***Title***

Urban sustainable mobility and planning policies. A Spanish mid-sized city case.

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***Highlights***

- Density and compactness are studied and correlated for a Spanish city case.
- Population and traffic generation data are combined in a GIS model using an innovative approach to perform a qualitative analysis.
- Results has shown a clear correlation between low population density and high number of car trips for the selected case.

# Urban sustainable mobility and planning policies. A Spanish mid-sized city case.

Abstract

Multiple previous studies at international level have examined the effects of land use policies regarding to sustainability, and particularly devoted to the induced private car mobility excess. However, it is remarkable the different urban planning tradition depending on the country or region. Thus, the Mediterranean urbanism has been generally featured by high or moderately high population and dwellings density, which has promoted the presence of pedestrians on streets. In this paper we analyse the case of Burgos city, as an example of mid-sized city in Spain. Although it isn't suffering sprawl symptoms, its local administration is trying to improve current modal share by increasing sustainable means of transport. The performed analysis includes population, dwellings density and absolute compactness, to check their influence in car trip generation. In coherence with previous studies, our results have shown a qualitative correlation between low densities and higher use of private car for the studied case. The effects of some urban planning policies are discussed as possible reasons of observed behaviour, serving as basis for future recommendations.

Keywords: sustainability; urban mobility; density; compactness; policies

## 1- Introduction

Many recent works have studied the land-use environment influence in urban city daily life from sustainability optics. A vast literature can be particularly found seeking the relations between land-use patterns and travel. Most part of previous research has focused in the use of statistical methodologies to address this issue by modelling and evaluating the influence of different variables on travel demand. There is a consensus to argue that results have shown that compact, dense and well-designed developments lead to a reduced vehicle kilometres travelled when compared with disperse or suburban ones (De Vos, 2015; Ewing & Cervero, 2010; Ewing, Tian, & Lyons, 2018), even though the influences may not be large or actually marginal if the variables are individually analysed. However, the studies have been worked out from a diversity of places and sources, so that the relationships are sometimes not consistent enough, or even, there is no clear effect to conclude (M. G. Boarnet & Sarmiento, 1998; Ewing, Deanna, & Li, 1996; Maat, van Wee, & Stead, 2005). Indeed, some authors have argued the complexity of this issue, and even about the differences between cities and regions, or the applied methods suitability (M. Boarnet & Crane, 2001; Lin & Yang, 2009).

We must note that the growing interest shown by the community in this field has been mainly devoted to the analysis of large cities and urban metropolises, specially due to the congestion problems and unbalanced modal share (M. Boarnet & Crane, 2001; M. G. Boarnet & Sarmiento, 1998; R. Cervero & Kockelman, 1997; Choi, 2018; Ewing et al., 1996; Gordon & Lee, 2015; Salon, 2015). Only a few studies have been devoted to small and medium cities (SMCs) (Hu, Xu, Shen, Shi, & Chen, 2018; Sarkar & Mallikarjuna, 2013; Wiersma, Bertolini, & Straatemeier, 2017; L. Zhou et al., 2018). Nevertheless, international reports and studies have explained the current and future importance of SMCs. United Nations 2016 report showed up that 59% of global population lives in SMCs (UN-Habitat, 2016). Following the OECD statistics, about 22% of total population lives in urban areas included in the medium-size group (OECD, 2019). About 56% of European urban population live in SMCs (Servillo, Atkinson, & Hamdouch, 2017), and more than 42% live in urban areas with less than 250,000. In addition, SMCs represent more than three quarters of the total number of cities in Europe (Dijkstra & Poelman, 2012). Their importance has also been highlighted in the EU strategy, noticing that medium-sized cities (MCs) can play a pivotal role in the national well-being, as they are essential, not only for avoiding rural depopulation and urban drift, but also for a balanced territorial development promotion (European Commission, 2011).

The interest in SMCs can be observed at international level too. A McKinsey Global Institute report forecasted that SMCs in emerging markets would generate 65% of global growth until 2025 (Dobbs, Remes, & Smit, 2011). In China, the 2008 National Urban and Rural Planning Act revised the planning strategies to include the critical role of small towns and medium sized cities to reduce the pressure on larger agglomerations (Qian & Xue, 2017), and policies oriented to a fiscal support of small and medium cities and their smart growth have been suggested (Chen & Cui, 2018). In Africa, large metropolises are the focus of main planning efforts while SMCs are also being rapidly transformed and have been recognized as favourable areas for rural migration (Andreasen, Agergaard, Kiunsi, & Namangaya, 2017), leading to reduce large-cities growth patterns (Christiaensen, De Weerdt, & Todo, 2013; Christiaensen & Todo, 2014).The key role of SMCs in future global urban growth was deeply discussed by de Noronha and Vaz (2015), defending them as “elementary vehicles for balanced prosperity” provided they grow using appropriate strategies for successful and sustainable development, and not assuming that future world tends inexorably to larger cities.

Therefore, the analysis of recent SMCs growth and urbanization cases is crucial to understand the suitable policies and planning recommendations to achieve the best development patterns, which may help to avoid undesirable or unsustainable pathways. We present here a case study for a Spanish MC, as an example of inadequate planning decisions and unsustainable growth pattern in mobility terms. To perform the analysis, we have introduced an innovative and simple methodology to get qualitative snapshot of city car use patterns. This way to face the problem allows a specific analysis in relative terms, checking the coherence with previous findings, as well as internal relations among selected urban parameters and car trip generation. The work starts with the selection and study of basic parameters to understand the recent growth behaviour. Secondly, official statistics and origin-destination matrix data are computed through GIS software to obtain the distributions of population, dwellings and automobile-trips generation. The current density and compactness map of the city is discussed, and finally partial results are used to find the underlying connections between them by a qualitative analysis, showing strong coherence with previously published findings. A comprehensive set of policies and improvements is subsequently suggested.

Taking into account the already mentioned importance of SMCs planning policies in the near-future, our conclusions may be very helpful in land-use and built-environment design of this kind of cities with growing perspectives, mainly in developing countries, and for smart growth of MCs in European countries.

## 2- Literature review

As it has been mentioned, the relations between built environment and urban mobility have been discussed for decades. Several studies suggest that an adequate use of planning policies may be useful to orientate the mean of travel in origin towards soft modes (R. Cervero & Kockelman, 1997; Robert Cervero & Duncan, 2003; Crane & Crepeau, 1998; M. White, 2006). Many of them have focused in vehicle miles travelled (VMT) generally using data from North American samples. In this last sense, a complete review was conducted by Ewing and Cervero (2010) where the influence of the so-called *5D*-variables were discussed by means of a meta-analysis: density, diversity, design, distance to transit, and destination accessibility. Even if results of isolated land use indicators showed low effects in terms of elasticity, the outcome of the addition was found to be significant enough and coherent with their own previous conclusions (Ewing & Cervero, 2001). Hence, these authors claim for the smart use of the *Ds* during planning decisions to achieve better mobility results.

After a huge reviewing effort, land use planning was also identified as one of the five main categories of factors involved in VMT (Salon, Boarnet, Handy, Spears, & Tal, 2012). Density, land use mix, regional accessibility, network connectivity and job-housing balance were in this case the individual variables selected in this group as basic variables. This selection is consistent to previously mentioned *5D*, considering diversity as a complex measurement that can include different urban parameters (such us land use mix or job-housing balance). The conclusions pointed out a range of results when comparing effects of density depending on data or methodology applied. Small impacts were reported in most cases for most of analysed parameters except for the employment accessibility and job-housing balance. Even if city morphology and transportation system characteristics may explain these results locally, authors argued the need of additional research to understand the variation of effects depending on inner areas of the same metropolitan region.

Although compact and diverse patterns may produce less VMT, a secondary effect is the origin-destination concentration which provokes higher congestion, mainly in large metropolises. This issue was recently evaluated trying to assess the counterbalanced effects of density and compactness in traffic, by using multivariate methods to explore the possible correlations between different variables (Ewing, Tian, et al., 2018). Their analysis showed that investments in highway and freeway capacity provoke a higher induced traffic which finally means increased VMT and congestion. Thus, alternative policies of pricing (fuel, highway use) were identified as appropriate recommendations to reduce car dependence. Moreover, the induced congestion was found to be lower in areas with extensive street network and hence this may be used as an additional strategy to reduce delays.

The positive compact and mixed-use development effects were found to be strengthened by adequate transit policies to obtain a significant reduction of car use in Calgary (Choi, 2018). In this study and by means of a regression analysis, travel behaviour was found to be dependent on the location within the city spatial structure. Density did not produce enough results by itself, but the need of promoting a polycentric distribution of core's functions was highlighted as a desirable pathway to reduce car dependence. The consequences of adopting an adequate mix of uses in traffic generation has also been modelled to assess its influence in road capacity design (Tian et al., 2016). Using samples from 13 American metropolitan regions, this study pointed the positive relationship between activity density at short distances and pedestrian mode, and explained by statistical indicators how mixed-use developments can capture walking, cycling and transit trips and produce trip generation reductions if compared with suburban development. This significant reduction can be accordingly accounted during traffic studies.

Average travel time was used as measure unit to understand the influence of origins and destinations on traffic conditions by Gordon & Lee (2015). Starting with the worry about sprawl consequences, the authors carried out a multivariate analysis in 79 American metropolitan areas. Results shown a 10% increase in average commute times when doubling population size, but dispersed employment and population decentralization were associated with shorter commute times. For non-work travels, accessibility to malls (which account half of total retail in United States) was found to be very similar independently where people reside. This spread of shopping areas has enhanced travel destination distribution in a polycentric fashion, so travel distances are accordingly reduced. Hence, when residential sprawl is followed by employment and services spread, many of the undesirable known effects of low density and low compactness are somehow counterbalanced. This conclusion is closely related with the fact of reaching a well-mixed distribution of uses at short distances. However, this way of measurement did not take into account the cost of mobility infrastructure needed for low densities, and forget the need of finding a more sustainable modal share.

Indeed, regarding to density and compactness, research has shown that development of new residential areas using low population densities may provoke several additional undesirable effects: environmental pressure (Borrego et al., 2006; Brian, 2016; Cárdenas Rodríguez, Dupont-Courtade, & Oueslati, 2016; Liu, Wu, & Yu, 2018; Skog & Steinnes, 2016); health and life expectancy (Frederick, Riggs, & Gilderbloom, 2018; Hamidi, Ewing, Tatalovich, Grace, & Berrigan, 2018); increased investment and maintenance costs in local services (Lityński & Hołuj, 2017; Sole-Olle & Hortas-Rico, 2008); energy consumption (Lasarte Navamuel, Rubiera Morollon, & Moreno Cuartas, 2018; Lopez Redondo, 2018); and changes in citizens style of life (Borsdorf, Hildalgo, & Vidal-Koppmann, 2016; Espindola, Carneiro, & Façanha, 2017; Salvati, Gitas, Di Giacomo, Saradakou, & Carlucci, 2017). Paying attention to mobility, higher densities are recognized to discourage car use and produce fewer emissions, effect that can be enhanced by mixed and compact land-use development or infill. However, their impact seems to reach a density peak due to speeds and driving attitudes (Hong, 2017). Likewise, low densities usually provoke an unbalanced modal share and excessive use of private car (Obregón-Biosca, Romero-Navarrete, Mendoza-Sanchez, & Betanzo-Quezada, 2016; Ralph, Voulgaris, & Brown, 2017).

We must notice that some initial features of the reviewed cases may substantially differ among cities or regions. For example, current modal share, city size or traditional compactness are local characteristics that are involved in other land use parameters and are mixed with previous planning local or national practices or citizens lifestyle and habits. Thus, we cannot compare distances in a small town with a megacity, or the cycle use in North America with China or some countries of North Europe. For example, Bertaud and Richardson (2017) established a comparison between United States and Western Europe cities, illustrating the problematic of achieving a more adequate travel share for the first through simple land use measures due to the different current scenarios. The differences between cities (including culture) were also highlighted by Ewing, Hamidi, et al. (2018) when revisited Newman and Kenworthy's affirmations regarding to population density and per capita fuel consumptions relationships. And even within the same country or same metropolitan area, the size effect and transit coverage dissimilarities may provoke a disparity of land-use measures effectiveness (L. Zhang, Hong, Nasri, & Shen, 2012). For Asian samples, the extremely high densities reached in some Chinese or Indian cities as well as the predominant building typologies used and the transit oriented developments explain the behavioural variances when comparing reported results with Western urban studies (Lu, Sun, Sarkar, Gou, & Xiao, 2018; Sarkar & Mallikarjuna, 2013; Y. Zhang, Li, Liu, & Li, 2014; W. Zhou & Li, 2016). Distinguishing between 'growth' and 'post-growth' environments, as a contrast between emerging economies (Asia, Africa and Latin America metropolises) and developed countries with population stabilization or decline (Europe mid-sized regions), may also introduce discrepancies when analysing car dependency reduction policies (Wiersma et al., 2017). Anyway, despite of all possible differences, sustainable development and mobility should be kept as medium and long term objectives for all sizes, shapes, placements, and growing perspectives of cities. Due to the global concern about environmental and health issues, many governments are actively encouraging citizens to drive less (Salon, 2015).

In summary, research has shown evidences to affirm the positive impact of density and dense development with car use reduction, mostly when those parameters are superposed with and adequate mix of uses and building typology selection. The convergence of these parameters allows an appropriate activity density at short distances that encourage active modes. In addition, although residential sprawl can be identified as a non-sustainable development pattern from different points of view, part of its negative effects can be counterbalanced by using a kind of polycentric or disperse distribution of uses (i.e., a not extremely concentrated fashion), and adequate transit investments. Besides, the already published results show how the impacts may differ from case to case in function of many urban and cultural variables, and throw differences between countries, regions and even neighbourhoods.

This paper tries to give more insight about an MC development behaviour in terms of mobility and land use planning policies applied, using an example of a European 'post-growth' case to explain the local effects of quick unsustainable urban development. MCs mobility problems are different in large metropolises where congestion is probably the main worry, but the reduction of unnecessary use of car for many of the trips is currently in many MC local agendas. With this aim, we carried out an internal comparative study to complete current literature in these particular contexts by discussing the impact of urban indicators on car trip generation distribution as basis of planning recommendations.

## 3- Methodology

### 3.1- Urban parameters selection

Taking the basis of the previously mentioned *5Ds* framework, an additional inspection of publications devoted to urban sustainability indicators in the most important international methodologies for this kind of assessment throw a variety of parameters (Martí, Nolasco-Cirugeda, & Serrano-Estrada, 2017). The most worldwide relevant methodologies may be LEED (LEED, 2009), CASBEE (CASBEE, 2014) and BREEAM (BREEAM, 2011). Moreover, the Spanish Ministry of Development published a methodological guide of sustainability evaluation (A.E.U.B., 2012) that includes possible national singularities. Despite of the variety, the *5D* seems to be a common vein when analysing all these methods.

Among the proposed variables we can highlight density and compactness, although urban complexity (as a way to measure the mixed land-use), social cohesion, and typological variety also appear in several of them. Nevertheless, used formulas are not the same in all cases despite of being oriented to the same concept. Particularly for the Spanish case, the national methodological guide (A.E.U.B., 2012) describes the statistical correlation found between dwellings density and absolute compactness ($R^2$= 0.63), as well as between compactness and urban diversity ($R^2$= 0.61) due to the special configuration of Mediterranean traditional urban development. Accordingly, a statistical correlation between urban diversity parameter and number of activities and urban uses per hectare has been identified for Spanish cities (Pearson=0.75) (A.E.U.B., 2012). Hence, in the Spanish context, an adequate population density added to high urban compactness is expected to lead to a well-balanced and organized urban fabric with adequate mix of urban uses and functions at short distances. This means a particular relationship between some of the *Ds*, whose dimensions can be considered overlapped or connected (Ewing & Cervero, 2010).

Otherwise, some assessment criteria differences may be identified when comparing the methodologies mentioned above. For instance, LEED manual (LEED, 2009) include as a prerequisite for new pedestrian-oriented residential areas a minimum of 12 dw/acre (approximately 25 dw/ha) to promote compact development; but Spanish guide includes a minimum of 80 dw/ha, recommending 100 dw/ha (A.E.U.B., 2012). In addition, Spanish guide distinguishes a special value for urban infill. In such a case, the recommendation is 100-160 dw/ha (corresponding to values in the range 200-400 inh/ha for population density).

The methodologies also contain other indicators that are more difficult to quantify in terms of data gathering and computation. However, these parameters are complementary to the mentioned as basics, and some connections may be observed as it has been already mentioned: connectivity, complexity, social cohesion, typological variety, distance to facilities and services, walkability, open spaces ratio… Therefore, we have selected the following parameters for the study due to their basic character:

- Population density, computed as: $PD\ (inh/ha) = \frac{\text{number of inhabitants}}{\text{area in hectares}}$

- Dwellings density, computed as: $DD\ (dw/ha) = \frac{\text{number of dwellings}}{\text{area in hectares}}$

- Absolute compactness, computed as: $AC\ (m) = \frac{\text{buildings volume in } m^3}{\text{area in } m^2}$

Checking and understanding the internal relation among these basic variables, the whole of *5Ds* are directly or indirectly analysed when the proper correlations are fulfilled.

### 3.2- Selected case and data sources

Burgos is a MC in the north of Spain, capital of a province in the Spanish Castilla y León region (figure 1). The city is placed in a low density of population region (<50 inhabitants/km$^2$) (European Union, 2014). Industry represents 26% of employment which nearly doubles national average, and unemployment rate ranks 11%, three points below the national numbers (Spanish Statistical Office, 2018). Current population reaches 175623 inhabitants (Spanish Statistical Office, 2018), reflecting its representativeness as European 'post-growth' MC according to statistics. Total population shows a decreasing trend since 2012, after growing continuously during the first decade of 21th century. Average drop between 2012 and 2017 is about -2.38%, i.e. 4238 inhabitants. The lower birth rate and the return of immigrants to their origin countries, people that came to Spain during the previous decade, have been identified as main reasons to this negative trend. However, we have to notice as well the positive growth experienced by up to 14 small villages nearby the administrative limits of Burgos city (Spanish Statistical Office, 2018). Statistical information shows an important population increase in the period 1997-2017 for these small municipalities, which sums 8262 inhabitants and represents a 95.15%. The change is also positive between years 2012-2017 (4.58%, 742 inhabitants), and the percentage grows to 7.81% (881 inhabitants) if we only select the villages which increased population during this last period. Thus, around 15% of Burgos population decrease in the period 2012-2017 may be explained with internal population movements inside the city's area of influence.

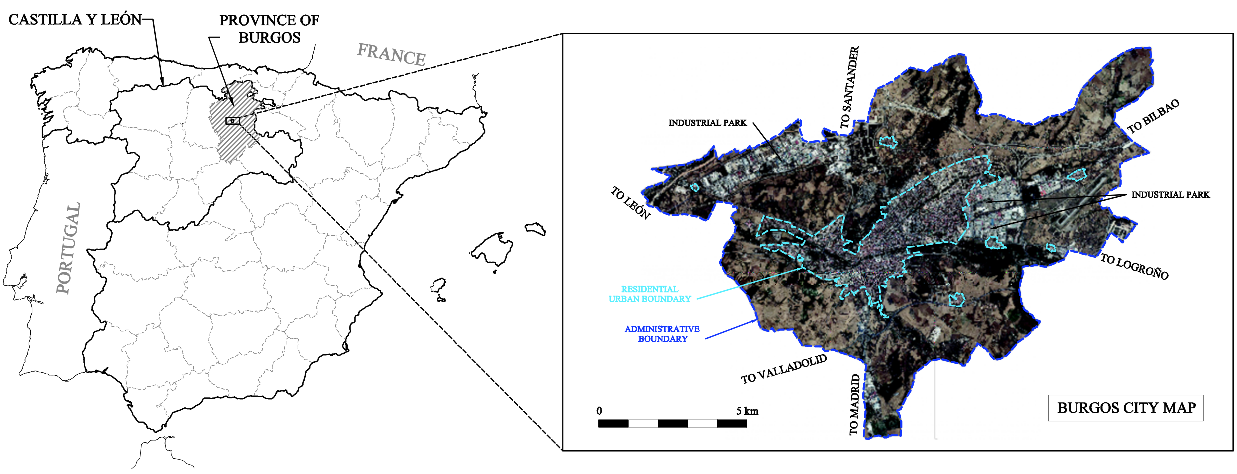

Figure 1. The city of Burgos is placed on the North of Spain, well connected with near capitals. Orthophoto from Spanish National Geographic Institute (IGN, 2017).

For the aim and objectives of the present work, different official data sources have been consulted. First, the municipal register for population data was used to obtain sorted information of inhabitants in census sections and districts. This information is collected every 10 years to publish the official statistics, which was the selected source for the 2011 data (Spanish Statistical Office, 2018). Burgos is divided in 145 census sections, but only 140 of them include significant population data. Additionally, some of them refer to industrial or non-residential areas, i.e. commercial areas unconnected from main urban core. For two sections no dwellings data was stored during last 2011 census, so data from previous 2004 were used instead. Due to the age of buildings, we can affirm that these two sections are placed in a consolidated urban area with no changes during years 2004-2011, so negligible deviation was made using 2004 values. Second, the electronic office of Spanish land registry (Spanish Cadastral Office, 2017) was accessed to query spatial information of all city buildings. A filtering procedure allowed to extract built areas and open spaces, and even to obtain the height and occupied land for each building. All gathered information was included in a Geographic Information System (GIS) model, using QGIS code and tools to perform the adequate operations (QGIS Development Team, 2017).

The General Plan of Burgos (Burgos City Hall, 2014) was the third source. This document distinguishes three main types of land according to current regulation: urban land (already urbanized), developable land (potential areas for new developments), and rustic land (land to be preserved from urbanization). In addition, a mobility study is included in the General Plan with a complete survey of traffic. In order to include generated car trips in our work, the origin/destination matrix was also analysed. Mobility study was done in 2008, which means we use values near in the timeframe: population from 2011 census, and traffic from 2008 surveys.

Regarding to modal share, two different surveys are available corresponding to years 2003 and 2017 (Burgos City Hall, 2017). No significant variations are shown in both reports, and main values may be summarized as follows respect to total trips: 50-53% on foot, 31-33% by car, around 10% in public transport, and around 6% others (including cycles). Although pedestrian trips have an important weight, car is still used for too many trips which is not convenient in terms of sustainability. The weight of cycles may be improved as well.

### 3.3- Urban planning policies in Castilla y León region

In the case of Castilla y León, the first Urbanism Law (Ley de Urbanismo, LUCyL) was published in 1998, with several minor changes during the following years. Moreover, a complementary regulation was approved in 2004 (Reglamento de Urbanismo, RUCyL) which strengthened planning requirements. Related to the scope of this article, we must note the basic principles of both LUCyL and RUCyL expressed in their preliminary sections where sustainable growth and development were highlighted, and the inclusion of different planning rules were oriented to these objectives: minimum density, compact shape, and adequate mixed land-use. In addition, minimum ratios of open spaces and public facilities were also defined as planning standards. RUCyL regulation extended LUCyL contents trough three additional indexes measured in terms of G.F.A. (Gross Floor Area): use variety index, typology variety, and social integration index (to ensure a minimum ratio of low-income oriented dwellings). Regarding to density, RUCyL states a range of 30-70 dw/ha and a maximum global F.A.R. (Floor Area Ratio) of 1 $m^2/m^2$ for all new developments in cities over 20000 inhabitants. Following previous urban standards and rules, RUCyL authors expected sustainable oriented results for new development plans.

Nevertheless, the application of the RUCyL indexes was not effective in most of recent city extensions of Burgos. Indeed, listing the latest urbanized areas in Burgos for the last 40 years (figure 2), we can identify three main different planning criteria and standards that can be summarized as follows:

- Zones planned using a maximum of 75 dw/ha (before 1999)
- Zones planned using LUCyL, with a maximum of 70 dw/ha and F.A.R. < 1 $m^2/m^2$ (1999-2004)
- Zones planned using RUCyL, with a maximum of 70 dw/ha, F.A.R. < 1 $m^2$/ and use variety index, typology variety index, and social integration index (after 2004).

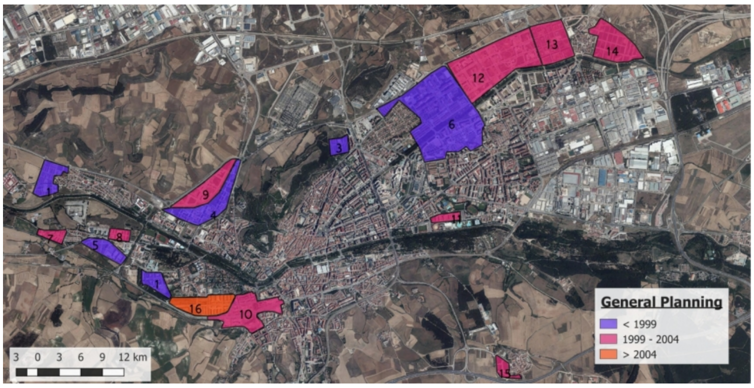


Figure 2. Distribution of General Planning policies in Burgos city, where only a small part of recent developments has been planned following the full RUCyL requirements (>2004). Orthophoto from Spanish National Geographic Institute (IGN, 2017).

### 3.4- Study methods

As highlighted in section 2, citizens travel behaviour may differ in function of region, country and even neighbourhoods. A case study helps determining the specific variables involved and their coherence with previous works. In this paper, we suggest an unexplored way to qualitatively check internal differences in private car trip generation and the selected urban parameters relationship by comparing density profiles (figure 3). Using public official data, population and dwellings number were gathered at census section levels using national statistics (Spanish Statistical Office, 2018)stored using GIS. An initial adjustment was done to cut non-urban areas and those not fulfilling residential or mixed land uses. In this way, distorted average density values in census sections were avoided due to unrealistic section areas. The used boundary was available in the Regional GIS Urban Planning System of Castilla y León (Junta de Castilla y León, 2018).

Secondly, filtered cadastral information was used. Built areas were calculated for every building and a variable related to number of stories was identified in the cadastral database. Through a manual revision, the last parameter was transformed in the total number of stories per building, which was subsequently used to compute the total height of each building. This last estimation was calculated using 4 m for ground floor and 3.5 m for upper floors. This GIS model was used to evaluate the basic urban parameters using QGIS code free available tools (population and dwellings density, and absolute compactness).

Finally, origin/destination matrix data available from General Plan (Burgos City Hall, 2014) were dump manually into a new GIS layer. This mobility study distributed surveys using 56 internal assignation zones and 15 additional external possibilities for the city area. Using this matrix, authors have computed indirectly the number of trips generated per inhabitant for each of these zones. QGIS plugins were again helpful tools to perform all the required spatial operations to translate population data from census into the traffic assignation zones. With this objective, an intersection of both layers was done to obtain new accurate areas in coherence to census sections previously defined. A new outline for 50 significant assignation zones was drawn, where population data was proportionally dumped using 2011 census values. This task was carried out by assignation of population in census sections, transforming this number in randomly distributed spatial points, which were later counted inside the 50 traffic zones. This procedure includes a random effect that may provoke a tiny spatial shift of trips distribution. However, this does not affect to the study at city scale due to the reduced zone areas, and computed results are accurate enough to understand mobility trends and correlations. Thus, a new full model of generated traffic and population was completed for a joint analysis, and the number of generated car trips per inhabitant was calculated to perform density profiles. The trips density distribution was generated by weighting total trips of each zone using population and area.

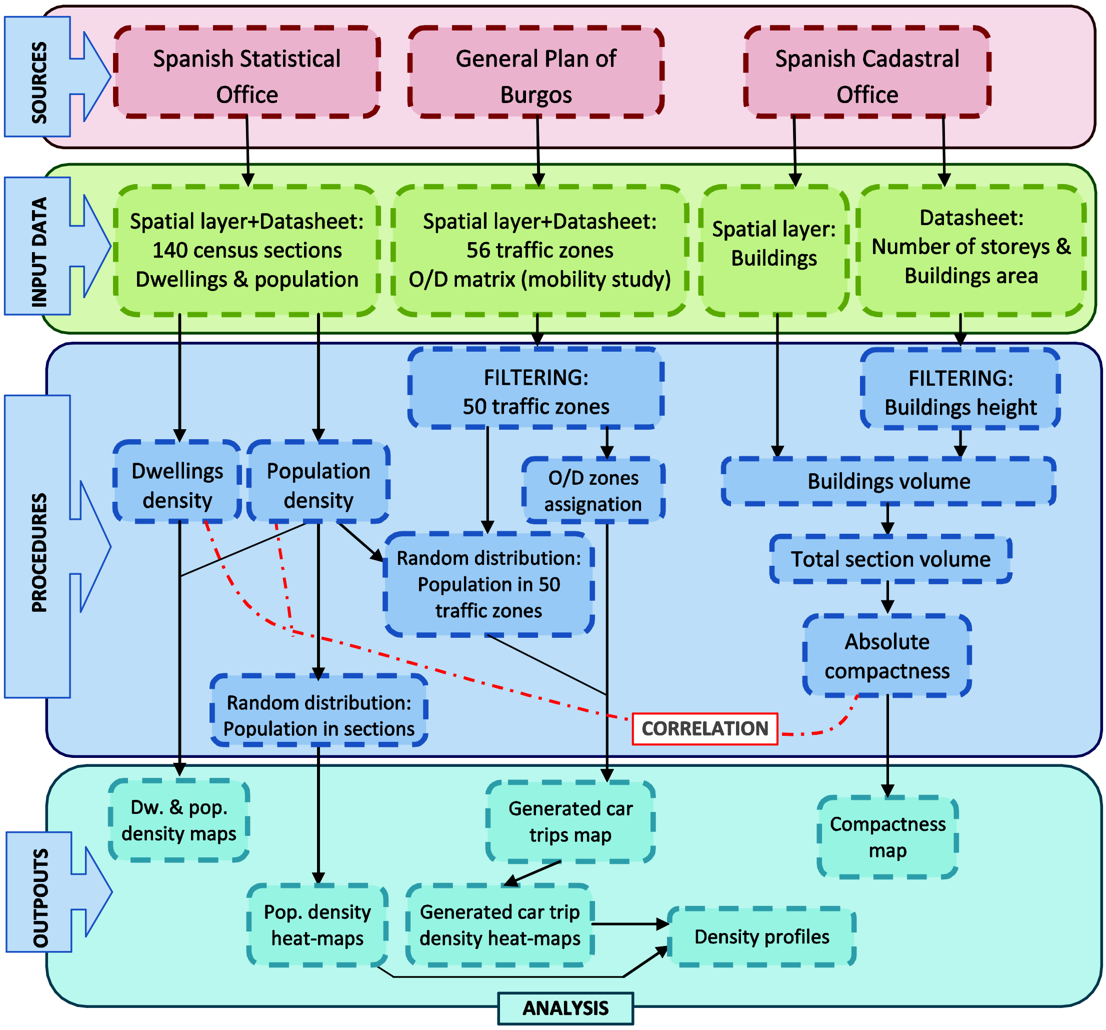


Figure 3. The applied methodology is explained in a glance, including sources and outputs.

## 4- Results and discussion

Graphic output of results allows a general overview of population and dwellings distribution, as well as absolute compactness, for Burgos city (figure 4). Thus, one can note that traditional pattern, fabric and typologies developments used in the Spanish cities extensions during the middle 20$^{th}$ century, in addition to some of the popular neighbourhoods erected while the emergence of the industrial park, are those which figure with the highest densities. We can see sections with densities higher than 100 dw/ha and even 200 dw/ha in consolidated urban areas, reaching a maximum over 500 dw/ha in small sections. Some of these high-density zones shows scarce of open spaces and/or public facilities due to lack of adequate planning standards. Although the reduced section area may distort the average value of density at some point, a combination of these reasons explain the extreme values. Except in some particular areas, these highly populated neighbourhoods are those which follow the Spanish guide recommendations (A.E.U.B., 2012) as mentioned in section 3.1.

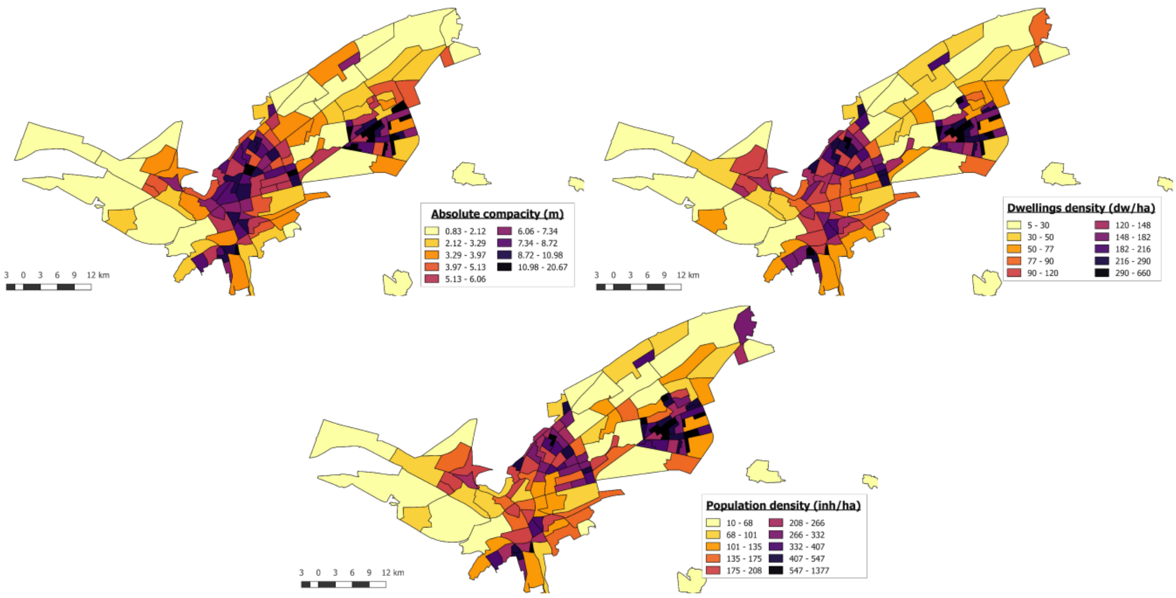


Figure 4. Results for dwellings density, population density and absolute compactness in census sections.

The two main dense zones represent the main centrality nodes inside Burgos city: the first, in the surroundings of Historic centre; the second, in the East part of the city near an industrial zone. In addition, two additional compact areas may be identified with lower total population, but also with centrality features, in the West and the South of urban core. On the other hand, large areas with low densities can be detected as well, with less than 50 dw/ha. These areas match with one of the following cases:

- Developments in seventies of 20$^{th}$ century (between the two main centrality nodes), where extreme zoning standards were applied following Modern Movement principles so that residential blocks and towers emerge separated one each other, the land use is not well mixed, and streets are car oriented.
- Low density residential areas, based in the repetition of single-family typologies with any of its variant, mainly placed in the North and West periphery.
- Recently developed peripheral zones where the planned number of buildings has not been completed yet, mostly in the North and Southwest zones.

- Some sections that include large non-residential uses (e.g., sports, educational, recreational) following a concentrated distribution.

In the middle term of both density extremes, an important number of sections fall in the range 50-100 dw/ha. These are localized in the Historic centre, in some of the extension areas in transition to the core periphery, or in recently built sections were planned densities have not been reached yet.

Visually compared, compactness and density maps agree, showing a correlation between both parameters. A dispersion graph may be plotted (figure 5) which allows to compute the internal correlation among indicators ($R^2$=0.8082), that is consistent with the previously published in a study of different fabrics in multiple Spanish cities (A.E.U.B., 2012). The results confirm the goodness of performed computations. In general, absolute compactness overpass 5 m unless low or medium density areas, which indicates where the higher urban vitality can be expected. These numbers prove that, generally speaking, traditional city developments pattern has followed adequate density, diversity, design, and distances. Thus, a good performance would be expected in terms of reduced private car usage (Ewing & Cervero, 2010).

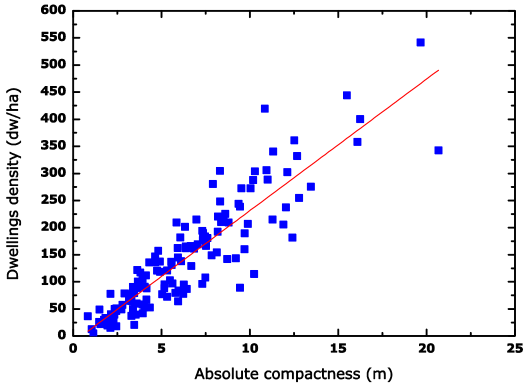


Figure 5. The graph Compactness vs. Dwellings density shows a correlation ($R^2$= 0.8082) in agreement with previously published values for a set of Spanish cities (A.E.U.B., 2012).

To verify this, population and trips density maps were merged to analyse the possible effect of previous parameters in generated car mobility as explained in section 3.4. The obtained maps suggest a coincidence between high number of car trips per inhabitant and low population densities. Otherwise, a relative low number of car trips are shown in compact sections. The effect is especially strong in both centrality nodes (figure 6). Population density allows here the economic viability of retail market and neighbourhood services, which increases on foot and bicycle movements (Tian et al., 2016). Similarly, a certain overlapping can be clearly detected among some medium/high population density sections and high traffic generation areas. In some of these cases, the tertiary use of important parts of buildings (offices and some commerce) has distorted the land use mix and created a particular mobility. In some others, an important reason the presence of three malls in the city that have high traffic attraction features (Gordon & Lee, 2015). In parallel, the emergence of these three commercial complexes has provoked negative effects on consolidation of traditional retail shops and braked the creation of new ones. Finally, industry has a key role in Burgos labour market. This implies a massive commuting trips generation that can be proportionally distributed all over the city, although some sections are more affected by this. The fact of being a MC, with relative small commuting distances and free parking availability in industrial areas (Hess, 2007), provokes the undesirable use of private car even with improved transit frequency.

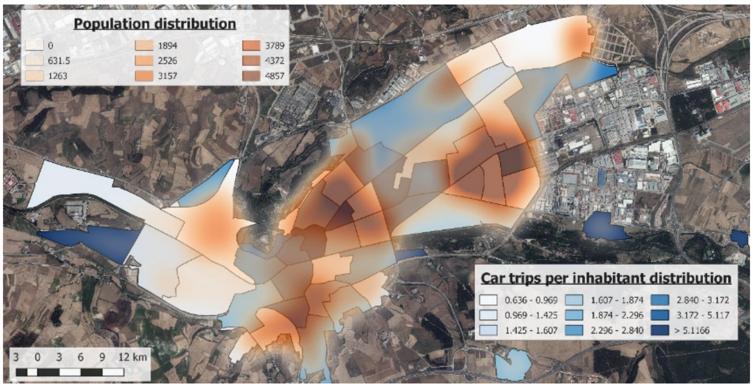


Figure 6. Population density distribution heat-map is plotted over a map of Density of generated car trips per inhabitant. High car trips densities (dark blue in online-version) are placed over low population density areas. Orthophoto from Spanish National Geographic Institute (IGN, 2017).

All the mentioned connections between density and car trips became even more visible when plotting a profile of the city using a West-East axis (figure 7). Using this procedure, relative maximums obtained for generated car trips clearly match with relative minimums in population distribution and vice versa. These results confirm a qualitative correlation between both parameters in the studied case. Lastly, when plotting the points-cloud of density of trips per inhabitant and corresponding population (figure 8a), a clear trend to decrease is observed for higher population densities. In fact, most of high number of trips data accumulates in the low dense sections, where reduced diversity is present and longer trips are needed. The accumulation of car use is even strongly noticed when plotting maximums of the profiles as dots in a density vs. trips graph (see point 1 to 8 in figures 7 and 8b). This effect of short distances on travel choice is consistent with previous findings in other MCs (Hu et al., 2018; Wiersma et al., 2017; L. Zhou et al., 2018). Therefore, once density and compactness are appropriately correlated (meaning mixed land-use, diversity and vitality), the applied methodology allows a quick analysis of generated traffic within a city, and helps to explore other variables involved at comparing different neighbourhoods (Salon, 2009). In this type of context, density may be considered as an adequate indicator of car use behaviour. However, this is not true in places where density, diversity and short distances to uses are not correlated.

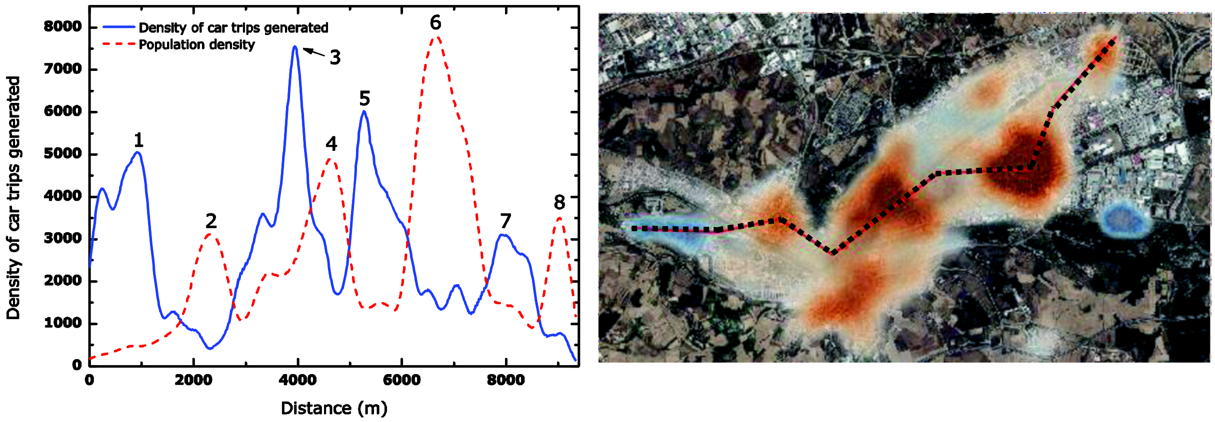

Figure 7. A profile of both population density (dashed line) and car trips generated per inhabitant density (continuous line), using the West to East axis plotted on the map in the right. Relative minimums and maximums position suggest an internal connection between both variables for the studied case. Orthophoto from Spanish National Geographic Institute (IGN, 2017).

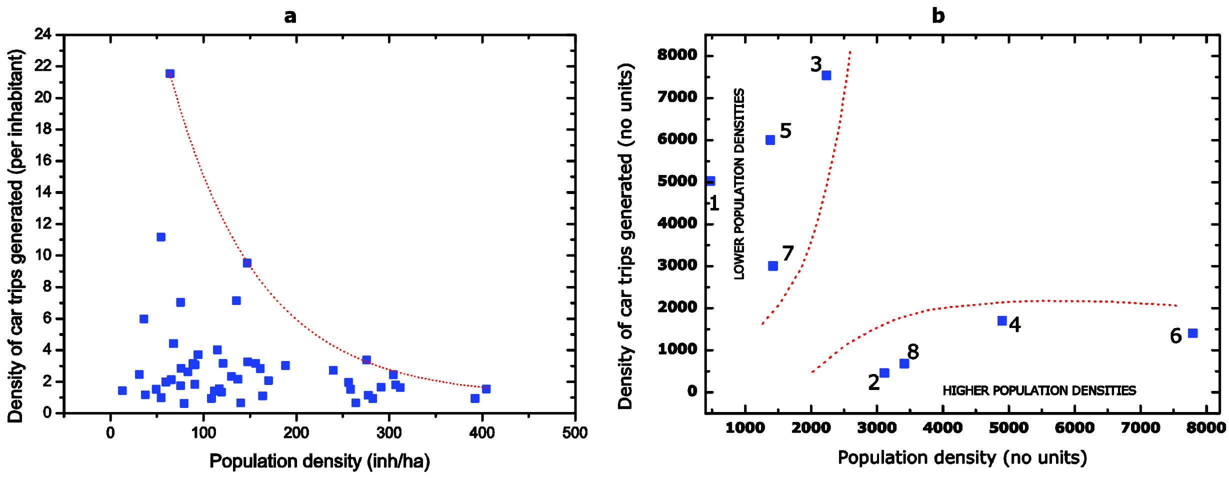


Figure 8. Left (a): Population density vs. density of car trips generated per inhabitant in studied sections. A decreasing number of trips are observed for higher population densities, as showed by dashed line. Right (b): Maximums from figure 7 plotted in a density vs. car trip generated plot. Concentration of higher car use is clearly observed for lower densities and vice versa. As this graph is derived from a density profile, units cannot be applied.

Castilla y León planning regulation was aimed to promote sustainable designs and particularly in terms of mobility. However, some particularities must be discussed for the analysis. Spanish real estate market underwent a housing boom in the period 1997-2007, which meant a too quick urban growth and an excessive number of dwellings. This increase was not balanced with population growth in Burgos. Despite of preserved lots for public facilities, there have been no time and budget for their complete execution and functional integration (see zones 1, 9, 10, 12, 13, 14, 15 y 16 in figure 2). Years after the initial urbanization of many zones, most of them have not completed the construction of all the planned buildings due to a lack of purchasers or investors. Moreover, several of those which have been erected are not really used as principal residence, decreasing the average population density. The growth of housing bubble can be argued as one of the reasons, as dwellings were understood as investment looking for near benefits instead of a living place. That provoked lower densities than planned, not reaching a minimum critical mass of population to allow economic viability of public transport and retailing in most of new neighbourhoods. As a consequence, compactness and urban diversity parameters were affected in the same way, and higher use of car is therefore present.

We can also compare recent development areas with traditional urban fabrics using population density parameters. This analysis reflects that those fully developed in last 40 years correspond to medium and low density areas, which means a change from Mediterranean traditional well-mixed possibilities. That has counterbalanced other City Hall efforts to promote sustainable modes (e.g. public transport, pedestrian and cycling networks improvements), and provoked a higher car trip generation per inhabitant. Hence, we can highlight here that current and previous policies using limited densities around 70-75 dw/ha have created less sustainable mobility frameworks than other consolidated and traditional solutions in older neighbourhoods, where density and diversity are quantitatively higher. Additionally, we can analyse particularly the more recent developments (zone 16 in fig 2). Here, RUCyL current standards were applied, but even harmful design was developed leading to higher mobility problems. In this case, despite of verifying variety and social indexes, closed blocks with private oriented urbanization criteria were used as building solution. The block fences do not make possible for non-residents to enjoy open and recreational spaces inside, and they even create an impervious zone for pedestrian itineraries. Besides, horizontal zoning has provoked a separation from commercial areas, increasing distances, which does not favour pedestrian movements. Therefore, most of residents uses car for daily tasks and shopping.

From the comparison of modal share (see section 3.2), we can deduce that the locally performed strategies have meant no significant improvement in trips distribution. Both car and public transport percentages are widely improvable. Summarizing, despite of a legal framework supposed to be oriented to sustainable growth, the achieved densities are too low compared with traditional ones, with undesirable effects on induced car use.

## 5. Planning and design recommendations

As research has shown, land-use policies and design criteria may seriously affect travel choice. The performed analysis allows identifying helpful recommendations for sustainable oriented development, to complete those usually included in manuals, mainly useful in SMC with growing perspectives:

- An appropriate regulation framework is needed, but not enough to ensure good results if low ambitious standards are applied. Current international sustainability assessment methods promote densities too far from those traditionally used in Mediterranean cities, where diversity and short distances have been demonstrated to lead well balanced modal shares. To reach diversity and vitality at pedestrian distances, a high mixed land-use is needed including retail and services. The economic viability requires, accordingly, a high population density.
- The use a variety of building solutions and typologies (multifamily and single-family) to avoid homogeneous solutions may help to achieve a polycentric distribution of densities. However, this requires a minimum development density for positive impacts. In coherence with our results, appropriate densities may be considered over 80-90 dw/ha to observe adequate compactness and diversity.
- Otherwise, high densities are not useful if the diversity and short distances variables are not correlated. The abuse of some high density residential typologies (towers, closed condominiums, large isolated blocks) are negatively connected with the rest of required parameters, so they must be carefully used and well mixed. The repetition of these solutions in a neighbourhood will provoke undesirable effects if only density is controlled, contrary as expected.
- Design of large single-use complex (sports, educational, health) should be exceptionally used due to their high trip attraction features. Polycentric distribution of smaller facilities will perform better in terms of mobility, reducing distances. In addition, too large closed areas create islands where mixed land-use is not accomplished. If large infrastructures are projected, pedestrian and cycling itineraries must be carefully observed to allow free crossing and avoid permeability barriers.
- Regulation should take care of free parking lot standards, and avoid too large free parking areas. Parking availability favour only car use (travel attraction), and means a barrier for pedestrians and cyclist.
- Regulations may include specific standards to be fulfilled in new development projects to ensure minimum values of mixed use, for instance through a % G.F.A. However, these standards are not restrictive enough measures to achieve sustainable results: land-use zoning must be organized to

avoid non-pedestrian distances. Hence, retail and services will provoke better effects if they are not spatially concentrated, but well distributed on neighbourhoods (e.g., using ground floors of multifamily residential). Likewise, a concentration of uses will perform well enough only if distances are strictly controlled to behave in a multi-core fashion. A minimum 10-20% of G.F.A. is here recommended to be kept to uses different than residential (commerce, offices, workshops).

- The human scale and the street width are also important. Too wide streets, even too large sidewalks, will change pedestrian perception of distances and active modes will be not favoured. Special proportions and sizes should be exceptionally used for singular buildings. The same recommendation applies on open spaces: although large areas are sometimes needed, developers must no abuse of concentration. Too big open spaces may reduce vitality or create a desert-like perception if they are not properly designed. To avoid negative effects, a good distribution of smaller spaces should be studied at higher scales, projecting a larger one only when it is really needed or the benefits expected are measurable. Open space ratios are often regulated to reach minimums, but the adoption of strict ranges may provoke the mentioned undesirable effects in some cases. The particular study of current spaces distribution in the surroundings and predicted growth (including current and potential use) maybe the best practice recommendation in this aspect.
- The scale effect must be taken into account also during pedestrian and cycling itineraries design, favouring connection between attraction nodes and avoiding maze-like pathways. The size of junctions must be similarly controlled to limit excessive occupation and avoid pedestrian diversion from natural itineraries.

## 6- Conclusions

This paper has tried to immerse the reader into the urban and planning regulation reality of a Spanish MC, as well as to analyse the effect of some urban planning parameters to induced mobility. Published works in the field suggest the positive impact of the so called *5Ds* to seek a reduced car use. After comparing international standards and those suggested by a Spanish guide for urban sustainability, non-negligible differences were pointed out. Traditional Mediterranean compactness is behind some of these differences. The applied methodology has confirmed the presence of the positive *D* features mentioned by academic literature in this case. The study of Burgos urban parameters has shown coherence with other Spanish patterns in terms of diversity, mixed land-use and vitality. In addition, a polycentric compactness distribution has been identified, which helps to reduce distances for non-work travels and favour soft modes. All this has allowed the confirmation that, as remarkable finding, density may be considered an important indicator of travel behaviour within an adequate compact context. Despite favourable characteristics and distances in consolidated areas, more than 30% of trips in this MC are still done by private car. The last two decades quick growth and housing boom were not adequately managed by planning policies and restrictions, building more dwellings than needed and expanding the city occupied land. Thus, a decrease in density and compactness was promoted in periphery, followed by specific private-oriented residential typologies, which has partially distorted the modal share. In any case, the expected effect of *5Ds* framework has been confirmed by the applied methodology for the studied case.

The revealed travel behaviour may exemplify the negative influence on local mobility induced by unsatisfactory land-use policies and decisions, even when applied regulations are supposed to promote sustainable development. Accordingly, authors have identified a set of recommendations to be applied during the growth of SMCs regarding to planning and design.

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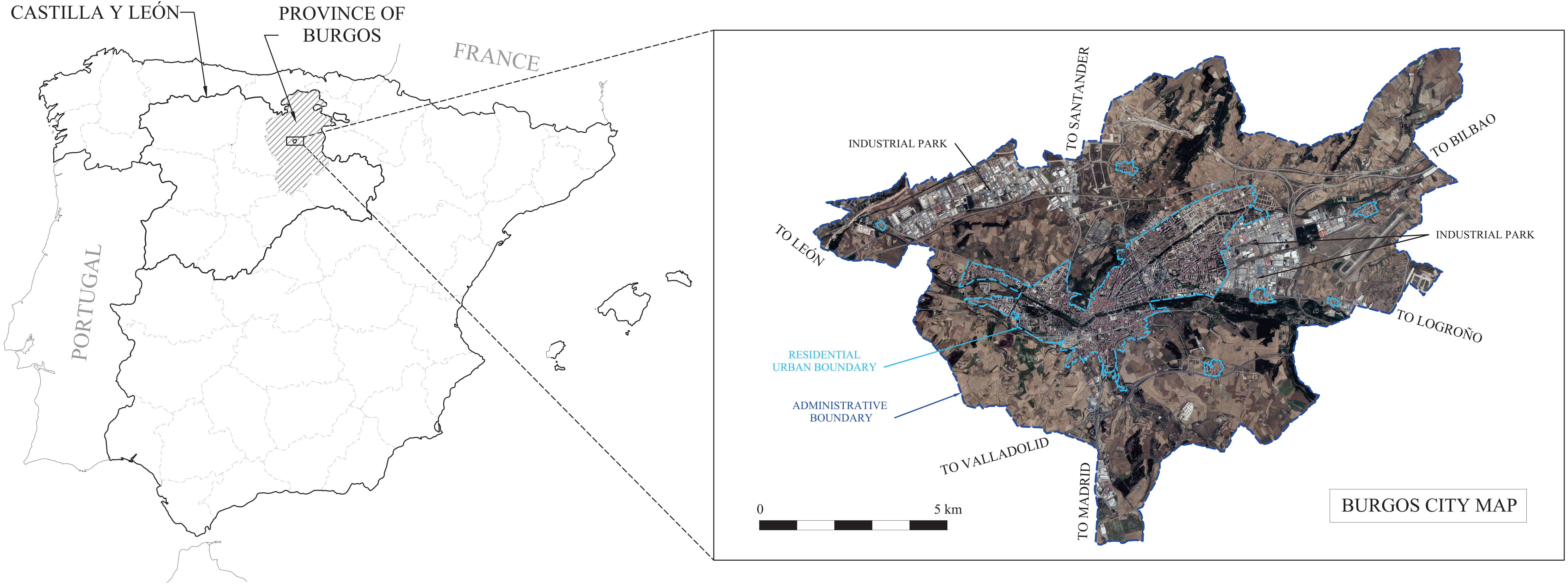
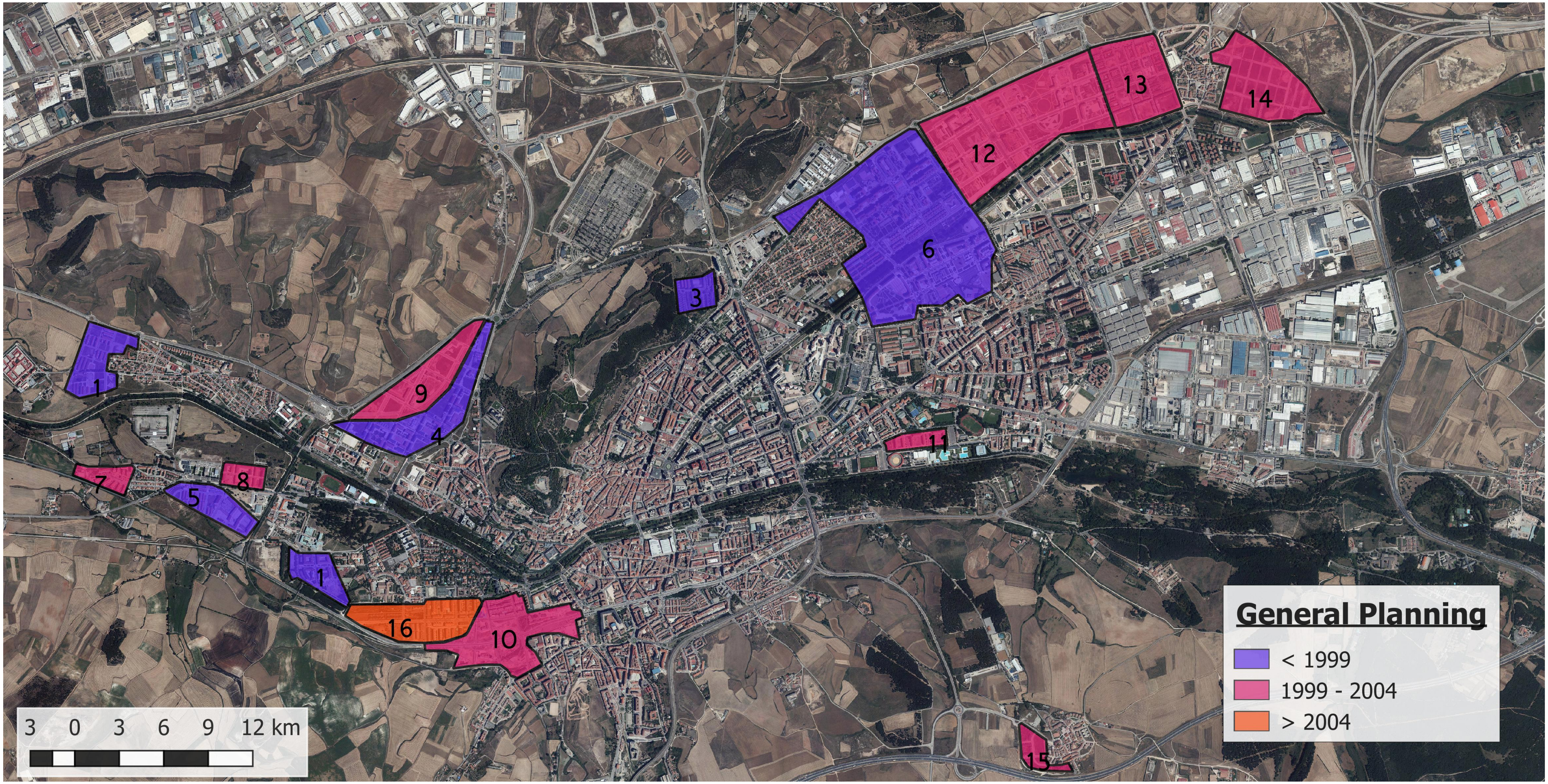
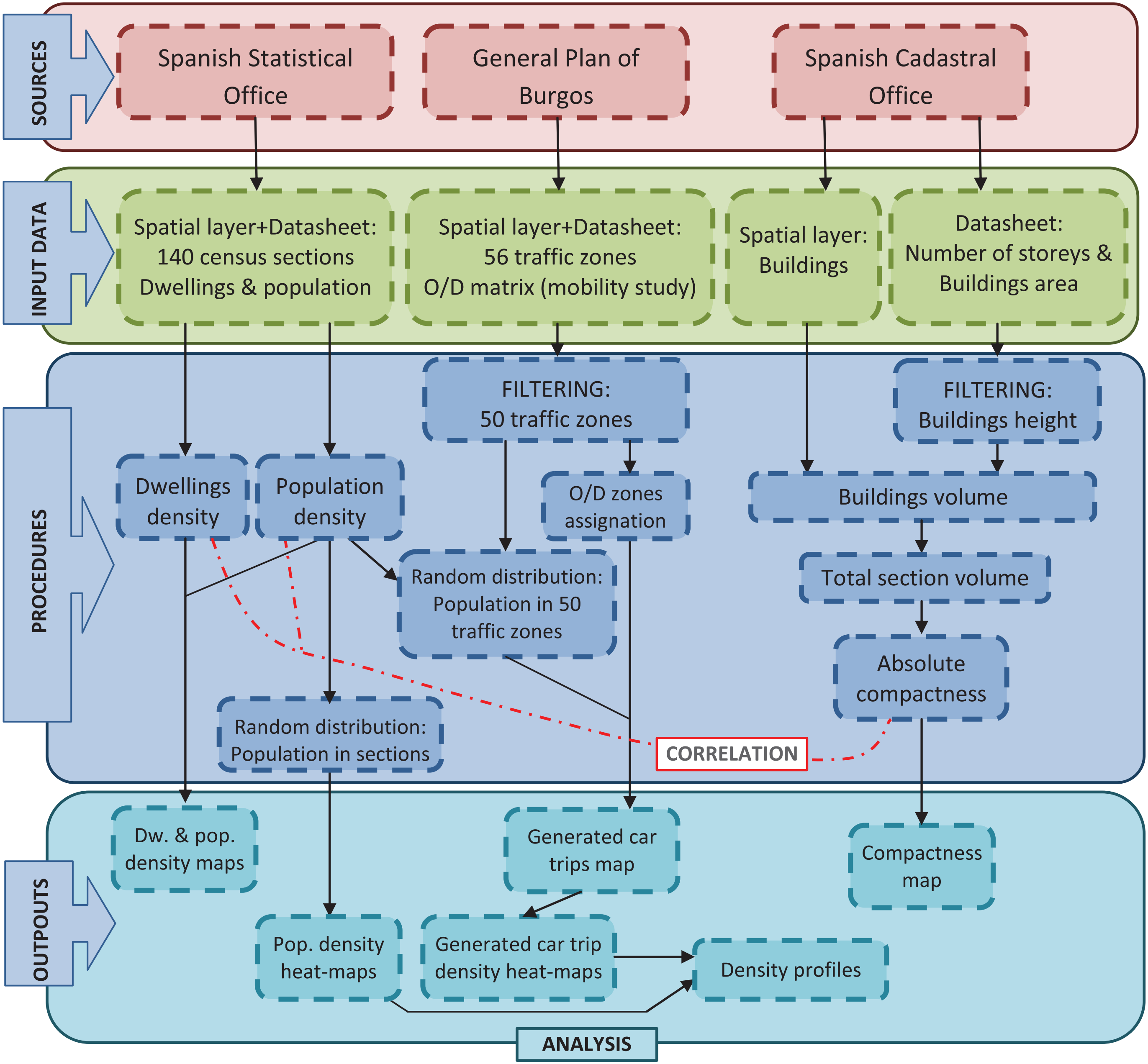
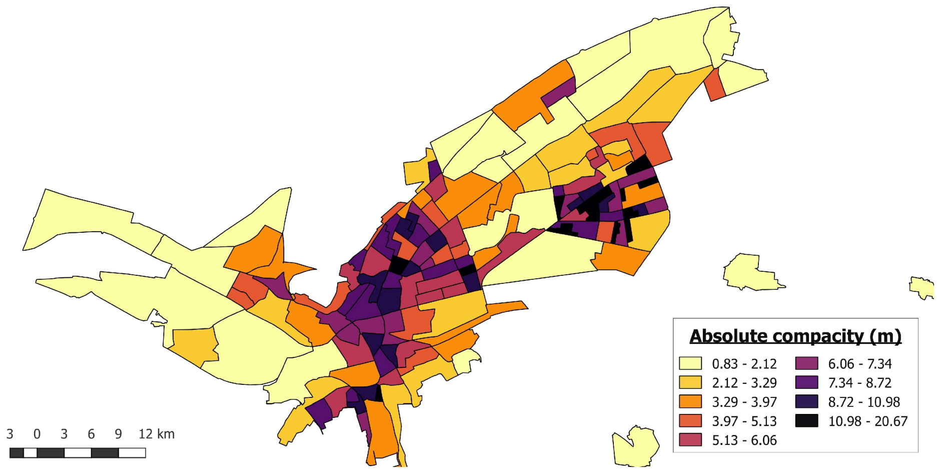
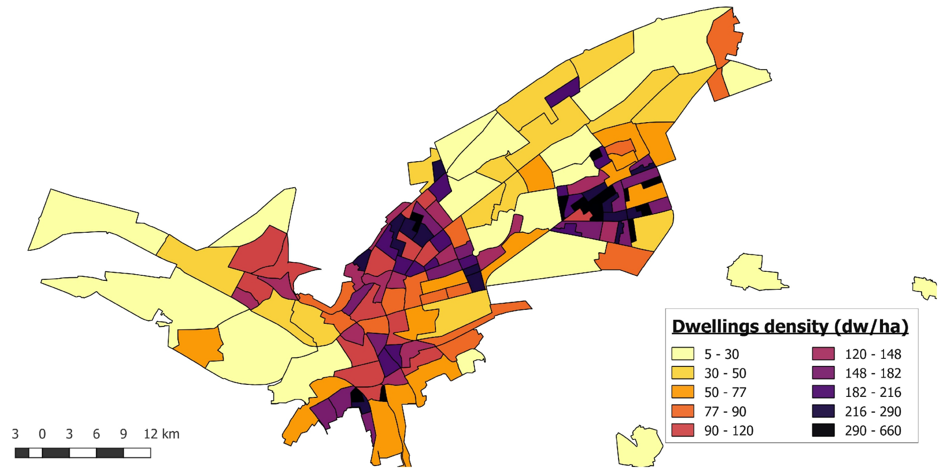
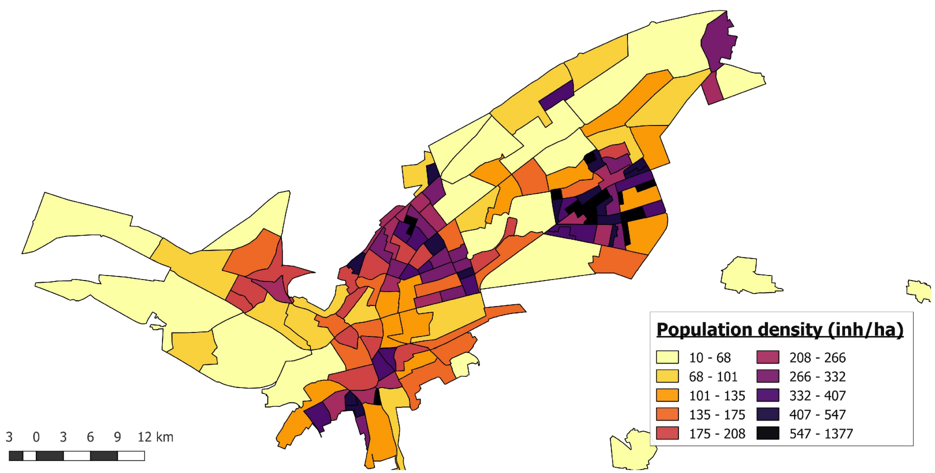

CASTILLA Y LEÓN
PROVINCE OF BURGOS
FRANCE
PORTUGAL
TO SANTANDER
INDUSTRIAL PARK
TO BILBAO
TO LEÓN
INDUSTRIAL PARK
TO LOGROÑO
RESIDENTIAL URBAN BOUNDARY
ADMINISTRATIVE BOUNDARY
TO VALLADOLID
TO MADRID
0
5 km
BURGOS CITY MAP

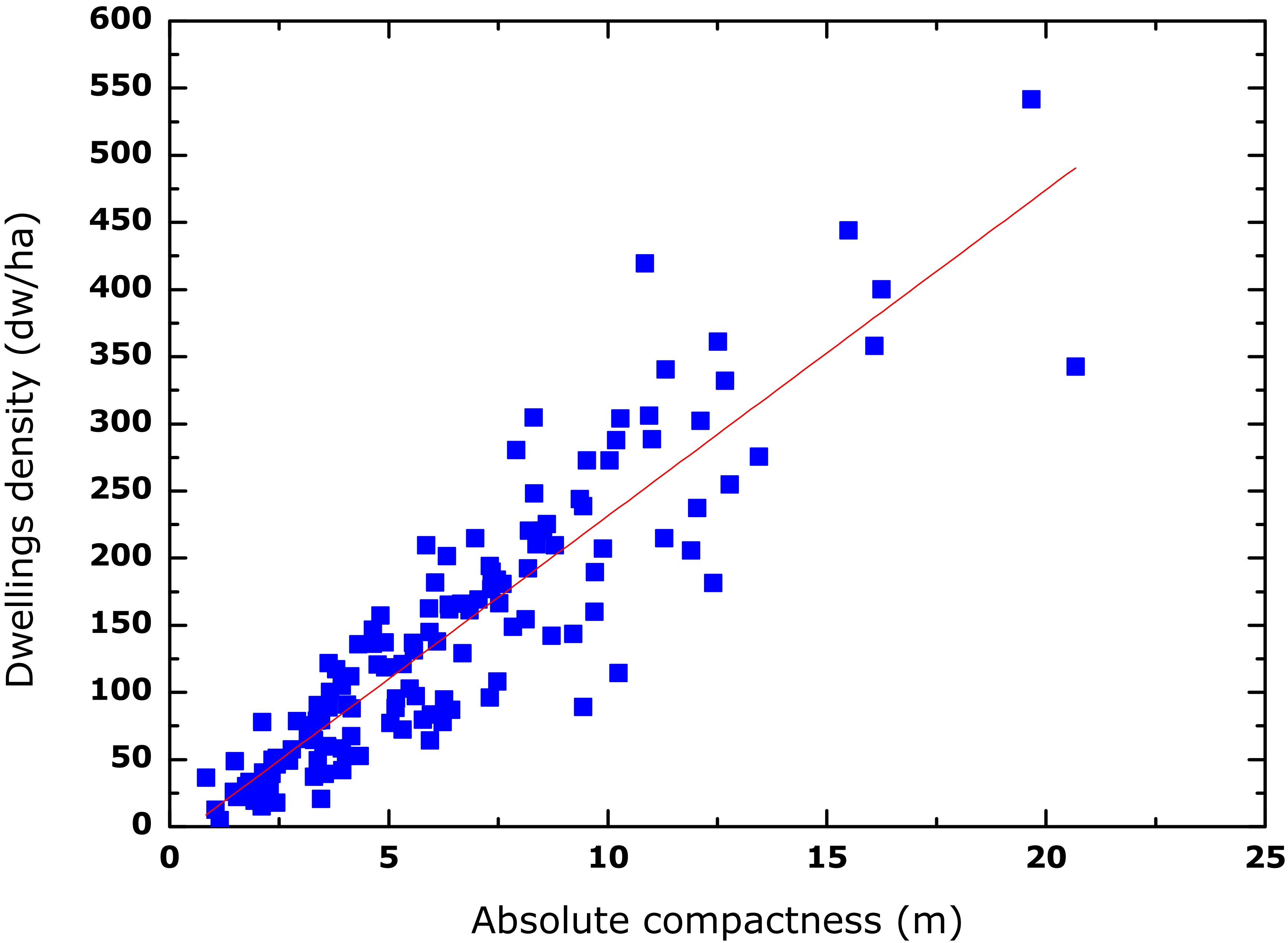

General Planning
< 1999
1999 - 2004
> 2004
3 0 3 6 9 12 km
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16


SOURCES
Spanish Statistical Office
General Plan of Burgos
Spanish Cadastral Office
INPUT DATA
Spatial layer+Datasheet: 140 census sections Dwellings & population
Spatial layer+Datasheet: 56 traffic zones O/D matrix (mobility study)
Spatial layer: Buildings
Datasheet: Number of storeys & Buildings area
PROCEDURES
FILTERING: 50 traffic zones
FILTERING: Buildings height
Dwellings density
Population density
O/D zones assignation
Buildings volume
Random distribution: Population in 50 traffic zones
Total section volume
Absolute compactness
Random distribution: Population in sections
CORRELATION
OUTPOUTS
Dw. & pop. density maps
Generated car trips map
Compactness map
Pop. density heat-maps
Generated car trip density heat-maps
Density profiles
ANALYSIS

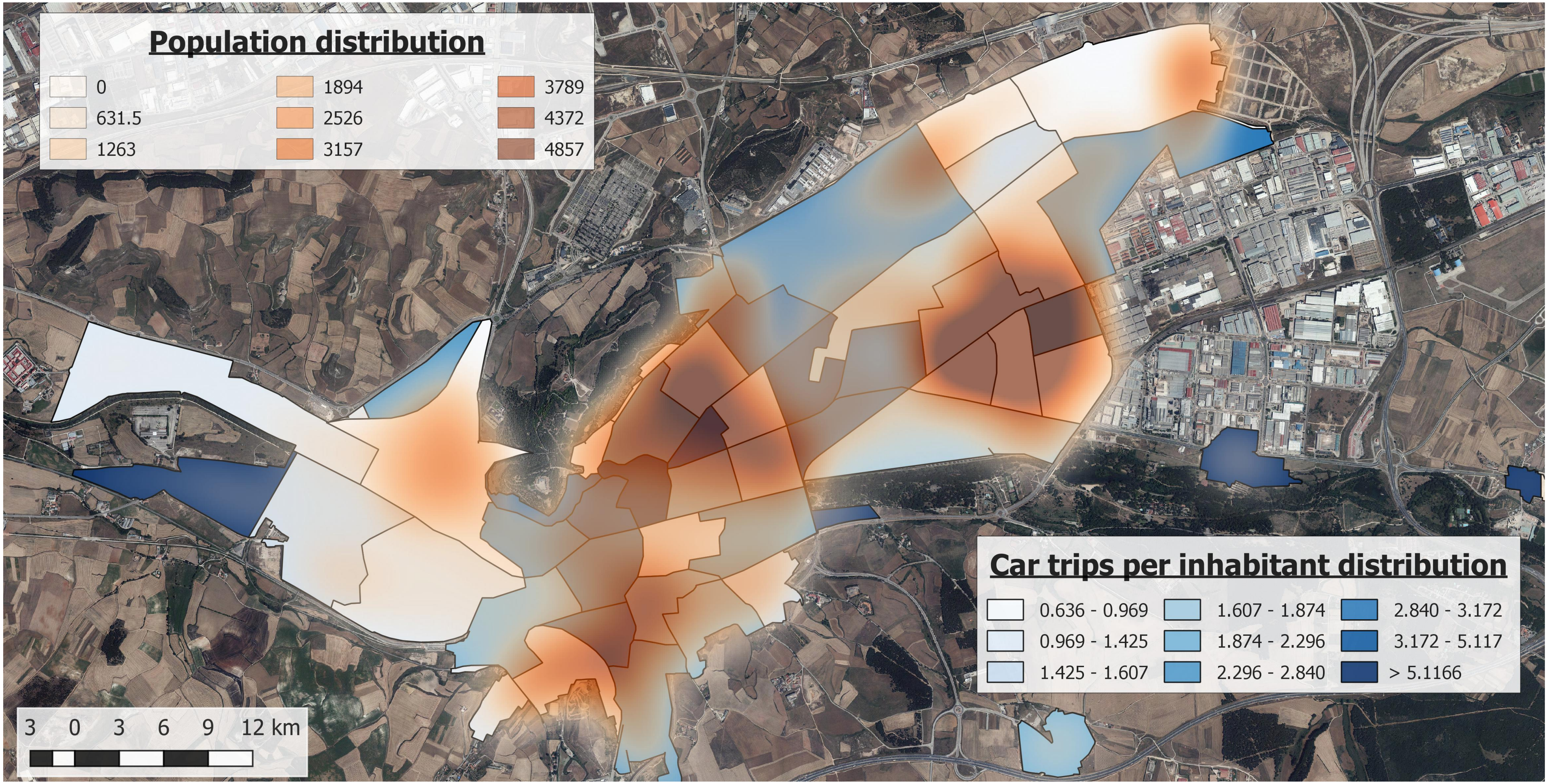

Absolute compacity (m)
0.83 - 2.12
2.12 - 3.29
3.29 - 3.97
3.97 - 5.13
5.13 - 6.06
6.06 - 7.34
7.34 - 8.72
8.72 - 10.98
10.98 - 20.67
3 0 3 6 9 12 km

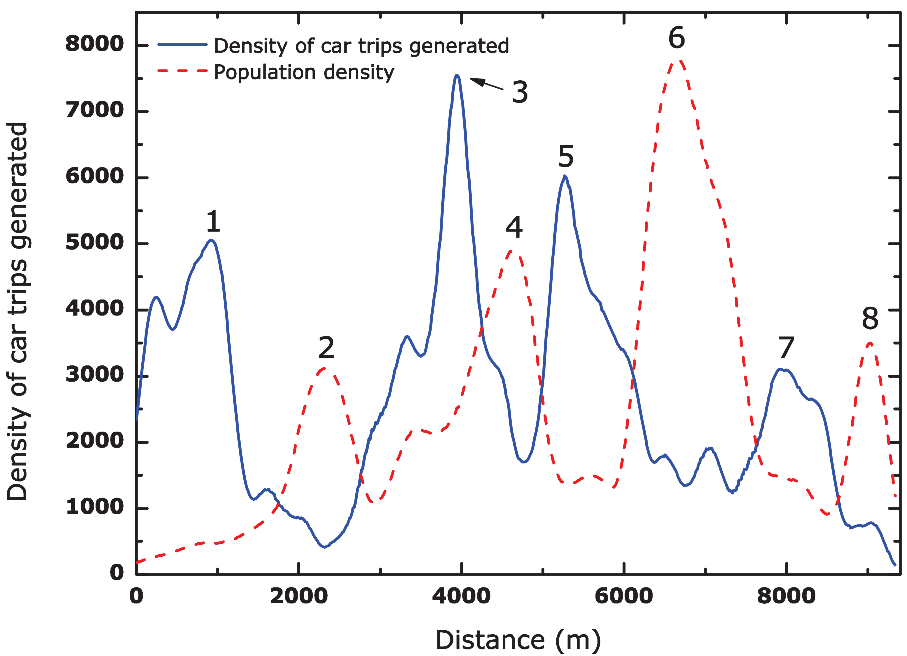

Dwellings density (dw/ha)
5 - 30
30 - 50
50 - 77
77 - 90
90 - 120
120 - 148
148 - 182
182 - 216
216 - 290
290 - 660
3 0 3 6 9 12 km

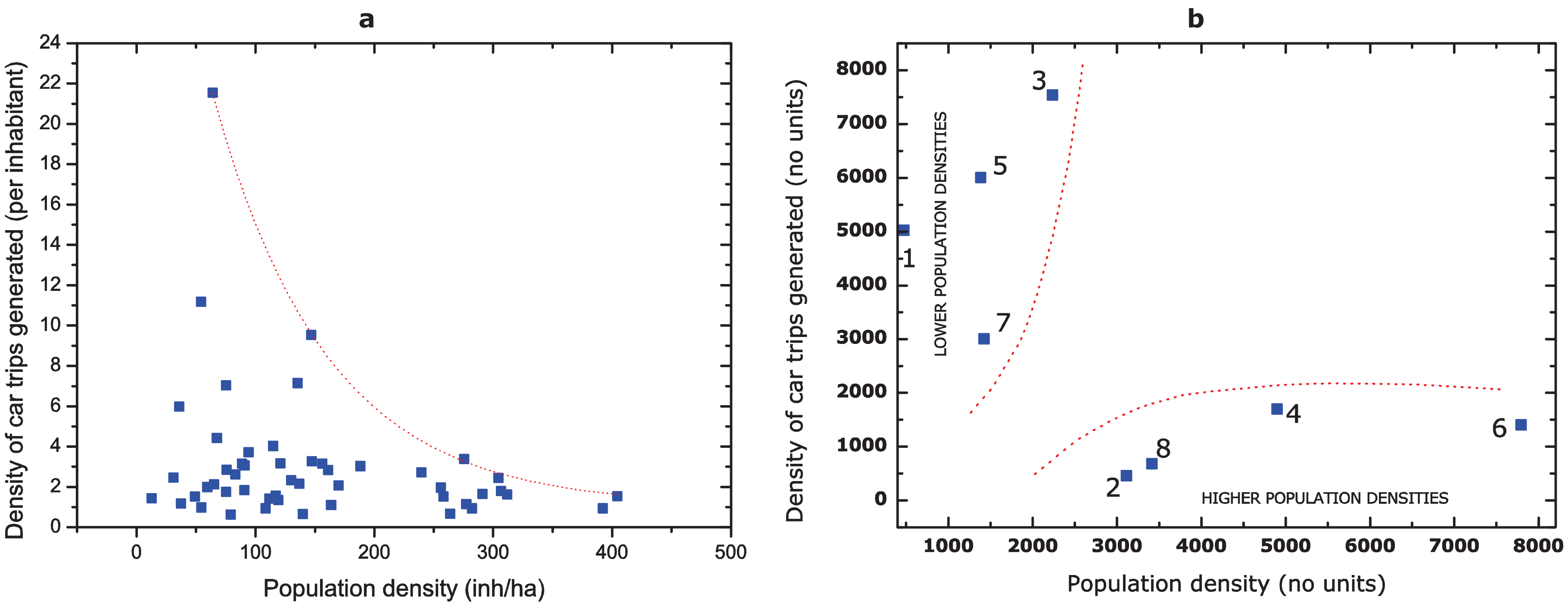

Population density (inh/ha)
10 - 68
68 - 101
101 - 135
135 - 175
175 - 208
208 - 266
266 - 332
332 - 407
407 - 547
547 - 1377
3 0 3 6 9 12 km



600
550
500
450
400
350
300
250
200
150
100
50
0
Dwellings density (dw/ha)
0
5
10
15
20
25
Absolute compactness (m)


Population distribution
0
631.5
1263
1894
2526
3157
3789
4372
4857
Car trips per inhabitant distribution
0.636 - 0.969
0.969 - 1.425
1.425 - 1.607
1.607 - 1.874
1.874 - 2.296
2.296 - 2.840
2.840 - 3.172
3.172 - 5.117
> 5.1166
3 0 3 6 9 12 km


Density of car trips generated
Population density
1
2
3
4
5
6
7
8
0
1000
2000
3000
4000
5000
6000
7000
8000
0
2000
4000
6000
8000
Density of car trips generated
Distance (m)


a
Density of car trips generated (per inhabitant)
Population density (inh/ha)
b
Density of car trips generated (no units)
Population density (no units)
LOWER POPULATION DENSITIES
HIGHER POPULATION DENSITIES