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AN END-USER EVALUATION TO ANALYZE THE EFFECTIVENESS OF CARTOGRAMS FOR MAPPING RELATIVE NON-MOTORIZED ACCESSIBILITY

Aldo Arranz-López [a,*], Julio A. Soria-Lara[b], Amor Ariza-Álvarez[b]

[a] *Institute für Humangeographie, Goethe University, Germany*
[b] *Transport Research Centre, TRANSyT, Universidad Politécnica de Madrid, Spain*

Abstract

Relative accessibility provides one approach that recognises the access to major locations as subjective and affected by individual circumstances (e.g. individual preferences, habits, and cultural norms). One missing element has been how relative accessibility can be effectively mapped for decision-making. By using the city of Zaragoza in Spain, this paper evaluates whether cartograms can be an appropriate tool for mapping relative accessibility (or not) and why. First, relative accessibility to retail in Zaragoza is calculated and compared for a total of four socio-economic groups of population (young employed, young unemployed, seniors, and adults). Second, the obtained accessibility results are mapped by using three different techniques: grid-based maps, diffusion-based cartograms, and Dorling-based cartograms. Third, an end-user evaluation, engaging a total of 30 local practitioners, was conducted analysing the effectiveness of cartograms to map relative accessibility in comparison with grid-based maps. Participants signaled that diffusion-based cartograms could become a complement for grid-based maps, providing a better visualization of spatial dissimilarity patterns of accessibility between population groups. However, participants noticed higher difficulties in identifying Dorling-based cartograms as an appropriate and complementary technique for mapping relative accessibility. The strengths and weaknesses of these visualization techniques for the field of accessibility planning are finally discussed.

Keywords: Practitioners; Walking; Cycling; Active modes; Cartography

* *Corresponding author. E-mail address:* arranz-lopez@geo.uni-frankfurt.de

1. Introduction

1.1. The visualization of relative non-motorized accessibility: Challenges and prospects

These are challenging times in which cities must confront the difficulties of rapidly increasing urbanization and growing mobility needs (Bertolini, 2017). To address that, practitioners and decision-makers enjoy the advantage of the digitalization age, when computer graphics, large geospatial databases, data science tools, and visualization techniques are in their ascendant (Chen et al., 2016; Robinson et al., 2017; Romanillos et al., 2015). Under this context, it seems more relevant than ever the design of (new) maps that support decision-making, presenting planning outcomes in a format easily accessible from the practitioners' and decision-makers' cognitive skills (Griffin, 2017). This reinforces the argument to move from the dominating product-oriented cartography to a more user-oriented approach (Bandrova et al., 2014; Soria-Lara et al., 2016), making maps that generate a strong interface of reciprocal learning processes between the researcher, the city planner, and the decision-maker (Arciniegas et al., 2013). A case in point is the need for effective maps that support the development of policies that enhance non-motorized accessibility to major activities (e.g., health care facilities, grocery shops) (Wang et al., 2019), capturing such non-motorized accessibility as a relative concept highly dependent on individual preferences, habits, and cultural norms (Kelobonye et al., 2019; Páez, Mercado, et al., 2010).

Relative non-motorized accessibility is here defined as "the proportion of opportunities available on foot and/or bicycle to an individual with defined characteristics at a selected location, relative to an individual from a reference group at the same location" (Páez et al., 2010, p.3). This concept is based on the idea that people´s willingness to travel and choice of mode is affected by contingencies such as personal characteristics, the physical environment, budget constraints, and cultural norms (Arranz-López, Soria-Lara, Witlox, et al., 2019). For this reason, variations in relative accessibility between socio-economic groups can result in social and spatial inequalities, being particularly relevant when considering non-motorized accessibility as universal transport mode (Delbosc and Currie, 2011; Pereira et al., 2016; Ricciardi et al., 2015). Some reasons can underline the interest of practitioners and decision-makers in mapping relative non-motorized accessibility. First, it would facilitate the identification of urban areas where certain population groups are disadvantaged to participate in the social, political, and economic life of the community by limitations in non-motorized accessibility (Arranz-López, Soria-Lara, and Pueyo-Campos, 2019; Lucas et al., 2016). Second, since maps can be shown in a format easily understandable for the widest variety of planning actors, common language codes between professional domains can be created invoking interaction and deliberation processes to address those social inequalities linked to non-motorized accessibility (Billger et al., 2017; te Brömmelstroet and Bertolini, 2008; Innes and Booher, 2018). Third, the public could also be easily engaged in decision-making by using friendly maps, providing additional insights into the perception of non-

motorized accessibility to major destinations and its individual effects (Reyes Nuñez, 2014; Stewart, 2017).

Despite there is a growing interest in improving visualization techniques for accessibility planning (Coppola and Silvestri, 2018; Silva et al., 2017), the design and use of effective maps for relative non-motorized accessibility are lagging behind. It seems unclear that traditional methods for mapping accessibility (e.g., choropleth and grid-based maps) are the most suitable approach to highlight spatial dissimilarities of non-motorized accessibility to major destinations for different socio-economic groups. The main hindrance is that traditional cartographic visualization techniques usually try to maximize the representation of general accessibility patterns, assuming standard accessibility levels for all groups of population (Lovett et al., 2014; Owen et al., 2010). For example, choropleth maps are commonly used to map non-motorized accessibility, taking both administrative boundaries (e.g. neighbourhoods) and catchment areas as base map (Ford et al., 2015; Kompil et al., 2019; Mayne et al., 2013; Zhao et al., 2003). In both cases, the visualization of certain advantaged sub-groups of population in terms of non-motorized accessibility can be missed, because of they cannot be dominant socio-economic groups in the context of such administrative and catchment areas. Furthermore, higher attention to larger areas -but not necessarily with better relative accessibility values- can prevail (Lovett et al., 2014). To overcome those limitations, grid-based maps have been adopted by some authors (Mayaud et al., 2019; Páez et al., 2012; Papa and Bertolini, 2015; Pereira, 2018). However, an overrepresentation of general accessibility patterns still remains (Schuurman et al., 2010; Welch and Mishra, 2013), since grid-based maps have visual difficulties to emphasize the spatial dissimilarities of accessibility levels between socio-economic groups, which are in many cases associated with spatial outliers of the general accessibility pattern common for everyone (Iacono et al., 2008; Páez, Gertes Mercado, et al., 2010). Based on those relevant issues, the use of cartograms is here explored as part of the solution.

1.2. Can cartograms be an effective instrument for mapping relative non-motorized accessibility?

Cartograms are a type of maps in which the geographic space is distorted based on quantitative information (Dorling et al., 2006; McNeill and Hale, 2017). They have been widely used since the 19th century (Tobler, 2004) for mapping several topics mainly related to human and social geography (e.g. society, demography, political, and health issues) (Dorling, 1995; Nusrat and Kobourov, 2016). Despite a wide range of algorithms to build cartograms can be used, in this research we focus on two of the most conventional: *diffusion-based and Dorling-based* (Figure 1). On the one hand, *diffusion-based cartograms* were originally proposed by Gastner and Newman (2004). It consists of projecting the original input onto a distorted grid following an iterative diffusion process. The main advantage is this method allows for minimal cartographic error, maintaining shapes relatively recognizable (Li and

Clarke, 2012; Nusrat and Kobourov, 2016). That is relevant for mapping accessibility, as locations with major destinations can be easily identified. A relevant example using diffusion-based cartograms is the project WORLDMAPPER (Dorling et al., 2006). On the other hand, *Dorling-based cartograms* were created by Danny Dorling (Dorling, 1995; Nusrat and Kobourov, 2016). In this case, feature classes are represented by circles, which have been demonstrated as more effective than other shapes (e.g., rectangular cartograms) (Stachoň et al., 2018). The larger the circle, the higher the data value represented. This characteristic can be useful for developing cartograms at local contexts where accessibility differences are expected to be reduced. A relevant example using Dorling-based cartograms is the social atlas of Britain in the 90s (Dorling, 1995).

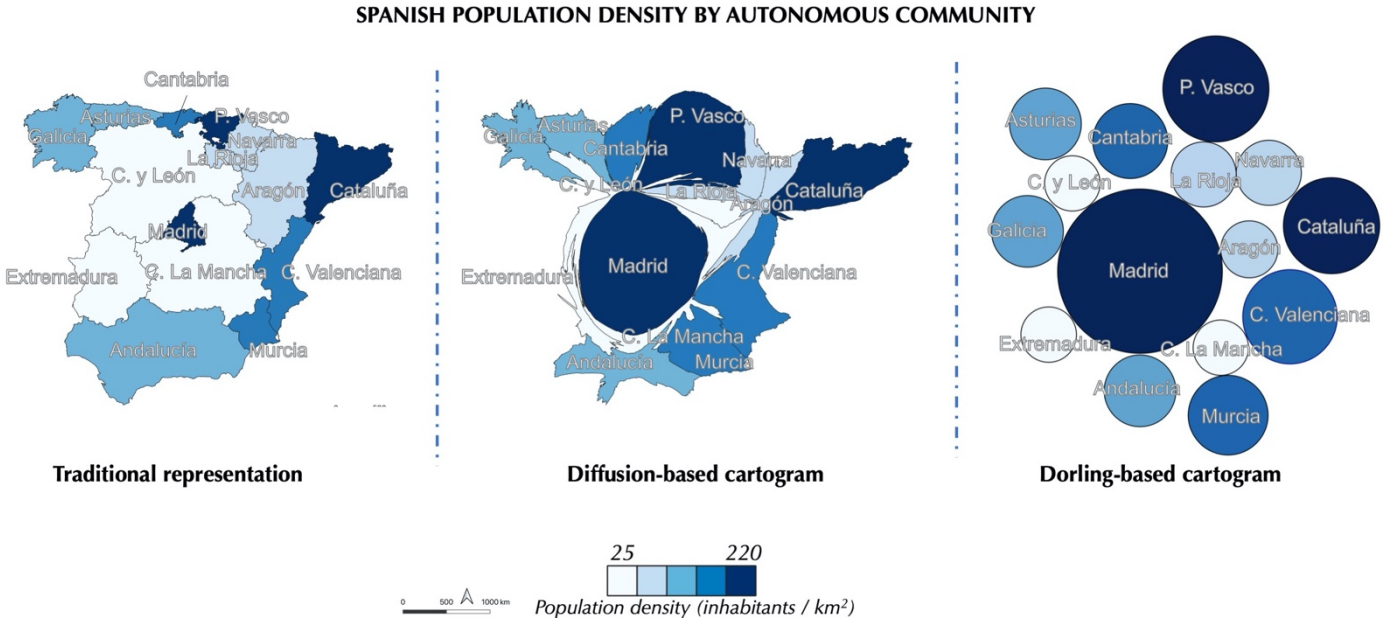

Figure 1. Conceptual representation of diffusion-based (on the left) and Dorling-based cartograms (on the right)

There are several reasons to believe that cartograms can be an effective instrument for mapping relative non-motorized accessibility, although their use in accessibility analyses is almost unexplored (Condeço-Melhorado et al., 2014). First, both diffusion and Dorling-based cartograms combine statistical and geographical information, which provides a more friendly and easier visualization of spatial trends and outliers (Gusein-Zade and Tikunov, 1993; Nusrat and Kobourov, 2016). That is particularly relevant for mapping relative non-motorized accessibility, as most of differences in accessibility levels between population groups are frequently associated with spatial outliers to the general pattern. Second, the comparison of traditional accessibility maps with cartograms can provide practitioners and decision-makers with additional insights into how relative accessibility patterns operate in a given place (Keim et al., 2004). Furthermore, that comparison of traditional maps and cartograms can more easily trigger interaction and deliberative processes between planning actors, as the visual perception of people is more sensitive to the area size variations than merely colour variations (Li and Clarke, 2012). Finally, unlike grid-based maps, cartograms allow to colour

deformed regions by accessibility levels displaying a second possible variable (McNeill and Hale, 2017). That is also a relevant issue, since showing population data as a second variable would help to merge vulnerable population groups and accessibility levels in one single visualization.

Together with the low use of cartograms in the field of accessibility, another relevant research gap remains. That is based on the lack of studies evaluating the usability of cartograms for planning practice with intended users (Biedl and Ruiz Velázquez, 2014; Evans et al., 2018; Van Kreveld and Speckmann, 2007; Langton and Solymosi, 2019; McNeill and Hale, 2017). An example of this type of research comes from Han et al. (2017), who distributed an online questionnaire to the general public, aimed to judge the usability of cartograms for representing land use data at world level. Subjects had to compare proportional symbol maps and cartograms for evaluating their effectiveness, efficiency, and satisfaction. The authors found that the thematic maps were seen as most suitable than cartograms to map quantitative data. Another example is the work co-authored by Ullah et al. (2016), carrying out a laboratory test with the general public. They analysed the usability of centred-time cartograms to answer spatiotemporal questions related to the Dutch railway network. In this case, participants had a better perception of cartograms when geographical references as railroads were included in the cartography. Similarly, Sun and Li (2012) disseminated an online survey among the general public in which individuals involved in the experiment compared traditional maps (choropleth and proportional symbols) and cartograms, as well as different types cartograms with each other. They found that Dorling-based cartograms were the least effective, followed by diffusion-based cartograms. Finally, Nusrat et al. (2018) evaluated the effectiveness of cartograms by recruiting students in selected classes at the University of Arizona. They found that all types of cartograms performed well excepted the rectangular cartograms.

Based on these important issues, this paper aims to evaluate the effectiveness of cartograms for mapping relative non-motorized accessibility to retail according to the view of practitioners. The context of Zaragoza, Spain provides the empirical focus. Local authorities in Zaragoza are promoting several plans and initiatives orientated towards improving non-motorized accessibility to major locations, and specifically to in-store retail. For this reason, the research application focuses on non-motorized accessibility to retail destinations rather than other major locations. A 3-stage methodological process was implemented, including an end-user evaluation to compare grid-based maps and cartograms that show values of relative non-motorized accessibility to retail for four groups of population (young employed, young unemployed, seniors, adults). Semi-structured interviews (including rated statements) were used, engaging a total of 30 local practitioners. The end-user evaluation covered four main blocks on: cartographic design, readability, suitability, and usability.

The remainder of the paper is structured as follows. Section 2 describes the case study. Section 3 presents the research design, while Section 4 details the main results obtained. Finally, Section 5 provides concluding remarks and points to future research issues.

2. Case study: the city of Zaragoza, Spain

Local institutions in Zaragoza (north-eastern Spain) (Figure 2), are currently addressing relevant challenges for land use and transport integration at the city level. Those challenges are fundamentally orientated towards achieving a more sustainable and socially inclusive city. Non-motorized accessibility to in-store retail is a relevant case in point. Local government has promoted several plans to improve non-motorized accessibility to basic need services for the population, including retail. This effort tried to stop the development of shopping centres in suburban areas over the last decades – fundamentally car-oriented projects that significantly threaten traditional retail activity in the city's old neighbourhoods.

Furthermore, the local government is actively working on a new Sustainable Urban Mobility Plan to address the abovementioned issues among others. Some actions in progress include urban renewal of the historic centre, pedestrianisation of streets with high retail density, implementation of a Light Rail Transit system to connect suburban areas to city centre, and the expansion of the bicycle lane network. Guided by the stated goal to promote non-motorized journeys to retail, local institutions are making large investments to revitalise small and disseminated retail (mainly food markets) in the heart of traditional neighbourhoods. This is also supported by specific marketing events, such as street markets, advertising campaigns, urban regeneration of neighbourhoods, etc. In this context, the process of mapping and emphasising visually relative non-motorized accessibility to retail can make a significant contribution to developing a more customised and efficient policy-making process.

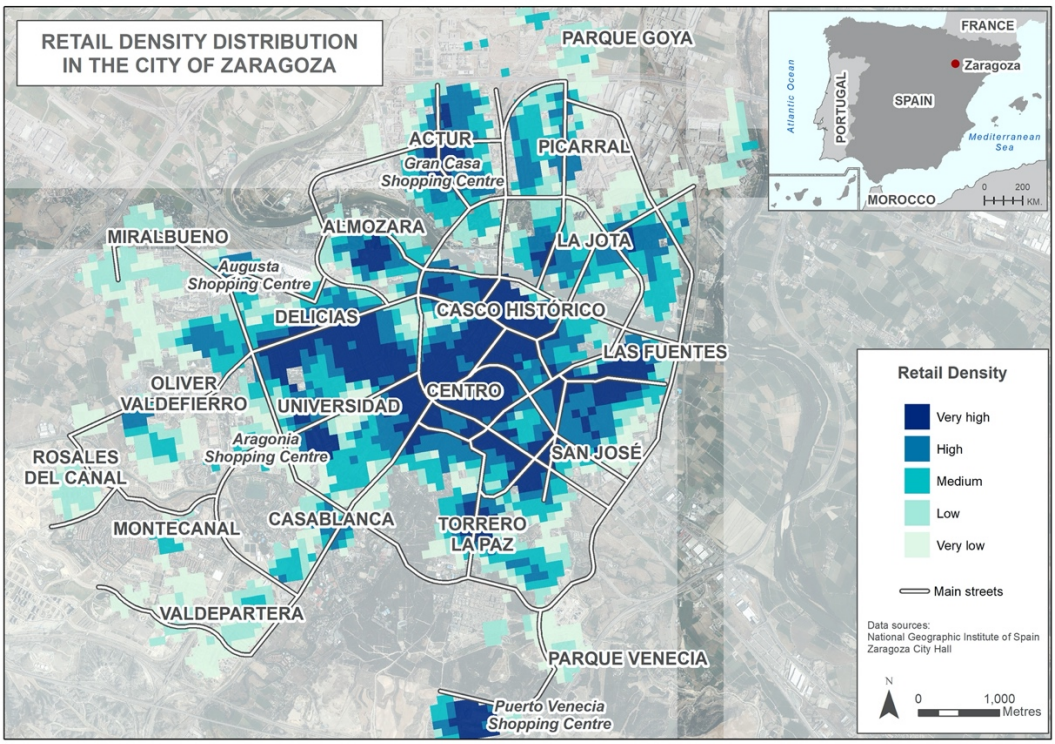

Figure 2. Neighbourhood distribution in Zaragoza (Spain), including retail density

3. Research design

To evaluate the effectiveness of cartograms for mapping relative non-motorized accessibility to retail, three sequential phases were followed: (i) Elaboration of grid-based maps on relative non-motorized accessibility to retail; (ii) Elaboration of relative non-motorised accessibility cartograms; (iii) End-user evaluation. The remainder of this section will provide in-depth details on each methodological phase.

3.1. Phase 1: Elaboration of grid-based maps on relative non-motorized accessibility

An individual questionnaire, totaling 530 responses was the main data source for this study (Arranz-López et al., 2017; Arranz-López, Soria-Lara, and Pueyo-Campos, 2019). Such questionnaire collected information on both socio-economic characteristics of respondents and their willingness to reach in-store retail by walking and cycling. The questionnaire information was firstly used to identify homogeneous socio-economic groups of population through clustering techniques. A K-modes algorithm was specifically chosen due to the categorical characteristics of the collected data on socio-economic attributes (Chaturvedi et al., 2001). Four socio-economic groups of population were identified: (i) Young employed (Cluster #1) are between 19 and 44 years old and have jobs and access to a car; (ii) Young unemployed (Cluster #2) are between 19 and 44 years old, unemployed, and have access to a car and a bicycle; (iii) Seniors (Cluster #3) focused on elderly people (>65 years old), most of

whom were retired and had access to a car; (iv) Adults (Cluster #4), consisted of adults between 45 and 64 years old, who were employed. This last group tended to see walking and cycling as healthy options.

A gravity-based model was used to calculate relative non-motorized accessibility to retail for the four socio-economic groups of population. Then, a square grid-based map (cell of 100x100m) was obtained for each group.

3.2. Phase 2: Elaboration of relative non-motorised accessibility cartograms

Two types of cartograms were elaborated to show values of non-motorised accessibility for the four groups of population previously mentioned: diffusion-based and Dorling-based. The accessibility grid-based maps obtained in Section 3.1 served as input to draw those cartograms.

The elaboration of diffusion-based cartograms was based on the algorithm developed by Gastner and Newman (2004), which transforms areas by dividing each value by its original area to get its density, thereby computing an overall average density for the whole map. It is one of the most popular cartogram applications, since it generates cartograms with nearly zero area error and maintaining recognisable region shapes (Nusrat and Kobourov, 2016). In this case, the geographical deformation was based on accessibility values for each socio-economic group, while a colour legend was used to show the density of population in the city for each socio-economic group. Supplemental layers such as the main streets and the aerial image were also deformed by the same algorithm, in order to match all elements of the map. An external toolbox[1], compatible with ArcMap 10.5, was used to draw diffusion-based cartograms.

The second type of cartograms used were Dorling-based (also known as circular cartograms), which draws circles as the simplest of all shapes for the main variable to represent. The algorithm developed by Dorling (2011) calculates the radius of the circles proportionally to its accessibility for each socio-economic group. By using the software GeoDa 1.12.1, we ran 10,000 iterations in order to avoid overlapping circles. The centroid of each cell, which contained accessibility values, served as the input to calculate the radius of the circle, while population densities for each socio-economic group was represented by the colour legend. Due to Dorling cartograms are non- continuous cartograms, supplemental layers such as the main streets and the aerial image (continuous spatial information) were not included in the final maps.

[1] The external toolbox was developed by CarolAP. It was downloaded from https://www.arcgis.com/home/item.html?id=d348614c97264ae19b0311019a5f2276

3.3 Phase 3: End-user evaluation

The evaluation of the cartograms' effectiveness was based on an end-user study that engaged local practitioners. Specifically, a set of 30 semi-structured interviews (including rated statements based on 5-points Likert scale) were carried out to local practitioners from private companies in the transport sector. The obtained responses, based on their experience and reflections, served as input to explore strengths and weaknesses between cartograms (diffusion-based and Dorling-based) and grid-based maps to show variations of non-motorized accessibility to retail for four socio-economic groups of population.

Before starting the round of semi-structured interviews with local practitioners, the research team provided them with rules and instructions to ensure the correct development of the end-user evaluation, as well as to avoid that the included questions were interpreted subjectively. First, the set of rules and instructions included a definition of relative non-motorised accessibility, underlining that its distinctiveness relies on those spatial dissimilarities of different socio-economic groups to access to major destinations by non-motorised modes (walking and cycling). Second, local practitioners were informed about the types of cartograms included in the study, their characteristics and their process of design. Special emphasis was paid to explain that the values of relative non-motorised accessibility had been represented in different ways for grid-based maps and for cartograms. In the case of grid-based maps, practitioners were informed that the values of relative non-motorised accessibility had been represented as a single variable with a colour scale. For cartograms, practitioners were reported that the values of relative non-motorised accessibility corresponded to the size of deformed areas (circles in the case of Dorling-based cartograms), while the colour scale had been used to show the population density of each socio-economic groups of population (Section 3.2). In order to facilitate the distinction between accessibility values and population density, the colour scale used in grid-based maps and cartograms varied.

The rules and instructions also provided local practitioners with specific information about the two parts of the questionnaire. The first part included questions related to general information about the participants, such as level of experience in the field of transport, frequency in mapping accessibility issues, and previous experience using cartograms. The second part of the questionnaire focused on comparing the effectiveness of grid-based maps, diffusion-based cartograms, and Dorling-based cartograms by discussing and rating their (i) design; (ii) readability, (iii) suitability, and (iv) usability. Rated statements based on 5 points Likert-scale were used during the evaluation of the abovementioned aspects, as well as open questions where participants could freely show their viewpoints. To avoid a subjective interpretation of the four mentioned cartographic aspects (design, readability, suitability, and usability), a specific definition of each aspect was provided by the interviewer (Table 1). That included clarifications on rated statements when necessary (Table 1). It is important to

highlighting that the questionnaire was not designed to directly compare grid-based maps, diffusion-based, and Dorling-based cartograms in every single question, but rather the cartographic aspects above-mentioned were independently rated for each of the three visualisation techniques used in this end-user experiment.

Table 1. Description of cartographic issues and interview content included in the end-user evaluation

Issue	**Interview content** *(instructions for local practitioners)*	**Rated statement**
Design	Despite the design of maps can become a matter of taste regarding a wide variety of aspects (e.g., text, colour), responses on design appropriateness should be based on two main issues. First, practitioners were asked to consider whether the used additional layers (aerial image and roads layer) and text facilitated (or not) the understanding of the spatial context in which accessibility values had been calculated. Second, practitioners were asked to discuss if the colour palette allowed them to distinguish individual categories represented in the legend (or not)	The design of grid-based maps / diffusion-based cartograms / Dorling-based cartograms is appropriate for showing relative non-motorised accessibility to in-store retail* Strongly disagree: 1 2 3 4 5: Strongly agree
Readability	Practitioners were asked to discuss the appropriateness of each visualization technique to correctly show both the highest and lowest values of accessibility for each group of population, including the capacity of each visualization technique to show a clear transition from the highest accessibility values to the lowest ones. Aspects related to the practitioners´ capacity to interpret map layouts that include two variables (e.g. cartograms) are also covered.	The readability of grid-based maps / diffusion-based cartograms / Dorling-based cartograms is appropriate for showing the highest and lowest non-motorized accessibility values for each socio-economic group of population* Strongly disagree: 1 2 3 4 5: Strongly agree
Suitability	Practitioners were asked to comment the suitability of each visualization technique to show spatial dissimilarity patterns between the non-motorised accessibility levels for the four socio-economic groups of population.	Grid-based maps / diffusion-based cartograms / Dorling-based cartograms are considered suitable for showing spatial dissimilarity patterns between the non-motorised accessibility levels of the four socio-economic groups of population* Strongly disagree: 1 2 3 4 5: Strongly agree
Usability	Practitioners were asked to discuss to which extent each visualization technique was usable in their daily transport planning practice and why.	Grid-based maps / diffusion-based cartograms / Dorling-based cartograms are considered usable in your daily transport planning practice* Strongly disagree: 1 2 3 4 5: Strongly agree

**Three rated statements with similar structure were conducted, one per visualization technique.*

4 Results

4.1 Mapping relative non-motorised accessibility to retail

Grid-based maps (Figure 3), diffusion-based cartograms (Figure 4), and Dorling-based cartograms (Figure 5) show the results on relative non-motorised accessibility between the four population groups identified (section 3.2): *the young employed* (C#1), *the young unemployed* (C#2), *seniors* (C#3), and *adults* (C#4).

Grid-based maps (Figure 3) show non-motorised accessibility to retail as a unique variable. For the group of *the young employed*, the highest accessibility values can be seen in the consolidated city (e.g. Delicias, Las Fuentes, Casco Histórico), while the lowest accessibility values are identified in the neighbourhoods located in the city outskirts (e.g. Montecanal, Rosales de Canal, Parque Goya). On the other hand, the groups of *young unemployed, seniors, and adults* present similar accessibility patterns, showing the highest accessibility values in the oldest and consolidated neighbourhoods (Universidad, Actur, Centro) and the lowest values in the newest urban developments (e.g. Valdespartera, Parque Venecia, Miralbueno). Nevertheless, some accessibility differences within neighbourhoods must be also highlighted. For example, in the transition area between Centro and Delicias, the group of *seniors* show higher accessibility values than *young unemployed* and *adults*. The opposite can be found in Almozara, where the group of *young unemployed* and *adults* present higher accessibility values than *seniors*.

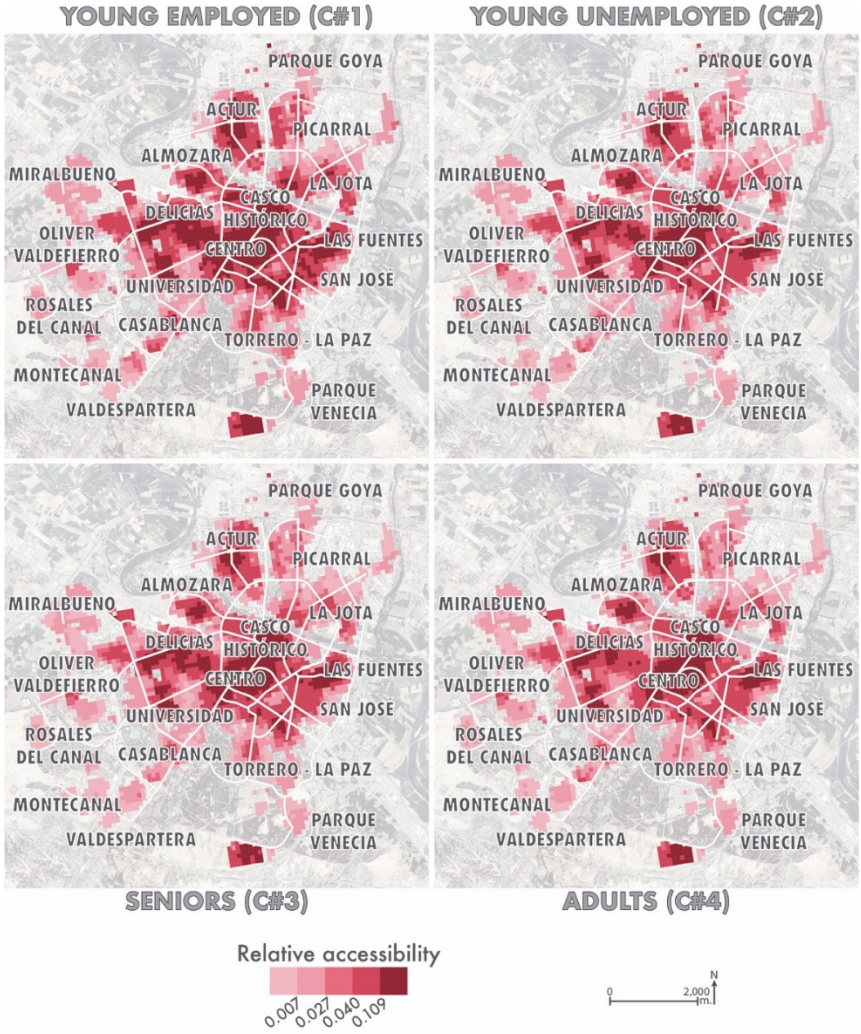

Figure 3. Relative non-motorised accessibility represented through grid-based maps

Regarding Diffusion-based (Figure 4) and Dorling-based cartograms (Figure 5), accessibility values were used to distort the original grid and the colour legend shows the existing population density for each population cluster. The incorporation of this second visual variable contributed to a more in-depth analysis of the potential impacts of accessibility on each population group.

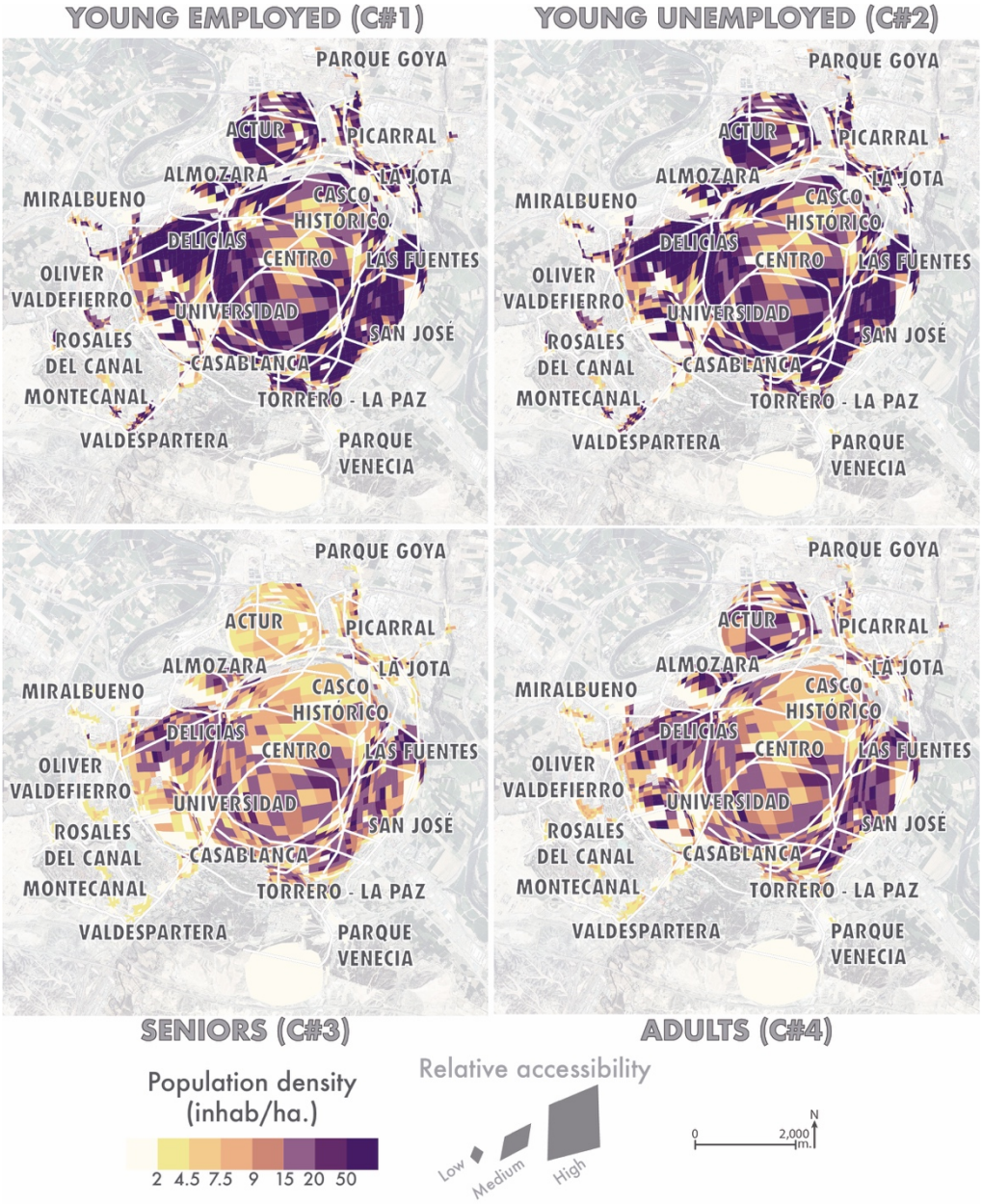

Figure 4. Relative non-motorised accessibility represented through diffusion-based cartograms

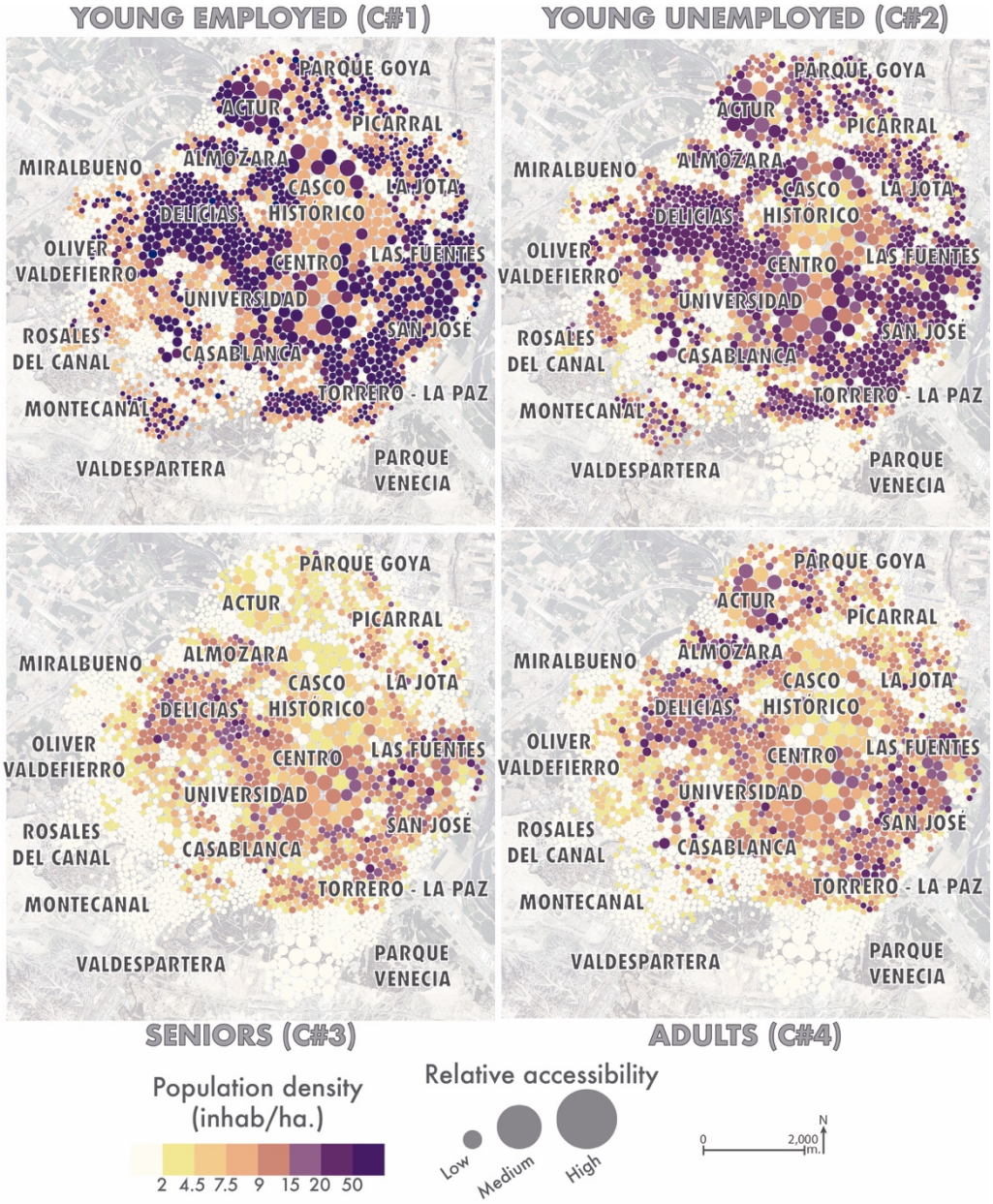

Figure 5. Relative non-motorised accessibility represented through Dorling-based cartograms

Both cartograms show how the group of *young employed* and *the young unemployed* mostly lived in traditional neighbourhoods (e.g. Delicias, San José, Las Fuentes, Actur) with medium and high non-motorised accessibility values. On the other hand, new neighbourhoods (e.g. Valdespartera, Rosales del Canal, Oliver-Valdefierro) showed high population densities for both t*he young employed* and *the young unemployed*, but low non-motorised accessibility values being forced to use motorised transport to reach retail locations.

The high population densities for the groups made up of *seniors* and *adults* were found in the consolidated neighbourhoods (e.g. Torrero-La Paz, Las Fuentes, San José). For those locations, accessibility levels were medium and high, excepting Torrero-La Paz where small and traditional stores have disappeared in favour of medium-size stores over the last decade. This issue is especially relevant for the group of *seniors,* since they have limited access walking long distances to cover their daily needs.

It is worthy to noting that diffusion-based cartograms initially seemed more suitable to visualise accessibility values, while Dorling-based cartograms seemed to be more suitable for identifying population density values that complement the information brought by accessibility levels. That became even more evident in areas with low accessibility values (e.g. Picarral, Miralbueno, Valdespartera).

4.2 Results of the end-user evaluation

A total of 30 participants completed the interview. A percentage of 80% of respondents declared to have more than five years of experience in the field, 20% of practitioners signalled that they had never mapped accessibility issues in their respective jobs, and 60% declared to have low or null experience in using cartograms in their daily work.

Regarding *cartographic design*, a total of 55% of participants agreed that the design of the grid-based maps was appropriate to show relative non-motorised accessibility. However, only 9% of practitioners considered that Dorling-based cartograms had an appropriate *cartographic design*. This percentage increases up to 18% of practitioners when asked about diffusion-based cartograms (Figure 6a). The use of additional layers (e.g. roads and streets) seems one of the most relevant reasons to explain the higher percentage of practitioners recognising as appropriate the design of diffusion-based cartograms in comparison with Dorling-based cartograms. In this respect, practitioners frequently indicated during open questions that "*the design of Dorling-based cartograms would strongly improve if the main roads and streets layers would have been included in the final layout. On the contrary, the spatial context is not well-described, originating misinterpretations regarding city locations and accessibility values*". However, the technical difficulties to include additional spatial layers are inherent to Dorling-based cartograms, as such cartographic outputs (mainly circles with the distorted variable) are not spatially continuous (Section 3.2). During the interviews, special attention was also paid to the use of text to describe the spatial context where accessibility values had been calculated. A total of 23/30 practitioners signalled that "*the text included in cartograms was key for a better identification of city locations against the spatial distortion originated by cartograms*". Regarding the effect of pallet colour on cartographic design, most of practitioners considered the colours used appropriate. However, they showed some difficulties to distinguish certain intervals of population density in both types of cartograms. Some practitioners signalled during the open questions that "*they would have opted for less population density intervals, making easier their visualization*".

The *readability* of grid-based maps and cartograms is the second cartographic aspect to be approached (Figure 6b). A total of 62.5% of participants agreed that the readability of grid-based maps was appropriate to distinguish places with the highest and lowest values of non-motorised accessibility for each population cluster. This percentage decreased to 31.25% in the case of diffusion-based cartograms and to 13.3% for Dorling-based cartograms. Nevertheless, it is worth to mentioning that a majority of practitioners (60%) commented that

diffusion-based cartograms were particularly appropriate to identify spatial transitions from the highest to lowest values of non-motorised accessibility. The difficulty to read two variables simultaneously (accessibility and population density) in cartograms was another topic discussed during the interviews. A relevant group of respondents (56.66%) unanimously signalled that both types of cartograms would become more readable "*if cartograms only showed one variable rather than two"*. Despite the interviewer systematically argued that showing two variables in the same cartographic layout (accessibility and population density) can provide practitioners with additional information in comparison with grid-based maps, respondents continued underlying that "*they usually mapped accessibility as a single variable in daily practice, which facilitated the understanding of maps specially during interactions with non-expert people"*. However, the representation of accessibility values by using one single variable notably limits the capacity to get a right visualization of accessibility variations between population groups, revealing the predominant approach to consider accessibility as an absolute concept -rather than relative- affecting equally to the full spectrum of population.

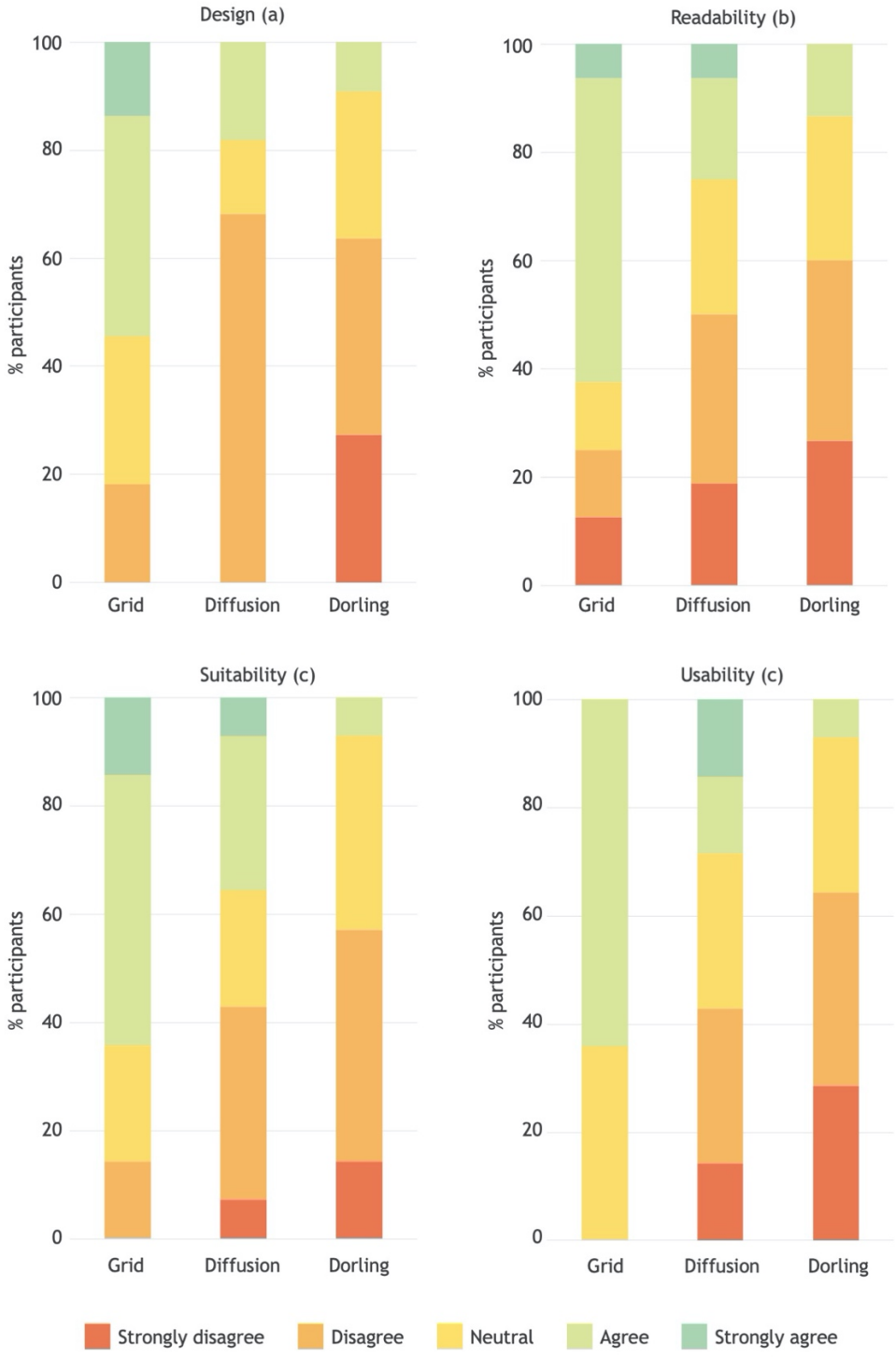

Figure 6. Cartographic aspects included in the end-user evaluation

Regarding the *suitability* of grid-based maps and cartograms to show spatial dissimilarity patterns of relative non-motorised accessibility between population groups, a total of 64% of participants agreed that grid-based maps were suitable. However, diffusion-based cartograms were recognised as suitable by 35.71% of participants, while only a 7,14% of practitioners perceived Dorling-based as suitable (Figure 6c). In sum, practitioners recognised Dorling-based cartograms as less suitable than the other two visualization techniques. As

discussed with practitioners during the interviews, "*the problem can be related to the circles used to distort the accessibility levels*, *since this circular shape would limit the capacity to detect spatial dissimilarities when such spatial dissimilarities are not strongly present"*. However, this spatial distinction seemed easier to achieve by using diffusion-based cartograms even when those spatial dissimilarities patterns are softly present (as spatial outliers) in a given context. A majority of practitioners declared that "t*he most effective way to visually identify spatial dissimilarity patterns of non-relative accessibility was based on combining grid-based maps and diffusion-based cartograms*". The capacity of practitioners to distinguish such spatial dissimilarity patterns is key, as the distinctiveness of relative accessibility mostly relies on such different spatial patterns of accessibility for different socio-economic groups of population.

The last part of the interview focused on how *usable* was grid-based maps and cartograms for daily practice (Figure 6d). A total of 64.28% of practitioners agreed that grid-based maps were a usable visualization technique to represent relative non-motorised accessibility in their daily work. The percentage of practitioners agreed with the usability of diffusion-based cartograms was 30%, and this percentage decreased to 20% for Dorling-based cartograms. During the interview, a relevant number of respondents (30%) declared that "*it is difficult to change a strong-established tradition in visualization techniques, as a transition to other techniques would require additional training for employees among others*". It was also mentioned by a total of 18% of practitioners that "*consultancy offers are frequently constrained to conducting specific spatial analysis according to the call for tender, which usually limits the capacity to add new visualization techniques".* Furthermore, another reasons brought by practitioners to contest the possible usability of cartograms to map relative non-motorised accessibility is related to "the need for using *new software"*, even when free software options are available for that (e.g. Geoda).

5 Conclusions and discussion

This paper aimed to gain insights into the effectiveness of cartograms for visualising relative non-motorised accessibility to retail. The city of Zaragoza in Spain, where there is a clear desire to foster non-motorised transport modes to reach in-store retail, served as case study. Together with four grid-based maps for four socio-economic groups of population (young workers, young non-workers, seniors, and adults), two types of cartograms were developed to map values of non-motorised accessibility to retail for each population group: (i) diffusion-based and (ii) Dorling-Based. Then, and end-user evaluation was conducted for assessing the effectiveness of cartograms regarding their design, readability, suitability, and usability. A comparison with the effectiveness of grid-based maps is also made. A total of 30 local practitioners were engaged in this end-user experiment.

In general, grid-based maps were perceived by practitioners as the most effective technique for mapping relative non-motorized accessibility in terms of design, readability, suitability,

and usability. However, diffusion-based cartograms were recognised as a suitable complement to grid-based maps for visually detecting spatial dissimilarity patterns associated with values of accessibility for each group of population. Furthermore, such diffusion-based cartograms were also proved particularly useful to detect spatial transitions between the highest and the lowest accessibility values of each population group used in this research. On the contrary and specially affected by the limitations to incorporate additional layers (e.g. road and aerial images) to the final layout, Dorling-based cartograms were perceived as the less effective visualization technique to map relative non-motorised accessibility.

The perception of a higher effectiveness of grid-based maps to visualise relative accessibility issues in comparison with cartograms is aligned to previous studies in literature. For example, Han et al. (2017) run an experiment to evaluate the usability of cartograms to represent global land use data. They found that traditional maps were preferred by users in comparison with cartograms. Cartograms used to be scored lower than traditional grid-based maps for the different items evaluated, being also the scores of diffusion-based cartograms higher than Dorling-based cartograms. The study co-authored by Li and Clarke (2012) used diffusion-based cartograms to show the distribution of population and wealth in China. Their results also concluded that diffusion-based cartograms seemed to be most suitable than other type of cartograms for making both quantitative and qualitative comparisons. Finally, Nusrat et al. (2018) analysed the effectiveness of cartograms to map a set of variables (e.g., GDP, population, country boundaries). However, contrary to the findings of previous research, they found Dorling-based cartograms as an effective visual representation technique of spatial data. In sum, previous studies showed how the effectiveness of cartograms to substitute or complement the traditional grid-based maps varies, depending on the topic and the type of experiment.

The reminder of this section will discuss some reasons that could provide additional insights into the obtained results in this research:

- *The object of the mapping process: relative non-motorised accessibility to retail*. As illustrated during the analysis of the questionnaire, 20% of practitioners were non-familiar with mapping and analysing issues of relative non-motorised accessibility, but they were familiar with transport planning issues. That could have originated a lower interest from this group in perceiving the added value of cartograms for the specific problem of how to visualize relative non-motorised accessibility. Another issues that can affect to the interest in incorporating new techniques to visualize accessibility planning is the dominant view of accessibility as an absolute concept for practice. For this reason, a group of respondents unanimously asserted that “it was better to visualize accessibility values as a single value to make its interpretation easier”. A last argument related to mapping relative non-motorised accessibility is linked to legal

constrains in official planning documents, limiting the incorporation of new visualization techniques in planning processes.

- *The evaluation of diffusion-based and Dorling-based cartograms.* Being aware that other types of cartograms are also available, such as balanced cartograms and hexograms (Harris et al., 2018), and table cartograms (Evans et al., 2018), this research focused on comparing diffusion-based and Dorling-based. It must be considered that the main noticed limitations were related to the spatial distortion originated by cartograms, an aspect inherent in all of them. With this in mind, new user experiments including a wide range of cartograms can provide more robust findings.

- *The low participant´s experience using cartograms*. While differences in non-motorised accessibility values for the four groups of population had been tested in previous studies (Arranz-López, Soria-Lara, Witlox, et al., 2019), local practitioners had difficulties to perceive those spatial dissimilarities by using cartograms, specially by using Dorling-based cartograms. That may be related to the low experience of practitioners in using and visualising cartograms. It should be taken into consideration that more than a half of the participants declared that they had not use cartograms ever. Although this can be considered a significant barrier (Keim et al., 2004), practitioners neither declared special interest in cartograms after being familiarised with such visualization techniques during the research.

- *The use of cartograms at city leve*l. Frequently, cartograms have been used at worldwide and regional scales where significant differences between spatial patterns can be more easily visualised. However, this research tried to depict comparisons and relations between different groups of population in a continuous and smaller geographic area. That led to the problem of the size of the representation unit. Distorting large surface areas (e.g. countries and regions) make easy to distinguish spatial variations in the showed values e.g. population, income, GDP. However, the use of a smaller surfaces (grid size of 100 x 100 metres), which are more appropriate for analysing patterns at the city level become more complex to perceive that values.

It can be concluded that new end-user experiments would be needed to improve our understanding about the potentiality of cartograms in daily practice. This would entail the use of a wide range of cartograms not only for mapping accessibility, but also for representing other indicators commonly used in the field of transport planning. Some examples include environmental indicators (e.g., transport emissions, air pollution), social indicators (e.g., total time spent in traffic, traffic injuries), and economic indicators (e.g., transport user benefits). In this context, the suitability of cartograms to map large data sets, which are being increasingly used in transport research, is a field for exploration (Moya-Gómez et al., 2018;

van Wee, 2016; Zannat and Choudhury, 2019). From the technical side, future research might investigate how to develop new tools capable to (i) better map the differences of non-motorised accessibility between groups of population at the city level; (ii) enable the implementation of complementary visual layers (e.g. roads, orthophoto) in non-continuous cartograms (Dorling-based cartograms in this study). Overcoming those barriers seem clear not only for better mapping relative accessibility, but also for increasing the effectiveness of visualization techniques in decision-making.

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