findings show that for compact urban forms, such as the central parts of Oslo, where the main travel modes are walking, cycling, and public transport (Mouratidis et al., 2019), the use of e-scooters mainly replaces these travel modes, while in more car-oriented contexts, e-scooters can replace higher percentages of car trips (ridesourcing, taxi, and private car), potentially resulting in lower car use, lower congestion, and less demand for parking. If e-scooters are used synergistically with public transport and active travel, they could also contribute to providing alternatives to car use and car ownership especially in car-oriented contexts. If used to promote sustainable mobility, by facilitating public transport and active travel and reducing car use, e-scooters could contribute to freeing up spaces occupied by cars and car infrastructure.

4.2.6. Mobility as a Service

Enabled by ICT – smartphones and mobile internet – Mobility as a Service (MaaS) offers a platform that connects and integrates different transport systems and suggests ideal transport options adjusted to the user’s needs (Hietanen, 2014). Users of MaaS pay a single fee to use all the integrated transport options for a certain time period. MaaS aims to achieve an efficient transition from private car ownership to an integrated, multi-modal urban mobility (Hensher, 2017; Jittrapirom, Marchau et al., 2018; Li & Voege, 2017). The ideas of MaaS are not new. MaaS was preceded by ideas about connecting and integrating different systems and is now enabled by the advances in ICT (Lyons et al., 2019). MaaS is not a form of sharing economy per se, but takes advantage of the sharing economy, and shared mobility in particular, and aims to offer seamless, door-to-door, multi-modal mobility services via online platforms that bring together users and service operators (Hensher, 2017; Kamargianni et al., 2016; Li & Voege, 2017; Pangbourne et al., 2019).

Another concept that is related to MaaS is Mobility on Demand (MOD). MOD is a concept “where consumers can access mobility, goods, and services on demand by dispatching or using shared mobility, courier services, unmanned aerial vehicles (UAVs), and public transportation solutions. The most advanced forms of MOD passenger services incorporate trip planning and booking, real-time information, and fare payment into a single user interface.” (Shaheen et al., 2017, p. 1). COVID-19 has promoted the on-demand delivery of goods and certain services, while it has slowed down the use of some shared mobility options.

Little knowledge exists so far on the effects of MaaS on travel behavior since it has not been applied yet on a large scale (Utriainen & Pöllänen, 2018). Cost efficiency and mode efficiency theoretically could lead to reductions in the use of the car. But MaaS results mainly depend on the goals that it aims to achieve and the accompanying policies and regulations (Moscholidou & Pangbourne, 2019; Sochor et al., 2018; Wong et al., 2019). Door-to-door, on-demand transport using some form of car travel (carsharing, ridesourcing, taxi) is neither in line with sustainable mobility nor with the development of environmentally friendly compact cities (Wong et al., 2019). If instead of public transport, people (are encouraged to) choose to use carsharing, ridesourcing or taxi then car use and traffic will increase (Hensher, 2017; Pangbourne et al., 2019). If on the other hand, MaaS implementation focuses on sustainable mobility, it could help decreasing the use of private cars and increasing the use of sustainable transport modes, according to a review of 31 relevant publications (Utriainen & Pöllänen, 2018). A MaaS implementation that focuses on sustainable mobility would be based on spatially efficient travel modes (walking, biking, public transport, e-scooters). Policies accompanying MaaS could use pricing to penalize spatially inefficient modes (Wong et al., 2019) and optimize the use of public space and the environmental and well-being benefits of sustainable mobility. If aimed towards sustainable mobility, MaaS can contribute to changes in the built environment including: reduction in cars, reduction in parking space, free space for other land uses (e.g. public space), and additional infrastructure for walking, cycling, and public transport. In this way, MaaS would be in line with compact city policies. If used in other ways, MaaS could favor decentralization and urban expansion by facilitating mobility in more remote areas.

5. Emerging transportation technologies

In addition to contributing to the dramatic increase in teleactivities and the sharing economy, ICT plays a crucial role in the development of emerging transportation technologies. For example, vehicle automation relies on ICT to function by using sensors and big data to analyze information and is also enabled by ICT for and during the vehicle usage (e.g. on-demand app services, apps for buying tickets, using smartphones, laptops, and tablets during trips). Emerging transportation technologies are either at a developing and testing stage or have recently been introduced to a limited extent but are expected to drastically change urban mobility in the future. Emerging transportation technologies include autonomous vehicles, air taxis, hoverbikes, drones, and robots (see e.g. European Commission, 2017). The use of these technologies is expected to influence travel behavior via substitution, complementarity, modification, and neutrality pathways. Moreover, depending on policy goals, on how technologies will be used, and on accompanying

Table 3
Summary of how emerging transportation technologies may influence travel behavior and the built environment.

Emerging transportation technologies	Travel behavior	Built environment	Source
Autonomous vehicles	• Private autonomous cars: can increase car travel, lead to more vehicle miles traveled, reduce public transport use, and reduce active travel • Shared autonomous cars: seem to have similarities to carsharing, but with additional vehicle miles traveled • Autonomous buses: could offer more frequent departures due to lower costs thus increasing the use of public transport and reducing car dependency	• Private autonomous cars: increased congestion, potential urban expansion/urban sprawl, and reduced car parking • Shared autonomous cars: may reduce parking space, but may also lead to parking relocation • Autonomous buses might be in line with urbanization and compact city policies if their introduction is combined with appropriate policies	Abe (2019); Ainsalu et al. (2018); Bösch et al. (2018); Carrese et al. (2019); Childress et al. (2015); Duarte and Ratti (2018); Fagnant and Kockelman (2014, 2015); Fraedrich et al. (2019); Gkartzonikas and Gkritza (2019); González-González et al. (2019); Kim et al. (2020a, 2020b); Litman (2020); Milakis et al. (2018); Milakis et al. (2017); Mouratidis and Cobeña Serrano (2021); Narayanan et al. (2020); Nazari et al. (2018); Nenseth et al. (2019); Nordhoff et al. (2018); Salonen and Haavisto (2019); Soteropoulos et al. (2019); Sperling (2018); Stead and Vaddadi (2019); Tirachini and Antoniou (2020); Zakharenko (2016); Zhang and Guhathakurta (2018); Zhang and Wang (2020)
Delivery drones	• Could reduce travel to stores and facilities • But could have complementary rebound effects on travel by freeing up time for other activities	• Would introduce air traffic into the aerial environment • Could facilitate decentralization or urban expansion since they can increase accessibility to several material products	Chiang et al. (2019); and authors' elaborations
Delivery robots	• Could replace some of the personal trips to stores and facilities • But could have complementary rebound effects on travel by freeing up time for other activities	• City infrastructure (e.g. sidewalks, pathways, building entrances, traffic regulations) may need to adapt to accommodate delivery robots	Authors' elaborations
Urban air mobility	• Increased mobility and accessibility • Replacement of traditional transport modes • Increased total travel distances due to quick access to destinations	• Would introduce air traffic into the aerial environment • Could facilitate decentralization or urban expansion as it has the potential to cover distances very quickly	Al Haddad et al. (2020); Cohen et al. (2020); Fu et al. (2019); NASA (2018); Shaheen et al. (2018); and authors' elaborations

regulatory frameworks, emerging transportation technologies may influence transport systems, land uses, and location choices.

The following subsections review some of the major app-enabled emerging transportation technologies – autonomous vehicles, delivery drones, delivery robots, and urban air mobility – and how these relate to travel behavior and the built environment (see also Table 3 for an overview).

5.1. Autonomous vehicles

An autonomous vehicle, also known as automated vehicle, connected and autonomous vehicle, self-driving vehicle, or driverless vehicle, is a vehicle that is capable of sensing its environment and moving safely with little or no human interference (Taeihagh & Lim, 2019). Autonomous vehicles use artificial intelligence, sensors, and big data to analyze information, adapt to external conditions, and make decisions (Long et al., 2007; Taeihagh & Lim, 2019). Vehicle automation is classified into different categories based on its features ranging from 0 to 5; at level 5 the vehicle is expected to drive itself under all environmental conditions.

Autonomous vehicles can be private or shared (Fraedrich et al., 2019). Shared autonomous vehicles can be part of on-demand, shared mobility. Private autonomous cars can substitute conventional private cars, while shared autonomous cars can be used as taxis and rental cars or for carsharing purposes (Nazari et al., 2018). Autonomous vehicles can also be used as public transport modes in the form of autonomous buses (including minibuses and shuttles) (Ainsalu et al., 2018; Mouratidis & Cobeña Serrano, 2021; Salonen & Haavisto, 2019). Automated driving technology can be combined with electric vehicle technology, so autonomous vehicles can be electric in the form of private cars, shared cars, and public transport vehicles. Thus, overall, autonomous vehicles can be classified as (1) private autonomous cars, (2) shared autonomous cars/taxis, and (3) and autonomous buses (Bösch et al., 2018; Litman, 2020).

Vehicle automation will change the experience of private-car traveling since users will be able to engage in activities other than driving while traveling. Such activities may include eating or reading a book but also teleactivities such as teleworking, teleconferencing, or online entertainment (Burns, 2013). Technological development of autonomous vehicles has been rapid, but in order to become a significant part of cities' daily mobility, further development is needed in terms of technology as well as governance and regulations to handle risks associated with safety, privacy, employment, environmental impacts, cybersecurity, and liability (Taeihagh & Lim, 2019).

Since full automation is still in a developing and testing phase, adequate data from the use of this technology are not yet available. Most studies are based on theoretical approaches, hypothetical models, and simulations. Based on these studies, autonomous cars are expected to increase vehicle miles traveled due to longer trips, shifts from public transport and active travel to the car, increased mobility especially for people with mobility restrictions, and more vehicle trips (Childress et al., 2015; Fagnant & Kockelman, 2014, 2015; Milakis et al., 2017). Increases in vehicle miles traveled are expected by both private and shared use of autonomous driving (Narayanan et al., 2020; Zhang & Guhathakurta, 2018). Policies accompanying autonomous vehicles are being considered such as per mile usage charges may counteract the increased travel distances (Childress et al., 2015). Parking relocation of shared autonomous vehicles may also induce environmental issues by generating a considerable amount of empty vehicle miles traveled (Zhang & Wang, 2020). Shared autonomous vehicles in the form of carsharing/taxi can offer the benefits of carsharing and potentially reduce private car usage and car ownership (Fagnant & Kockelman, 2014), but only if they compete with the private car and not with public transport.

Automated driving could be used to support public transport and not private mobility and car travel in the form of autonomous buses (Ainsalu et al., 2018; Fraedrich et al., 2019; Mouratidis & Cobeña Serrano, 2021; Nordhoff et al., 2018). Autonomous buses could have lower operational costs than conventional ones (Abe, 2019; Gkartzonikas & Gkritza, 2019; Tirachini & Antoniou, 2020); therefore they could be used to complement or substitute conventional public transport and could potentially increase the frequency of the departures (Bösch et al., 2018; Mouratidis & Cobeña Serrano, 2021). This scenario could result in an increased modal share of public transport and reduced car travel making this autonomous vehicle technology potentially positive for sustainable mobility (Litman, 2020; Nenseth, Ciccone, & Kristensen, 2019).

Autonomous vehicles are expected to not only change the way people travel, but also change the built environment in cities. Some studies have come up with different scenarios on how urban development will integrate autonomous vehicles and how the built environment will change because of this. Some scenarios suggest that autonomous vehicles may regenerate urban cores, reduce car parking, and free up spaces for other land uses, while other scenarios suggest that, by increasing mobility by car, autonomous vehicles will increase car dependency and lead to further urban sprawl (Sperling, 2018; Stead & Vaddadi, 2019). The implications of autonomous vehicles for urban development depend on how the technology will be used and the relevant policies. In other words, it will depend on whether automated driving technology will be used for private cars, for shared cars, or for public transport such as autonomous buses, but also on whether and how this use will be regulated and based on what goals it will be regulated (Soteropoulos et al., 2019; Stead & Vaddadi, 2019).

The adoption of autonomous vehicles may lead to higher efficiency in car parking and reduced space for car parking relieving land for other uses (Fagnant & Kockelman, 2015; Milakis et al., 2017; Zakharenko, 2016). Especially shared autonomous vehicles can reduce parking space, but also lead to parking relocation (Zhang & Wang, 2020). Private autonomous cars may increase accessibility for those who are not able or willing to drive, increase car use, and result in reduced use of public transport and active travel modes thus favoring residential relocation and urban sprawl (Carrese et al., 2019; Meyer et al., 2017; Soteropoulos et al., 2019; Zakharenko, 2016). According to international experts on accessibility issues, autonomous cars are expected to have two contrasting effects on urban form: densification of city centers and further urban sprawl (Milakis et al., 2018). The idea of autonomous cars leading to more urban sprawl has been questioned, as cities might attract even more residents if autonomous vehicles combined with sharing schemes manage to reduce congestion, pollution, and space used for car parking (Duarte & Ratti, 2018). Regarding shared autonomous vehicles in specific, it has been argued that although they will provide more freedom in choosing a residential location due to increased accessibility, this will not necessarily lead to urban sprawl because of commuting costs (Zhang & Guhathakurta, 2018).

Research has also examined the potential impacts of an era of autonomous vehicles on land use and travel by asking residents themselves. The majority of respondents in Georgia, USA expected that autonomous vehicles would not make them relocate or change the number of vehicles in their household, while some respondents imagine relocating or change vehicle ownership and travel behavior, depending on individual and household characteristics, neighborhood characteristics, and attitudes (Kim, Mokhtarian, & Circella, 2020a, 2020b).

To avoid urban expansion due to a potential introduction of autonomous vehicles, relevant urban and transport policies might be necessary. For environmentally friendly and livable urban development, scenario studies point to the use of autonomous vehicles combined with "mixed-use development policy, the clustering of urban facilities and services, the restriction of motorized access in cities and the adoption of shared high-quality multimodal transport" (González-González et al., 2019). If autonomous vehicle technology is used for public transport instead of car travel, urban expansion could be, at least partially, countered (Soteropoulos et al., 2019).

5.2. Delivery drones

Drones are driverless small aircraft that are also called unmanned aerial vehicles. They can function either using a remote control or autonomously like autonomous vehicles. The use of drones has been rapidly increasing. Current uses include aerial photography and video capturing; scientific research; police, surveillance, and military purposes; inspections of infrastructure; and recreation (Berkowitz, 2014). Several ethical, practical, and privacy issues are associated with drones (Lidynia et al., 2017; Murray & Chu, 2015). A new application of drones that is currently under development is the delivery of goods (Grippa et al., 2019; Pinto et al., 2019; Ulmer & Thomas, 2018). Drones are being developed to deliver products such as groceries, food from restaurants, mail, packages, medicines, vaccines, and equipment.

Using delivery drones in cities could have implications for urban mobility and travel behavior. Such uses of drones may provide easier access to certain products which could reduce travel to stores and facilities. This could result in some reductions in transport emissions and costs (Chiang et al., 2019). As in the case of certain teleactivities, time saved from traveling to such stores could be spent on travel for other purposes. Yet, there are not enough insights into how exactly drones could influence travel behavior. Potential impacts also largely depend on accompanying policies and regulations.

Drones can cause drastic changes in the urban built environment by becoming part of the aerial environment in cities. Increased areal transport may also lead to a decrease in land transport, freeing up space for alternative land uses. Such a form of transport may also create new urban soundscapes, with possible negative impacts. The exact impacts of all these changes are hard to be foreseen. If drones are to fly within or between cities to deliver goods, strong policies and regulations would be needed to reduce associated risks. Delivery drones could potentially facilitate decentralization or urban expansion since they can increase accessibility to several material products. The implications of delivery drones for the built environment have not been sufficiently examined by existing research.

5.3. Delivery robots

In addition to delivering goods with drones, mobile robots are also being developed for this purpose (Buchegger et al., 2018; Raza et al., 2019). Delivery robots take the form of small vehicles or legged walking robots. They can deliver several types of material products such as food, mail, packages, and medicines. Delivery robots are so far designed for last-mile delivery and take-out services. Several startup companies have already developed such robots and pilot projects are already applied in various cities (e.g. San Francisco, Berkeley, and Los Angeles in the United States and Milton Keynes in the United Kingdom).

Similarly to delivery drones, delivery robots may increase accessibility to goods, especially for people with mobility difficulties, people who are not in proximity to certain stores and facilities or people with time restrictions. As with delivery drones, delivery robots may replace some of the personal trips to stores and facilities but could also have complementary rebound effects on travel by freeing up time for other activities. City infrastructure would need to adapt to accommodate delivery robots. For example, sidewalks and pathways would need to enable the unobstructed movement of the robots, building entrances might have to be adjusted, and traffic regulations may also be necessary. These adjustments would depend on the level of automation of the robots. Highly developed robots may not need heavily standardized environments. Since, for the moment at least, delivery robots are not expected to travel long distances, location choices and spatial structure are not expected to be significantly influenced by delivery robots. However, the impacts of delivery robots on both travel behavior and the built environment could rapidly grow and should be further studied.

5.4. Urban air mobility

Urban air mobility is the concept of moving people by air within cities (Al Haddad et al., 2020; Fu et al., 2019). Transport modes of urban air mobility are in a development and testing phase, and progress is rapid. Urban air mobility can be private or shared. It can also be on-demand and automated. Examples of urban air mobility are personal air vehicles, air taxis, and hoverbikes. There is a growing body of literature on urban air mobility that focuses on challenges and barriers such as societal acceptance, safety, equity, weather, legal/regulatory, among others (e.g. Cohen et al., 2020; Serrao et al., 2018; Shaheen et al., 2018). Although the familiarity with the urban air mobility concept is still relatively low among the public, there is an important minority of potential consumers in the United States that would consider traveling by urban air mobility options (NASA, 2018; Shaheen et al., 2018). Public concerns about urban air mobility are generally related to safety, privacy, unemployment, environment, noise, and pollution (NASA, 2018).

Urban air mobility has the potential to cause unpreceded changes in urban mobility as we know it today. When relevant technology develops, it could allow people to cover long distances very quickly (Cohen et al., 2020). Therefore, the distance traveled could dramatically increase. Increased accessibility offered by urban air mobility could result in replacing part of the usage of traditional travel modes. At the same time, covering long distances so easily could facilitate living in more remote places or on the outskirts of cities, and this could encourage sprawled development. Urban air mobility would cause changes in the aerial environment in cities and regions as it would introduce air traffic. Peer-reviewed research examining potential impacts of urban air mobility on travel behavior and the built environment is scarce (Cohen et al., 2020), but urgently needed, since technology is developing rapidly.

6. Conclusions

6.1. Summary of findings and discussion

In this paper, we synthesized the state of knowledge on the implications of teleactivities, the sharing economy, and emerging transportation technologies for travel behavior and the built environment. Teleactivities, the sharing economy, and emerging transportation technologies have three common characteristics. They are enabled by the use of online apps by residents and visitors, are interconnected, and may influence both the built environment and travel behavior. As an umbrella term for the emerging trends found in literature, we may call cities encompassing these three app-enabled elements “App Cities”. We believe that such a concept could be helpful in highlighting the interrelatedness of these trends and their accumulative impact on the built environment and travel behavior.

The synthesis of literature presented in the paper shows that App Cities already have important implications for travel behavior by altering modal shares, travel distances, trip purposes, and trip frequencies. Further changes are expected with the rapidly increasing adoption of teleactivities and engagement in the sharing economy, while emerging transportation technologies will cause drastic changes in urban mobility as we know it today. At the same time, the paper demonstrates that teleactivities, sharing economy, and emerging smart mobility options are changing the built environment in cities: (a) by becoming part of it as new transport systems, (b) the built environment is being transformed to accommodate them (e.g. new city infrastructure), (c) the changes in people's lifestyles and behaviors lead to subsequent changes in the built environment including changes in location choices and land uses.

Our findings addressing the first research question of the paper – the implications of teleactivities, sharing economy, and emerging transportation technologies for travel behavior – can be summarized as follows. Telecommuting and teleconferencing may result in reductions in total travel distances. Online shopping, online education, teleleisure, telehealth, and online social networking do not seem to reduce overall travel distances, as time saved from physical travel for these activities may free up time for traveling to reach other activities. Bikesharing seems to increase cycling modal share, replace the use of public transport, walking, and car, and increase total active travel; and thereby it seems to reduce vehicle miles traveled. E-bike sharing may further replace the use of public transport and car and could in turn further reduce vehicle miles traveled. Carsharing, if not intended to replace regular use of private cars with regular use of shared cars, could be conducive to increases in walking, cycling, and use of public transport and reductions in private car use, private car ownership, and vehicle miles traveled. Ridesharing in the form of carpooling or vanpooling may increase mobility and car travel efficiency but is competitive to and may replace public transport. Ridesourcing, as an informal, cheaper form of taxi, could give rise to more car travel. E-scooters and other forms of micro-mobility can facilitate the use of public transport as a first-last mile option, while they replace active travel, public transport, and car travel. Accommodation sharing may increase total travel in three ways: by displacing residents to less central locations, by inducing additional long-distance travel for tourism and business, and by providing hosts with extra income that could, in turn, incentivize them to engage in more frequent long-distance trips or holidays in destinations that are further away. Private autonomous cars can increase car travel, induce extra vehicle miles traveled, and reduce public transport usage and active travel. Shared autonomous vehicles seem to have implications similar to carsharing, but with additional vehicle miles traveled. Autonomous buses could offer more frequent departures due to lower costs thus having the potential to trigger further use of public transport and to reduce car dependency. MaaS is largely dependent on its goals. If steered towards sustainable mobility, it could provide incentives for using active travel and public transport, while discouraging car travel, and then it could contribute to reductions in car use and car ownership. If steered only towards greater car mobility, cost reductions, and comfort by offering door-to-door, on-demand transport with some form of car travel (carsharing, ridesourcing, taxi), then it could contribute to increased car travel and vehicle miles traveled. Delivery drones and delivery robots would facilitate access to goods and could reduce travel to shops, but they might have rebound effects on other forms of personal travel. Urban air mobility with personal air vehicles, air taxis, and hoverbikes may cause dramatic changes in travel behavior in cities. Potential impacts include increased mobility and accessibility, replacement of traditional transport modes, and increased total travel distances.

Our findings addressing the second research question of the paper – the implications of teleactivities, sharing economy, and emerging transportation technologies for the built environment – are classified according to three pathways. (a) New transport modes including shared bikes, shared cars, and shared e-scooters are now integrated into the built environment, while emerging transport modes will also be integrated into the built environment: autonomous cars and autonomous buses, delivery drones, deliver robots, personal air vehicles, air taxis, and hoverbikes. (b) The built environment is changing to accommodate the elements of the App City. New infrastructure is or will be developed to accommodate bikesharing and e-scooter sharing systems, or urban air mobility. Sidewalks and pathways could be adjusted to facilitate the movement of delivery robots. Roads could be adapted to facilitate the movement of autonomous vehicles. (c) Behavioral changes due to teleactivities, the sharing economy, and emerging transportation technologies may have a subsequent influence on the built environment. Modal share changes could lead to changes in land use and transport infrastructure. Reductions in car use and ownership could result in more efficient use of space by freeing up space due to reduced needs for road capacity and car parking. Free space could result in new land uses. On the other hand, increased car use could result in more congestion and expansion of car infrastructure. Online access to certain goods and services is conducive to the decline or disappearance of certain "brick and mortar" shops and facilities. Increased long-distance travel, partially induced by accommodation sharing platforms such as Airbnb, can contribute to more tourists and business travelers and higher demands for city infrastructure and building capacity. Increased accessibility and mobility due to ICT, sharing systems, and new transport modes could enable remote residential locations or workplace locations, thereby triggering decentralization and urban expansion, if spatial development is not regulated.

Based on the findings from our literature review we can draw some preliminary conclusions on the potential of the App City components to contribute to sustainable mobility. Among the strategies for achieving sustainable mobility are the shift towards more environmentally friendly travel modes and the reduction of travel distances with appropriate land use development (see e.g. Banister, 2008). The implications of the App City components for sustainable mobility (in terms of travel mode and total travel distances) could be classified as: positive for bikesharing; potentially positive for autonomous buses, carsharing, telecommuting, and teleconferencing; potentially negative for private autonomous cars, ridesourcing such as Uber, accommodation sharing such as Airbnb, and urban air mobility; mixed (due to possible rebound effects) for online shopping, online education, teleleisure, telehealth, and online social networking; mixed/context-dependent for e-scooter sharing and ridesharing; largely dependent on goals, use, and regulations for Mobility as a Service; and relatively unknown (but possibly mixed due to rebound effects) for delivery drones and delivery robots. It should be noted that even potentially eco-friendly technologies and mobility services should be accompanied by strong policies and regulatory frameworks in order to promote sustainable mobility (e.g. to reduce car driving and prevent urban sprawl) (Lyons et al., 2018; Moscholidou & Pangbourne, 2019; Stead & Vaddadi, 2019; Wong et al., 2019).

App City developments might occur more quickly than expected due to the COVID-19 pandemic in 2019–2020. This global crisis has made even more evident the potential of certain elements of App Cities, especially teleactivities but also to some extent transportation technologies such as drones and robots, to reduce the negative impacts of the crisis. During the "lockdowns" that occurred in several geographical areas, people who had access to the internet were enabled or forced to virtually perform, to the extent possible, a wide range of activities including accessing certain health services, paying bills, following classes of physical exercise, socializing with friends and relatives, engaging in several forms of online recreation, and even working or studying when possible using teleworking and online education options. In addition, certain emerging transportation technologies were relevant during the COVID-19 crisis. In several cities worldwide, drones and robots were used for delivering products such as food, paper, and medicines; sanitizing and disinfecting; and monitoring the restrictive measures during the lockdowns. Although COVID-19 has boosted the adoption of teleactivities, and to some extent drones and robots, it may have slowed down the development and use of some shared mobility options and may have unclear effects on other emerging transportation technologies and automation.

6.2. Future research directions

Due to the rapidly evolving changes in ICT and transport technology, researchers are being seriously challenged to produce constantly updated knowledge. Emerging from this paper, we list the most eminent research directions about the implications of App Cities for travel behavior and the built environment. We grouped them into two categories: substantive and methodological.

6.2.1. Substantive research directions

There is a need to study the constantly transforming built environment in App Cities (see conceptual model in Section 2, the link between App City and Built environment) and especially how exactly the behavioral changes due to different App City components are influencing the different built environment factors and their interplay (see conceptual model in Section 2, the link between Travel behavior and Built environment). The lack of a more nuanced understanding of these links surfaced for all three App City components discussed in this paper. Understanding these influences in more nuanced ways is essential in order to be able to steer and coordinate these developments, mitigate negative impacts, and support App City components that are in line with policy goals.

The implications of certain teleactivities for travel behavior and the built environment need to be studied in more depth: online education, teleconferencing, teleleisure, telehealth, and online social networking (see Section 3, Table 1). Existing knowledge on these implications is ambiguous, in particular because of the under-researched problematic effects of teleactivities such rebound effects or possible effects on urban sprawl. A comprehensive and nuanced understanding of both the positive and the negative impacts of teleactivities on sustainable mobility is necessary in order to inform planning policy and decision making within this area.

More in-depth studies are needed on the evolving shared mobility options including carsharing, ridesourcing, and e-scooter sharing (see Section 4, Table 2). Also here, existing research shows ambiguity about possible effects, and results seem to be highly context-dependent. In particular, the positive and the negative impacts of these options, in different contexts and in relation to sustainable mobility goals, need to be disentangled and assessed.

Studies should place more emphasis on ongoing pilot projects of emerging transportation technologies: autonomous cars and buses, Mobility as a Service, delivery robots, and urban air mobility (see Section 5). Further, there seems to be a general lack of research examining emerging transportation technologies such as urban air mobility, delivery robots, and delivery drones. Scenario studies could be a powerful tool to critically assess their implications (see Section 5, Table 3).

Across all sections, the paper has shown that the impacts of App City components are strongly dependent on policy and governance tools to steer urban development. Different existing government models should be compared regarding their influence on different possible pathways for App City developments.

Another research need is to continuously investigate how App City developments relate to safety, social equity, gender issues, well-being, and environmental outcomes. These implications of App Cities have not been investigated in-depth in the paper, but they are clearly important avenues for future research that need critical exploration. Future research could provide a synthesis of the magnitude of each technology on urban form and environmental and social sustainability and discuss the outcomes of possible future scenarios.

Although the paper has explained the interplay between App City components and has examined how this might influence travel behavior and the built environment (Sections 2–5), the main aim has been to present an overview of each component individually. Future studies could examine the implications of the interplay between App City components in greater depth.

Finally, App City developments should be studied in relation to disruptions in travel and activity behavior, such as the COVID-19 pandemic outbreak (Section 6.1). Future research could explore how App Cities changed during and after this crisis and how travel behavior and built environments have been affected and will be affected. We expect disruptions like pandemics to affect society way less, thanks to options provided by the App City, at least options for teleactivities. The social and environmental implications of changes in App Cities due to the pandemic crisis also need to be explored.

6.2.2. Methodological research directions

There is a need for more complex research designs including before-after studies, panel studies, and (quasi) experimental studies to provide a more robust understanding of changes in travel behavior due to teleactivities, sharing economy, and emerging transportation technologies (see for example Section 3.1).

There is a need for more complex statistical models of travel behavior that would include geo-referenced data on and factors like attitudes, and personality and that would be analyzed with more sophisticated statistical techniques such as structural equation modeling.

The large majority of the studies reviewed in this paper reports findings that are based on quantitative research. These studies are helpful to identify possible impacts and assess the strength of the relationships identified in our conceptual model. There is, however, a strong need for qualitative research to understand causal pathways. Qualitative or mixed-methods studies are necessary in order to not only identify possible impacts, but to disentangle and explain the causal mechanism behind patterns found in quantitative analyses.

Finally, and closely linked to the previous research need, the relationship between App City developments, travel behavior, and changes in the built environment may be strongly context-dependent. There is a need for research to be context-sensitive, for example conducting comparative studies in diverse cultural, social, and governmental settings. This would also help to understand the partly contradictory findings of some existing studies.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix

Literature search

The paper reviews around 200 studies. To keep the literature scope more manageable, we focus mostly on academic peer-reviewed articles, written in English, but we also include other sources like books, book chapters, reports, and conference papers, especially in the absence of peer-reviewed literature. Our literature search commenced by identifying recent literature review papers, when available, and was supplemented with a systematic search in Scopus. The next step in our literature search was backward snowballing (van Wee & Banister, 2016). To perform backward snowballing, we departed from relevant review papers for topics that have been sufficiently explored by previous research. For topics that were underexplored, we used the few relevant papers found in our Scopus searches as points of departure for backward snowballing. The search string comprised keywords for the targeted App City element in combination with keywords for the implications investigated in the paper. For example, in our Scopus search for e-scooter sharing, we used the following search string (("scooter sharing" OR "scooter-sharing" OR "scooter share" OR "scooter-share" OR "electric scooter" OR "e-scooter") AND ("use" OR "travel" OR "built environment" OR "land use" OR "transport" OR "location")). For topics that are covered by large amounts of literature such as autonomous vehicles or telecommuting, we reviewed relevant literature review papers, seminal papers, and highly relevant papers to keep the size of the literature manageable. Several related papers have naturally been omitted during this process. For topics that are not covered by literature or when literature is scarce (e.g. emerging mobility technologies like delivery drones, delivery robots, or urban air mobility), we discuss the research questions of the study mostly at a conceptual level and recommend directions for future work.

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