Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company’s public news and information website.

Elsevier hereby grants permission to make all its COVID-19-related research that is available on the COVID-19 resource centre - including this research content - immediately available in PubMed Central and other publicly funded repositories, such as the WHO COVID database with rights for unrestricted research re-use and analyses in any form or by any means with acknowledgement of the original source. These permissions are granted for free by Elsevier for as long as the COVID-19 resource centre remains active.
ICT use and spatial fragmentation of activity participation in post-COVID-19 urban societies

Aldo Arranz-López a,*, Julio A. Soria-Lara b,c

a Luxembourg Institute of Socio-Economic Research (LISER), 11, Porte des Sciences, 4366 Esch-sur-Alzette, Luxembourg
b Transport Research Centre -TRANSyT-. Universidad Politécnica de Madrid. Avda. Profesor Aranguren s/n, Ciudad Universitaria, 28040 Madrid, Spain
c Instituto de Economía, Geografía y Demografía. Consejo Superior de Investigaciones Científicas -CSIC-. Calle de Albaceras 36, 28, 28037, Madrid, Spain

Keywords:
Time geography
Fragmentation
ICT
E-working
E-shopping
E-leisure
Transport

Abstract

With the outbreak of the COVID-19 pandemic, the use of Information and Communications Technology (ICT) came to dominate daily activities (e.g., e-working, e-shopping, and e-leisure). The intensive use of ICT might trigger higher levels of spatial fragmentation of daily activities, having significant consequences for planning purposes. This paper seeks to estimate how ICT use and habits affect the individuals’ spatial fragmentation patterns in urban contexts on post-COVID-19 societies, while controlling for socioeconomic and built environment characteristics. The city of Alcalá de Henares (Madrid Metropolitan Area, Spain) serves as the case study. The research design is based on activity diaries obtained by face-to-face interviews, and Tobit and Poisson regression analyses are used to examine the relationships between spatial fragmentation measures (outcome variable) and ICT use (predictors). The results reveal that ICT might originate higher spatial fragmentation for work-related activities than for shopping-leisure purposes. For working activities, higher spatial fragmentation patterns are found among people with higher willingness to e-work and individuals who e-work at least once a month, but rather dependent on the occupation type. Regarding shopping and leisure activities, higher spatial fragmentation patterns are noted with car owners and more frequent consumers of online entertainment. The study provides insight into how ICT use is transforming spaces traditionally adapted for a single purpose into multifunctional spaces as well as the spatial effect of this phenomenon.

1. Introduction

Information and Communications Technology (ICT), via e-working, e-shopping and e-leisure, is playing a significant role in reorganizing daily spatial patterns at urban and regional levels (Shen et al., 2020). People can perform daily tasks anywhere and at any time, thus overcoming space-time barriers (Ben-Elia and Zhen, 2018; Thulin and Vilhelmson, 2019). It also serves as a catalyst in new fragmentation patterns of daily activities in both space and time, reshaping planning practice, for example, by changing use of dedicated places and modifying traditional travel patterns (Alexander et al., 2011). The COVID-19 pandemic accelerated digitalization, fundamentally altering perception and use of ICT in daily life (Mouratidis and Papagiannakis, 2021). However, the potential impact of the “new online habits” on spatial patterns and activity fragmentation processes (e.g., fragmented vs clustered), as well as the persistence of this phenomenon in the mid- and long-term, is not yet clear (Lyons, 2009; van Wee and Witlox, 2021).

Time geography (Hägerstrand, 1970), with its concept of activity fragmentation, is a good approach to examine the impact of ICT. Inspired by Couclelis (2003), activity fragmentation “is a process whereby a specific activity is divided into several smaller components, which are performed at different times and/or locations” (Hubers et al., 2018, p.95). Spatial fragmentation is traditionally made up of three measures (Ben-Elia et al., 2014): (i) number of locations, indicating the number of unique locations where each activity is performed on a certain day; (ii) distribution of fragment sizes, measuring how the total time spent on one activity in a particular day is spread across different locations; and (iii) configuration of fragments, estimating the spatial dispersion of locations in which one activity is completed in a given day. Since mandatory (e.g., working) and discretionary activities (e.g.,
shopping, leisure) have different rationales and spatial fragmentation is conceptualized and analysed in an independent manner for each (Coulcélis, 2009). This research considers the implications of spatial fragmentation as a whole, as it might reveal the individuals’ spatial patterns, uncovering valuable insights (e.g., locations for particular activities and the transport modes used to reach them) (Alexander et al., 2011).

Despite the growing number of research on ICT’s spatial and temporal effects, key issues remain understudied. First, most efforts examining ICT impacts on urban space have been largely theoretical and empirical studies are scarce (Dadashporo and Yousefi, 2018; Tranos and Ioannides, 2020). Second, the spatial fragmentation of paid work has received much attention (Alexander et al., 2011; Hubers et al., 2018; Lenz and Nobis, 2007), while other activities, such as shopping and leisure, remain neglected (Ben-Ellia et al., 2014; Xi et al., 2017). This an important gap, as e-shopping and e-leisure rates have been growing even more than e-working rates during the last years. Third, a limited number of studies have focused on the relationships between ICT and activity fragmentation processes after the COVID-19 pandemic. This connection should be examined in detail, especially in light of the measures to tame the COVID-19 pandemic (social distancing, lockdowns, restricted mobility and opening hours), which forced people to adopt and intensify online habits.

This paper explores the following research question: What are the effects of ICT use (e-working, e-shopping and e-leisure) on post-COVID-19 spatial fragmentation patterns in urban areas? The city of Alcalá de Henares (Madrid Metropolitan Area, Spain) serves as the case study. The research design is based on activity diaries obtained by face-to-face interviews with 159 participants, conducted in April 2021. Tobit and Poisson regression analyses were carried out to determine the relationships between the spatial fragmentation measurements (outcome) and ICT use, socio-economic factors, and built environment variables (predictors).

The remainder of the paper is structured as follows. Section 2 covers the literature review, while Section 3 introduces the case study and the process of data collection. Section 4 illustrates the research design, and Section 5 outlines the obtained results. Section 6 closes the paper with concluding remarks and topics for further research.

2. Literature review

This section reviews the state-of-the-art on spatial fragmentation, paying special attention to two relevant aspects. First, the type of activity analysed: working, shopping, and leisure. Second, how ICT variables are affecting fragmentation processes.

Lenz and Nobis (2007) were among the first to implement fragmentation measures for work-related activities, aimed at establishing the relationships with ICT use (e.g., mobile phone ownership, internet access for e-working). Despite the uncovered evidence on the ICT effects on fragmentation patterns, their findings were not always consistent. Other authors developed analytical indicators to measure both temporal (Hubers et al., 2008) and spatial fragmentation patterns (Alexander et al., 2010, 2011). For example, Alexander et al. (2010) explore how ICT and socio-demographic attributes contribute to the spatial and temporal fragmentation of work activities. The authors confirm that ICT habits (e.g., owning a mobile electronic device, e-work, and general use of the internet), socio-demographic (at individual and household level), and work-related variables affect the fragmentation patterns of paid work. According to their results, temporal activity fragmentation is more common than spatial. Similarly, Alexander et al. (2011) also study the likely fragmentation patterns for work-related activities caused by ICT use, finding a limited cause-effect relationship. This might be due to the data collection timing (2007), when the internet was a largely location-fixed technology and mobile devices had limited internet access. Using the same database from Alexander et al. (2011), Hubers et al. (2018) explore gender differences in the fragmentation patterns of paid work. Their findings indicate that men and women adopt e-working in a different manner and with different impact on reorganizing paid work (e.g., working from home). Nevertheless, the potential of ICT to fragment paid work in space is seen limited for men, while women owning a laptop show highly spatially fragmented patterns. Similar findings by Burchell et al. (2021) confirm the gender differences in the fragmentation of working-related activities.

Expanding the scope, Ben-Elia et al. (2014) investigate how ICT affects activity fragmentation and travel behaviour for both work and non-work activities. The obtained results show that the use of ICT influences the spatial fragmentation for both types of activities. Nevertheless, non-work trips seem to be more sensitive to fragmentation than work trips. On the one hand, more intense internet experiences correspond to a lower number of work trips. On the other hand, ICT restricts personal travel to non-working destinations, spatially reallocating certain leisure activities (e.g., shopping). More recently, other studies have also analysed the likely impact of ICT on leisure activities and social interactions. For example, Xi et al. (2017) examine the fragmentation of both offline and online leisure, finding that ICT affect virtual and in-person leisure activities differently, with virtual leisure being more spatially fragmented. The authors signal that these more fragmented patterns could originate the beginning of a transformation from some traditional urban spaces. Finally, Lizana et al. (2021) analyse whether ICT affects individuals’ social interactions, finding that ICT reduces the spatial fragmentation of social life.

This study aims to add value to the existing research by overcoming, at least, two main research gaps. First, the literature review demonstrates that the spatial fragmentation for work-related activities is largely the centre focus. This paper complements those studies by exploring the ICT effects on the spatial fragmentation patterns of other daily activities to which people devote considerable time budget (shopping and leisure). Second, some of the research suggests that temporal fragmentation occurs more frequently than spatial fragmentation, on which ICT has rather limited effects. However, the fact that the data is somewhat dated could not reflect the current digitalization level of Western societies. This paper explores spatial fragmentation in a moment when the pandemic has pushed people to use digital tools, which might strongly affect to the spatial fragmentation of working and shopping-leisure activities.

3. Case study and dataset

3.1. The city of Alcalá de Henares, Spain

With 195,982 inhabitants, Alcalá de Henares is the third most populous city in the Madrid Metropolitan Area, Spain (Instituto Nacional de Estadística, 2022a, 2022b). While it is not one of the biggest Spanish cities, Alcalá de Henares is a consolidated urban area within Madrid Metropolitan Area, generating its own urban and demographic dynamics. This is partly due to its location within the so-called “Henares Corridor”, an industrial and business hub, makes it an important regional node for logistics and technology (Lafrante and Rodríguez Moya, 2009). Given the strong link between Alcalá de Henares and the industrial sector, local authorities are committed to the digital economy, a key and challenging issue after the COVID-19 pandemic (Ayuntamiento de Alcalá, 2019). Local and regional administrations are joining forces to help entrepreneurs implement digital strategies in start-ups and to build the population’s digital skills in e-working.

Regarding shopping and leisure, Alcalá de Henares offers a variety of facilities including seven theatres, eleven museums, and seven shopping centres. The city also has dense and diverse in-store retail network, mostly located in the city centre, which can be easily reached by public transport or on foot. As a result of COVID-19 policies (e.g., social distancing, restriction in opening hours), e-shopping rates have been growing (Instituto Nacional de Estadística, 2022a, 2022b), and local retailers are being encouraged to implement e-shopping as part of their business model. For example, in-store retailers can attend training...
workshops in online marketing and on hybrid retail approaches offered by the Madrid’s Chamber of Commerce. Additionally, residents of all ages can use socio-cultural centres that offer hybrid leisure spaces: physical (e.g., sports, boardgames) and online (e.g., videogames, social network).

3.2. Data gathering and sample characteristics

Face-to-face interviews were conducted during April 2021 with 159 participants. The average interview time was 35 min, consisting of two main blocks. Because of the length of each interview, the research team determined that the sample size would have 90 % of confidence interval with a margin of error between 6 % and 10 %, i.e., a minimum of participants between 69 and 189. Additionally, before starting the fieldwork campaign, the questionnaire was tested with a pilot population with different socioeconomic backgrounds, ensuring everybody could understand the questions.

The first was a short questionnaire covering the participant’s socioeconomic characteristics and “online habits” (e.g., e-working frequency, e-shopping frequency, internet experience), at both individual and household levels. The second block obtained an activity diary for a single workday. Activity diaries served to record the specific locations where participants conducted daily activities, with whom, the type of activity (working, shopping, leisure), whether it happened physically or online, the duration of each activity, and the travel mode. The interviews were conducted in five locations with different urban characteristics, in order to secure participants with diverse profiles. Because of the detailed information provided in the activity diaries (e.g., specific addresses where activities are performed), they were organized as an opt-in diary, i.e., using a convenience sampling approach. This is a non-probability sampling method, where the sample is taken from a group of people who are easier to contact. This type of sampling does not require a complicated sampling framework (e.g., a stratified sample in terms of gender or age). The only criterion is whether respondents are willing to participate in the survey or not. The main advantage is faster, easier and cost-effective collection of information, which is suitable for initial explorations of new topics, such as the impact of ICT on daily spatial fragmentation.

Regarding socio-economic characteristics (Table 1), a little over half of the respondents were men (52.83 %). The sample’s mean age was 45 (two years above the average for Alcalá de Henares), with people between 41 and 60 as the most represented cohort. Almost three-fifths (58.49 %) had higher education (bachelors or a higher). More than half (57.30 %) were working, of whom most were employed full time (70.32 %), with almost equal shares of students (17.61 %) and retirees half (57.30 %) were working, of whom most were employed full time (70.32 %), with almost equal shares of students (17.61 %) and retirees (18.87 %). Net monthly household income of 2000 to 2999 was most common (43.07 %), followed by €3000 to €5000 (29.93 %). More than a half live in a family unity (56.60 %), but only a few took care either of the elderly (9.43 %) or children (13.21 %). Nevertheless, more than one-third (37.11 %) declared to be in charge for household tasks, including shopping responsibilities (43 %). Finally, the vast majority had a driver’s license (79.87 %) and one or two cars available (80.50 %).

Regarding ICT (see Annex A), almost two-thirds have used either the internet or a smartphone for more than 15 and 10 years, respectively, and the vast majority (85.54 %) use two or more electronic devices daily. Almost half (45.05 %) e-worked at least one day per month and about 50 % were willing to e-work. Looking at e-shopping, one-fifth bought online weekly (20.75 %), mainly electronics (17.41 %), clothes (14.43 %), or streaming services (e.g., Netflix or similar) (12.69 %). Furthermore, three-fourths searched online before buying (74.84 %), and more than half were willing to buy online (59.75 %). Nevertheless, participants patronise brick-and-mortar stores more frequently (83.02 %) than shopping online (27.04 %). They shared that they like walking through shopping areas (77.36 %) or doing in-store shopping as reason to get out of the house (47.80 %). These points were particularly highlighted by those who never buy online (30 %). By product type, people preferred in-store shopping instead of e-shopping for different products, such as groceries, furniture, and second-hand products. Finally, three-fourths (76.10 %) enjoyed some type of e-leisure, such as videogames or home cinema.

In addition to the data obtained during the face-to-face interviews, information on built environment variables (jobs and retail density) was also collected. Job density and retail density were estimated from Mataos-Miguez et al. (2021). The city centre and the most populated neighbourhoods (e.g., Juan de Austria) had the highest job and retail densities, while the opposite was found for the city’s outskirts (e.g., Espartales, La Garena, Val). Notably, most respondents live in neighbourhoods with medium-high job density and/or high retail density.

4. Research design

The research design followed a two-stage approach: (i) calculating spatial fragmentation measures; and (ii) modelling the relationships between spatial fragmentation measures (outcome) and ICT use, socioeconomic factors, and built environment variables (predictors).

4.1. Calculation of spatial fragmentation measures

Face-to-face interviews were first coded with the PostGIS extension.
of PostgreSQL, to compile the data in a relational database. Then, spatial fragmentation measures at individual level were calculated for two types of daily activities (see Annex B): work and shopping-leisure. In the case of work, participants who did not have any paid employment were excluded from the analyses (n = 100), while the entire sample was used for shopping-leisure (n = 159).

It should be emphasized that each spatial fragmentation measures covers one feature of spatial fragmentation. For example, individuals with less fragmented spatial patterns would be simultaneously characterized by a smaller number of places (L) to perform daily activities; strong differences of the time spent at the daily locations (S\text{index}); and smaller activity spaces (S\text{xy}). Opposite values for each indicator would signify more fragmented spatial patterns. Fig. 1 illustrates a theoretical conceptualization of spatial fragmentation patterns according to the three measures included in this research.

4.2. Modelling the relationships between outcome and explanatory variables

Poisson and Tobit regression models were conducted to explore the relationships between the spatial fragmentation measures (outcome variables) and the use of ICT for working and shopping-leisure activities, the socio-economic attributes, and the built environment characteristics (explanatory variables). Since this paper analyses two activity types (work and shopping-leisure) and three measures for spatial fragmentation, six regression models were conducted.

Before carrying out the regression analyses, bivariate correlations were implemented to avoid multicollinearity. In the case of working activities, correlation analyses indicated that age, gender, employment status, car ownership, years of internet experience, willingness to e-work, e-working frequency, and job density were the less correlated variables. For shopping-leisure activities, the less correlated variables included the following: age, gender, car ownership, in-store shopping frequency, years of smartphone experience, willingness to e-shop, consumption of streaming services, online search frequency, and retail density.

As the number of locations is a non-negative count variable, the Poisson regression is considered as a suitable approach. A basic assumption of this type of regression is that the mean and variance to be equal. However, the number of locations for working and shopping-leisure showed to be under-dispersed, i.e., the variance was lower than the mean. On this basis, an alternative model named Conway-Maxwell Poisson (CMP) regression was finally chosen.

The other two fragmentation measures, the distribution size of locations (S\text{index}) and the configuration of locations (S\text{xy}), were continuous censored variables above and/or below. Tobit regression is an appropriate model to analyse censored variables. Although Tobit regression coefficients are interpreted similarly to Ordinary Least Squares regression coefficients, the linear effect is on the uncensored latent variable and not on the observed outcome. Thus, the expected outcome variable score changes by coefficients for each unit increase in the corresponding predictor. For both CMP and Tobit regressions, the Nagelkerke’s pseudo-\text{R}^2 statistic was used as a goodness-of-fit measure. The significance of the variables included in the models was assessed at p-values of 0.1, 0.05, and 0.01.

5. Results

5.1. Spatial fragmentation measures

As mentioned in Section 4.1, three spatial fragmentation measures were calculated for two activity types: working and shopping-leisure. The mapping of 157 work locations (Fig. 2), revealed that most participants exercise their vocation within Alcalá de Henares; however, some have to travel to Madrid City or to other locations in the Henares corridor. Table 2 shows that working activities are mostly conducted at a single location (\( \overline{x} = 1.57 \)). An office is the most common place for those who worked in person, while home was the preferred location for e-workers. For individuals who worked in two or more locations, the S\text{index} (\( \overline{x} = 0.2 \)) denotes that the time spent differs across locations (Fig. 2).

For example, many individuals spend longer at their workplace, while less time-consuming tasks (e.g., reading, writing emails) are usually completed elsewhere (e.g., home, coffee shops, etc.). Finally, the configuration of locations measure (S\text{xy}) reveals that working locations are not very spatially dispersed. Nevertheless, certain professions that require direct contact with clients (e.g., real estate agents, sales representatives) show higher dispersion levels of work locations (max = 15.39 km).

Shopping-leisure activities are mostly performed within the municipality of Alcalá de Henares and only a few in Madrid City or other locations throughout the region (Fig. 3). In total, 444 shopping-leisure locations are identified, and they show higher spatial fragmentation than noted for work. On average, shopping-leisure activities are performed in three different locations (\( \overline{x} = 2.79 \)), while some people visit up to five in a single day. Consistent to the sample description (Section 3.2), it indicates the participants’ preference for in-store shopping rather than e-shopping. Two reasons might explain this result. On the one hand, shopping during weekdays can be more related to groceries and food, a product not yet very popular among Spanish e-shoppers. On the other hand, the activity diary records a single day, which may not accurately represent the usual personal routine. However, it is more common to practice e-leisure, with social networks and messaging services as the most common activities. Again, this could reflect that the activity diaries recorded a weekday, while face-to-face social life (e.g., meeting friends) is more common during weekends. The S\text{index} suggest that, in general terms, the time spent at the different shopping-leisure

![Fig. 1. Conceptualization and spatial representation of extreme fragmentation patterns.](image-url)
Fig. 2. Work locations (above) and working time spent at each location (below).
locations is similar ($\bar{x} = 0.60$) (Fig. 3). Finally, the $S_{xy}$ measure reveals that despite people mostly buying in Alcalá de Henares, shopping-leisure locations tend to be dispersed within the study area ($\bar{x} = 2.81$ km).

Nevertheless, the highest dispersion levels are identified with participants who chose Madrid City as the place to perform shopping-leisure tasks (max = 15.39 km).

5.2. Spatial fragmentation of work activities: modelling results

The first model, estimating the number of locations ($L$) for work activities, has a pseudo-$R^2$ of 0.351 (Table 3). Regression results show that older persons (above 45 years old) and full-time employees tend to work, on average, in more locations (1.82 locations) than the youngest (1.39 locations). Most of participants older than 45 years old and full employed are academic staff at the University of Alcalá de Henares, engineers, and retailers. For the study’s sample, academic staff’s regular working schedule is as follows. During the morning, they go to the university to teach and attend meetings, while usually e-working during the afternoon: reading papers, emailing, and writing research proposals. Regarding the engineers, two profiles can be found. On the one hand, there are engineers who supervise civil works at several municipalities close to Alcalá de Henares and are not very familiar with e-working. On the other hand, other engineers primarily work in the office and carry out smaller tasks at other locations (e.g., park, supermarket), such as replying to emails or making phone calls. They use electronic devices more frequently and recognize that e-working facilitates a better balance between family life, which is especially important for women.

The model also shows that higher levels of the internet experience (ten years and more) are associated with higher numbers of work locations. The predominant occupations for experienced internet users are teachers (e.g., high school, university), health professionals, and banking. For example, primary school teachers with a high internet experience usually use electronic devices (e.g., tablet, laptop) to carry out minor work tasks (e.g., replying to emails). The regression also shows that daily e-workers tend to work in fewer locations compared to those who never work online. The activity diaries show that e-workers do not use the potential of e-working to work at different locations, while they prefer the household as the primary location. The choice to e-work at home could be influenced by three factors. First, social distancing measures implemented at the moment of collecting the activity diaries (e.g., limited capacity at physical facilities), coinciding with the period after the first three COVID-19 waves. Second, preventive quarantines at schools were common, and children had to spend 2-3 days at home. Third, personal preferences, such as keeping safe from a COVID-19 infection, can also influence choosing home as the primary workplace.

The second model estimates the distribution size of locations ($S_{\text{index}}$), i.e., whether people spend a similar amount of work time at the different locations. The Nagelkerke’s pseudo-$R^2$ was 0.377. Age is positively associated with the distribution of size locations. Notably, workers older than 45 years are more likely to spend similar durations across their daily locations ($S_{\text{index}} = 0.66$) than the youngest ($S_{\text{index}} = 0.22$). As in the previous model, the older workers are university teaching staff (see the general pattern in the previous model) and sales agents. Nevertheless, the $S_{\text{index}}$ might vary between these two types of profiles, as the figures for university teaching staff are more unequally distributed than for sales agents. For example, sales agents spend most of their work hours visiting clients at multiples locations, spending a similar amount of time at each client, and usually do not e-work at home.

Regarding the employment status, part-time workers are more likely to spend work hours more unequally across different locations ($S_{\text{index}} = 0.37$) than full-time employees ($S_{\text{index}} = 0.53$). It must be said that part-time workers normally work at only one single location due to their job specifics, and only three part-time workers in the sample work in two or more locations.

The last model for work activities estimates the configuration of locations ($S_{\text{xy}}$), i.e., the level of dispersion of work locations. A Nagelkerke’s pseudo-$R^2$ of 0.154 indicates that this model is the least accurate, compared to the previous two models. The statistically significant variables are employment status, owning a car, and e-working frequency. The work locations of part-time workers tend to be less spatially dispersed than for the full-time employed. This might be due to the fact that part-time workers generally work in one location, whereas their job requires being on-site (e.g., retailer, lawyer, general practitioner) or the distance between their home and workplace is smaller ($S_{\text{xy}} = 60$m). Car owners are more likely to work in more spatially dispersed locations; however, the highest spatial dispersion is due to a few workers who commute to Madrid City. It seems that almost all participants have their professional and personal lives within the municipality of Alcalá de Henares. Finally, e-workers tend to work in more spatially dispersed locations than individuals who never work online. Because the number of locations between e-workers and non-e-workers is rather similar (2 and 1.5 locations, respectively), other factors might explain this higher dispersion. Two feasible causes could be that e-workers have to travel longer distances to reach their workplaces and that they rely more on driving their cars instead of using public transport and active modes.

5.3. Spatial fragmentation of shopping-leisure activities: modelling results

The first model, regressing the number of locations ($L$), has a Nagelkerke’s pseudo-$R^2$ of 0.351 (Table 4). Car owners tend to perform shopping-leisure activities in a higher number of locations ($L = 2.83$) than non-car owners ($L = 2.64$). According to the activity diaries, car owners focus buying at a single location, while leisure is spread out across two or more. Two different spatial patterns for car owners emerge. On the one hand, those who patronise medium-size retail (e.g.,

---

**Table 2** Descriptive results of spatial fragmentation measures.

| Work | Shopping-leisure |
|------|------------------|
| L    | $S_{\text{index}}$ | $S_{xy}$ (km) | L    | $S_{\text{index}}$ | $S_{xy}$ (km) |
| N    | 100              | 100            | 159  | 159              | 159            |
| Mean | 1.57             | 0.21           | 2.79 | 0.60             | 2.81           |
| SD   | 0.86             | 0.35           | 1.04 | 0.29             | 4.99           |
| Min  | 1.00             | 0.00           | 1.00 | 0.00             | 0.00           |
| Max  | 5.00             | 15.39          | 5.00 | 0.99             | 15.39          |

---

A. Arranz-López and J.A. Soria-Lara

Land Use Policy 120 (2022) 106302
Fig. 3. Shopping-leisure locations (above) and shopping-leisure time spent at each location (below).
supermarket) and have a mix of leisure activities, both at home (e.g., streaming services, online videogames) and outside their home (e.g., cafeteria, restaurants). On the other hand, there are those who prefer larger stores, mainly shopping centres, because they can take care of shopping and leisure at one location. Shopping-leisure locations for car owners correspond to traditional car-oriented places. Non-car owners

| Table 3 | Regression model results for work activities. |
|---------|------------------------------------------|
|         | CMP | TOBIT |                  |
|         | L   | Sindex | Sxy  |
| Age     | 0.018**| 0.003 | 0.006*| 0.003 | 0.036| 0.025 |
| Gender (ref = male) | | | |
| Female | 0.036 | 0.091 | 0.101 | 0.099 | 0.825 | 0.677 |
| Employment status (ref = full-time) | | | |
| Part-time worker | -0.456***| 0.129 | -0.423***| 0.155 | -3.067***| 1.055 |
| Car ownership (ref = no) | | | |
| Yes | 0.100 | 0.123 | 0.323***| 0.160 | 2.706**| 1.098 |
| Internet experience (ref = less than 5 years) | | | |
| 5-9 years | 0.393 | 0.390 | 1.884 | 135.347 | 12.658 | 746.534 |
| 10-14 years | 0.877***| 0.343 | 2.102 | 135.347 | 14.037 | 746.533 |
| More than 14 years | 0.588*| 0.338 | 2.022 | 135.347 | 13.317 | 746.533 |
| Willingness to e-work (ref = willing) | | | |
| Somewhat willing | -0.162 | 0.130 | -0.289**| 0.154 | -1.508 | 1.014 |
| Neutral | 0.088 | 0.189 | 0.052 | 0.234 | -0.843 | 1.628 |
| Somewhat not willing | -0.173 | 0.152 | -0.183 | 0.172 | -1.228 | 1.150 |
| Not willing | -0.020 | 0.144 | 0.154 | 0.164 | -0.067 | 1.106 |
| E-working frequency (ref = never) | | | |
| Once a week | 0.247 | 0.193 | 0.394***| 0.215 | 1.617 | 1.459 |
| At least once a week | 0.121 | 0.112 | 0.412***| 0.126 | 2.002**| 0.848 |
| Everyday | -0.315***| 0.149 | -0.235 | 0.179 | -1.851 | 1.173 |
| Job density | -0.001*| 0.000 | -0.001 | 0.000 | -0.001 | 0.001 |

| Nagelkerke’s pseudo-R² | 0.351 | 0.315 | 0.154 |

***p < .01; **p < .05; *p < .1

| Table 4 | CMP and Tobit regression model results for spatial measures of shopping-leisure activities. |
|---------|------------------------------------------|
|         | L   | Sindex | Sxy  |
| Age     | 0.001 | 0.002 | 0.002 | 0.001 | 0.001 | 0.006 |
| Gender (ref = male) | | | |
| Female | 0.054 | 0.060 | 0.057 | 0.052 | 0.248 | 0.177 |
| Car ownership (ref = no) | | | |
| Yes | 0.144*| 0.074 | 0.051 | 0.063 | 0.265 | 0.216 |
| In-store shopping frequency (ref = never) | | | |
| A few times a year | -0.083 | 0.327 | 0.201 | 0.245 | 0.275 | 0.830 |
| Once a month | 0.115 | 0.296 | 0.212 | 0.242 | 0.611 | 0.820 |
| Once every 15 days | 0.107 | 0.159 | 0.152 | 0.134 | 0.606 | 0.453 |
| Once a week | 0.017 | 0.146 | 0.049 | 0.122 | -0.927***| 0.339 |
| A few times a week | 0.082 | 0.146 | 0.191 | 0.122 | 0.126 | 0.413 |
| Daily | 0.159 | 0.147 | 0.110 | 0.123 | -0.446*| 0.247 |
| Smartphone experience (ref = < 1 year) | | | |
| 1-2 years | 0.390 | 0.288 | -0.041 | 0.319 | -0.073 | 1.082 |
| 3-5 years | -0.239 | 0.172 | -0.070 | 0.147 | -0.199 | 0.499 |
| 6-9 years | -0.149 | 0.161 | 0.132 | 0.140 | 0.438 | 0.224 |
| More than 9 years | -0.037 | 0.162 | 0.104 | 0.141 | 0.386 | 0.479 |
| Willingness to e-shop (ref = willing) | | | |
| Somewhat willing | -0.076 | 0.080 | -0.149***| 0.070 | -0.283 | 0.237 |
| Neutral | -0.285**| 0.134 | -0.187* | 0.111 | -1.005***| 0.377 |
| Somewhat not willing | -0.099 | 0.106 | -0.124 | 0.092 | -0.311 | 0.315 |
| Not willing | -0.079 | 0.122 | -0.188* | 0.107 | -0.372 | 0.365 |
| Consumption of online leisure (ref = no) | | | |
| Yes | -0.059 | 0.075 | 0.073 | 0.065 | 0.380*| 0.220 |
| Online search frequency (ref = never) | | | |
| A few times a year | -1.025 | 0.641 | -2.180 | 95.300 | -7.534 | 162.382 |
| Once a month | -0.374*| 0.230 | -0.296* | 0.174 | -0.620 | 0.587 |
| Several times a month | 0.198 | 0.170 | -0.022 | 0.150 | -0.990***| 0.510 |
| Once a week | 0.178 | 0.177 | 0.055 | 0.165 | -0.229 | 0.561 |
| Several times a week | 0.086 | 0.165 | -0.117 | 0.140 | -0.54 | 0.473 |
| Once a day | 0.083 | 0.175 | -0.057 | 0.149 | -0.810***| 0.260 |
| Several times a day | -0.011 | 0.166 | -0.174 | 0.140 | -0.850*| 0.474 |
| Retail density | -0.001*| 0.000 | -0.001***| 0.000 | -0.002***| 0.000 |

| Nagelkerke’s pseudo-R² | 0.351 | 0.315 | 0.154 |

***p < .01; **p < .05; *p < .1
Accordingly, Saturday and Sunday may reveal a different spatial routine, when they face tighter schedules than during the weekends. Henares or at supermarkets on the way home. This is likely a weekday most of these participants are workers who do not buy in their neigh-

A. Arranz-Lopez and J.A. Soria-Lara

prefer medium and small-size stores (proximity retail), with some differences in leisure activities. While they also enjoy in-home entertainment (e.g., watching tv or streaming services) they prefer more active leisure when outside (e.g., gym, go for a walk, running) than car owners.

Regarding willingness to e-shop, participants who are “somewhat willing”, “neutral”, and “not willing” to e-shop are more likely to perform shopping-leisure in fewer locations than those “willing” to e-shop. This could be due to participants with the highest willingness to e-shop also buying in-store quite often, i.e., they probably were frequent in-store shoppers before starting to e-shop. Especially, those who see shopping as a relaxing activity usually visit more locations. However, as the willingness to e-shop decreases, in-store shopping also decreases, except for the elderly. Another significant variable is online search frequency. People searching monthly focus their shopping-leisure in a more limited number of places (L = 1.8), compared to those who never search online (L = 3). Almost three-fourths of those who never search online are retired and see daily shopping as leisure time for socializing, for example, meeting friends at bar to have aperitif after completing daily shopping tasks. However, those searching monthly would opt to e-shop some products, thereby replacing a few shopping trips. Furthermore, they would see shopping as a chore, decoupling it from leisure.

Finally, those living in neighbourhoods with high retail density tend to shop at fewer locations. While this may seem contrary to expectations, most of these participants are workers who do not buy in their neighbour-hood’s surroundings. According to their activity diaries, many are used to shopping after work, either at the shopping centers in Alcalá de Henares or at supermarkets on the way home. This is likely a weekday routine, when they face tighter schedules than during the weekends. Accordingly, Saturday and Sunday may reveal a different spatial pattern.

The second model, focused on the distribution size of locations (S\text{index}), has a Nagelkerke’s pseudo-R\textsuperscript{2} of 0.315. Individuals with a neutral or low willingness to buy online tend to spend variable durations across shopping-leisure locations (S\text{index} = 0.57 and 0.58, respectively) than people with the highest willingness to buy online (S\text{index} = 0.7). For example, those not willing are the elderly who visit three different locations. They spend two-thirds (64 %) of their leisure time at home, watching tv or playing cards. The other two main locations used to be shopping spots, where they spend, on average, 35 % and 12 % of the time, respectively. The time schedule for people “neutral” towards e-shopping follows a similar scheme, while the leisure activities and shopping destinations vary substantially. For people who are “somewhat willing” to e-shop, they present a very similar mean value of S\text{index} (S\text{index} = 0.68) than those “entirely willing”. This would be partly explained because people with higher willingness to e-shop (youngest respondents) are most active in e-activities and the use of electronic devices for shopping and leisure.

Young respondents, on average, spend 70 % of their time at home (shopping online, playing video games, watching YouTube, etc.) and only 31 % doing out-of-home activities. People younger than 34 years older spend, on average, only 13 % of the time on shopping tasks since they buy online often or quite often. Related to the online search frequency, those searching online would allocate their shopping-leisure time differently across locations. Their time distribution across locations might be quite similar than for participants somewhat willing to e-shop. Lastly, Alcalá de Henares’ residents living in high retail density areas tend to spend different durations at each location; however, when comparing the habits of residents living in high-density and low-density areas, the differences are quite small (13 % and 11 %, respectively).

The final regression model estimates the configuration of shopping-leisure locations (S\text{xy}) and is the least accurate model, with a Nagelkerke’s pseudo-R\textsuperscript{2} of 0.154. The results indicate that S\text{xy} correlates with in-store shopping frequency, smartphone experience, willingness to e-shop, consumption of streaming services, online search frequency, and retail density. Shopping locations for individuals buying in-store daily or weekly tend to be less spatially dispersed ($S_{xy} = 1.170$ km and $1.320$ km, respectively) than for those who never buy in-store ($S_{xy} = 3.420$ km). This might be due to in-store shopper preference of traditional retail close to their home or workplace, usually reachable on foot. Since shopping and leisure are jointly analysed, the higher spatial dispersion for non-in-store shoppers would be linked to leisure activities usually conducted at places located far from each other. For example, men above 52 years old do not shop in-store, as they consider it stressful, although they spend leisure time at two or three different locations. Also, young men (up to 25 years old), who usually e-shop, would allocate spending time in conducting leisure activities more spatially dispersed (e.g., sports, social life). Participants with a “neutral” position towards e-shopping would shop in less spatially dispersed locations than those who are “willing” to e-shop. Two potential reasons are behind this finding. On the one hand, retirees are an important part of neutral e-shoppers preferring proximity retail. On the other hand, the activity diaries reveal that neutrals were more oriented to buy groceries in places close to home or workplace. However, people willing to e-shop tend to buy other product than groceries (e.g., music, household items, clothes) in shopping centres.

Participants consuming online leisure tend to take part in leisure activities that are more spatially dispersed ($S_{xy} = 2.340$ km) compared to those who do not ($S_{xy} = 1.700$ km). This might reflect strong presence on social networks (e.g., WhatsApp, Instagram, Facebook) by e-leisure consumers. They engage often on these platforms at numerous locations: at home, at work, while travelling, and while they conduct other activities (e.g., shopping). Individuals searching online monthly or more often have a smaller spatial dispersion than those who never search online. This could be because individuals searching online tend to buy online more frequently, resulting in fewer and closer shopping-leisure locations. For example, the activity diaries suggest that participants searching online “monthly” covered the smallest spatial extent ($S_{xy} = 0.840$ km), followed by “daily” e-searchers ($S_{xy} = 1.226$ km). Finally, the shopping-leisure locations for residents living in high density retail areas tend to be more spatially dispersed. It seems logical, since people could reach the same number of (or even more) in-store retail and leisure facilities in a smaller area.

6. Discussion

This section compares the obtained results with previous research. Overall, the findings of this paper for work-related activities are aligned with previous research, while they differ for shopping-leisure. Neverthel-
fragmentation found in both papers were higher than in the presented research. This discrepancy could be explained by three reasons, the first one being the limited extent of the study area. While Hubers and Alexander analysed spatial fragmentation in a large region in the Netherlands, this research focuses on a medium-size Spanish city located within the Madrid Metropolitan Area. Second, they used a two-day activity diary and a larger sample, allowing richer and more varied data regarding work fragmentation patterns. Third, the COVID-19 restrictions did not allow fully freedom of movement in Alcalá de Henares at the moment of data collection. Even though ICT use (e.g., internet access, e-activities) allows for action at distance, and some work tasks no longer needed to be conducted at working places (Shen et al., 2020), two issues must be highlighted. On the one hand, working activities conducted out-of-workplace (e.g., home, park, while shopping) are usually secondary tasks such as phone calls or email. Therefore, it can be said that “the physical office” is still a relevant and dominant place for workers. On the other hand, the capacity to unlink work activities from the workplace is heavily dependent on the professional profile, as evidenced how easy it was for university academic staff to work from different locations.

Regarding shopping-leisure activities, the results do not closely follow previous research. Both Lizana et al. (2021) and Hubers et al. (2008) suggest that the technological dimension has a positive relationship with leisure fragmentation. This may be due to the scope of these studies, which are heavily focused on leisure activities (e.g., social relationships and social life) rather than combining shopping and leisure activities. Additionally, cultural norms and COVID-19 impacts could also contribute to shaping the differences between the findings. For example, the COVID-19 pandemic has increased the need to restore face-to-face social relationships, which could ultimately result in smaller spatial fragmentation patterns. This is especially relevant for the elderly who are less skilled with online communication, and for whom social isolation can have severe adverse consequences such as loneliness or depression (Sayin Kasar and Karaman, 2021). Nonetheless, the present study corroborates that online leisure is a relevant tool to maintain larger social networks (Carrasco et al., 2008; Delbosc and Mokhtarian, 2018). For example, the results reveal that the study’s participants are very active on social networks such as WhatsApp, Instagram, and Facebook, which is in line with the documented substantial increase in use of social networks in the last years, especially during the pandemic (Kaya, 2020; Tsao et al., 2021).

7. Conclusions

ICT use (e-working, e-shopping, and e-leisure) has become a central part of today’s lifestyle. The COVID-19 pandemic accelerated this process, forcing people to perform most of their work and social daily activities online. Accordingly, the spatial patterns of certain activities are changing, with likely impacts on land use, transport, and the urban form. This paper sought to examine whether the spatial fragmentation of work and shopping-leisure activities were affected by personal ICT use, their socio-economic characteristics, and built environment variables. The obtained results reveal higher spatial fragmentation patterns for work activities among older participants, full-time employees, car owners, those with higher willingness to e-work, and those who e-work at least once a month. Lower spatial fragmentation is identified with part-time workers, those who work online daily, and residents living in high job density areas. In the case of shopping-leisure activities, car owners and those consuming online entertainment exhibit higher spatial fragmentation patterns. In contrast, lower spatial fragmentation patterns mainly related to weekly and daily in-store shoppers, people who are not very willing to e-shop, and those searching online monthly and more frequently.

Regardless of the size of the effect of ICT use on spatial fragmentation, a major finding is that the household has become a key activity hub after the first waves of the COVID-19 pandemic. According to Qin et al. (2021), this study would support the hypothesis that the promotion of the ICT use during the pandemic has transformed the traditional space of the home. This might have some policy implications from two sides: social dimension and land use and transport planning. From the social dimension, it is argued that depending on the household composition and the home’s characteristics, some problems related to life quality may arise (Cuerdo-Vilches et al., 2021). For example, the most vulnerable population groups (e.g., low-income, large families) may live together in small flats or feel financial pressure to acquire electronic devices for each family member. The positive effect is that e-working would make easier to juggle employment and domestic responsibilities, especially for women (Schwanen and de Jong, 2008). Accordingly, further gender-oriented research is needed to confirm whether the gender differences found by Hubers et al. (2018) persisted during the COVID-19 pandemic (or perhaps even changed). For land use and transport planning, the relevance acquired by homes might have two major consequences. First, spending higher time at home for working and leisure purposes could reduce travel demand by public transport and active modes (Miller, 2005; Jamal and Habib, 2020), while increasing private car use due to the most occasional profile of travels (Batty, 2020). For example, public transport time schedules must be revised as the commuting peak hours might change if a majority of people finally e-work. This can have a relevant impact on sprawl processes existing in most of European urban areas, extending the limits of metropolitan areas due to the lower needs for travelling. Furthermore, rural areas could also experience relevant transformation, receiving a higher number of people that would originate new needs for local mobility. Second, if home becomes a more relevant space as the ICT use is intensified, people could desire to move to bigger flats/houses in urban peripheries reinforcing the metropolitan processes previously mentioned. This could affect policies implemented during the last twenty years aimed to achieving more compact cities and avoiding sprawl dynamics. Additionally, because people do not have the need to move to conduct certain activities (e.g., working), they could use the time saved to access other destinations (e.g., gym). Gaining insights into where people allocate their gained time budget could be used by practitioners and policymakers (Dharmowijoyo et al., 2018).

Further research should address some limitations of the present study. First, the activity diaries should be conducted for a weekday and a weekend day. Routines during the week and the weekend are different, and it could provide with new findings on the ICT impact on spatial fragmentation (especially relevant for shopping-leisure activities). Second, this research uses cross-sectional data, while longitudinal data will be needed to progress towards establishing causality between the ICT use and the spatial fragmentation patterns. Third, questions related to quarantine and lockdown periods should be taken into consideration, as they could affect activity-related spatial patterns. This will allow to establish whether the ICT adoption, and the subsequent spatial fragmentation levels are a consequence of the measures taken to diminish the COVID-19 spread or because of participants had strong ICT habits before lockdown policies. Fourth, a larger and representative sample should be considered to achieve conclusive results of the effects of ICT on spatial fragmentation. Fifth, while this study did demonstrate that shopping is linked to leisure for some population groups (e.g., the elderly), a distinction between these two activities might be necessary in further studies. Since the elderly are the group less familiar with ICT, the results could be different. Sixth, a continuous monitoring of the evolution of ICT use and e-habits should be addressed when the pandemic ends. This will inform whether the COVID-19 is producing a permanent shift from face-to-face to online activities and the likely impacts on the urban environment and its transport systems. These issues are especially relevant in the context of big agglomerations, with growing ICT use triggering a potential rethink of their structure, for example, as smaller urban areas organized in medium-sprawled cities (Czamanski and Broitman, 2017).
Data Availability

The authors do not have permission to share data.

Acknowledgements

The authors would like to underline the effort made by Paloma Mateos Míguez, technical assistant working in the research project iCITIES (Ref. M190020074JASL), in which this paper has been partially developed. This paper has been developed in the context of the following projects:

- "The effects of the Information and Communications Technology on transport-related social exclusion for vulnerable population". H2020-MSCA-ICHRONOS grant agreement No. 101026011.
- "iCITIES: Efectos urbanos y sociales del uso de internet para compras y trabajo" Acción financiada por la Comunidad de Madrid en el marco del Convenio Plurianual con la Universidad Politécnica de Madrid. No. M190020074JASL.
- "VIR2ALL: Realidad Virtual para simular una nueva generación de escenarios futuros colaborativos que integren usos del suelo y transporte". Proyectos Generación de Conocimiento 2021. Agencia Estatal de Investigación. Ministerio de Ciencia e Innovación. No. PID2021-123954NB-C21.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.landusepol.2022.106302.

References

Alexander, B., Ettema, D., Dijst, M., 2010. Fragmentation of work activity as a multi-dimensional construct and its association with ICT, employment and sociodemographic characteristics. J. Transp. Geogr. 18 (1), 55-64. https://doi.org/10.1016/j.jtranggeo.2009.05.010.

Alexander, B., Hubers, C., Schwaben, T., Dijst, M., Ettema, D., 2011. Anywhere, anytime? Developing indicators to assess the spatial and temporal fragmentation of activities. Environ. Plan. B: Plan. Des. 38 (4), 678-705. https://doi.org/10.1068/b35312.

Ayuntamiento de Alcalá de Henares, 2019. Plan de Modernización e Innovación. https://innovacioncienetecnologia.ayto.dealcalahenares.es/.

Batty, M., 2020. The Coronavirus crisis: what will the post-pandemic city look like. Environ. Plan. B: Urban Anal. City Sci. 47 (4), 547-552. https://doi.org/10.1177/2399807820926192.

Ben-Elia, E., Alexander, B., Hubers, C., 2014. Activity fragmentation, ICT and travel: An exploratory path analysis of spatiotemporal interrelationships. Transp. Rev. A: Policy Pract. 46, 56-74. https://doi.org/10.1080/01333272.2014.903161.

Ben-Elia, E., Zhen, F., 2018. ICT, activity space and travel: An exploratory path analysis of spatiotemporal interrelationships. Transp. Rev. A: Policy Pract. 42 (1), 190-204. https://doi.org/10.1080/01333272.2016.1160344.

Lena, N., 2007. The changing allocation of activities in space and time by the use of ICT-"Fragmentation" as a new concept and empirical results. Transp. Res. Part A: Policy Pract. 41 (2), 193-209. https://doi.org/10.1016/j.tranpol.2006.03.004.

Lizana, M., Carrasco, J.A., Viciotorto, R., 2021. Daily activity-travel and fragmentation patterns in the weekly cycle: evidence of the role of ICT, time use, and personal networks. Transp. Lett. 00 (00), 1-11. https://doi.org/10.1007/s11768-021-0706z.

Lyons, G., 2009. The reshaping of activities and mobility through new technologies. J. Transp. Geogr. 17 (2), 81-82. https://doi.org/10.1016/j.jtranggeo.2008.12.001.

Mateos-Míguez, P., Arranz-López, A., Soria-Lara, J., Lanzendorf, M., 2021. E-shoppers and multimodal accessibility to in-store retail: An analysis of spatial and social implications. J. Transp. Geogr. 96, 101098 https://doi.org/10.1016/j.jtranggeo.2021.101398.

Miller, H.J., 2005. Necessary space - Time conditions for human interaction. Environ. Plan. B: Plan. Des. 32 (3), 381–401. https://doi.org/10.1068/b31154.

Mouratidis, K., Papagiannakis, A., 2021. COVID-19, internet, and mobility: The rise of telework, telehealth, e-learning, and e-shopping. Sustain. Cities Soc. 53, 101939 https://doi.org/10.1016/j.scs.2019.101939.

Otteiza, I., March, S., 2021. Adequacy of accessibility and mobility during the COVID-19 pandemic. Technol. Soc. 63, 101380 https://doi.org/10.1016/j.techsoc.2020.101380.

Pagani, A., 2009. The effects of the Information and Communications Technology on the spatial evolution of mature cities. Socio-Econ. Plan. Sci. 58, 20-27. https://doi.org/10.1016/j.seps.2009.10.003.