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Metropolitan Barcelona 2001-2006 or how people's spatial-temporal behaviour shapes up urban structures

Traditionally, urban structure has been analysed using employment density or commuting. The main contribution of this paper is the use of a new source of information which includes other daily activities and which can be integrated into existing subcentre-identification methods. Thus, subcentres are identified using a time-density indicator departing from origin-destination-surveys. Results suggest that changes in urban structure during the period under review have taken place in parallel to economic growth and that urban sprawl has increased in all activities except for health care and work, where the timeshare lost by the CBD has been redistributed to subcentres and peripheries.

Keywords: urban structure; spatial-temporal behaviour; trip-chain analysis

1. Introduction

Urban structure (*i.e.* the spatial distribution of residence and jobs) has deep implications on social, environmental and economic dynamics. In the literature urban structure has been restricted to the analysis of the distribution of population and employment density or, alternatively, of commuting flows. Such approaches are correspond to the final period of industrialization when employment was the main driver steering the day-to-day organization. In contemporary Western societies, however, factors like flexiwork, the increasing number of temporary/part-time contracts and relocations, as well as the emergence of telework have dwarfed the importance of the workplace (Marquet & Miralles-Guasch, 2017). Simultaneously, social activities connected to the use of free-time, leisure and personal/family time (*i.e.* related to social and cultural reproduction) have gained more importance. Overall, this poses a challenge to the identification of urban structures. The purpose of this paper is not related to the creation of a new subcentre identification method but to provide a new source of information that can be integrated into preexisting subcentre-identification methods. Such information is based on data extracted from the spatial-temporal behaviour of population. The two main advantages of this source of information are the fact that it allows the inclusion of different activities other than work that drive people's daily lives and, thus, shape up the way they make use of the city. It also takes into consideration the time span people spend in each area of the city. Diversity of activities and permanence shape up the concepts of urbanity and sense of place, which have been acknowledged as relevant for city dynamism and, thus, of paramount importance for planning purposes.

The two objectives of this paper are the following:

- Identifying urban structures (*i.e.* subcentres) using information based on the spatial-temporal behaviour of people.

- Identifying changes in urban structures which have taken place in a short period of time characterized by a shift in the general evolution of the economy.

To that end, a trip-chaining analysis is performed based on household origin-destination-surveys from 2001 and 2006 for Metropolitan Barcelona. A time-density indicator is constructed on the basis of that analysis in order to identify/characterize subcentres using a simple but effective double-threshold subcentre identification method. The formal comparison of the efficacy of this approach versus those based on other indicators of urban structures is out of the scope of this paper. Yet, it lays the foundations for future research and usage of spatial-temporal data in order to identify causalities and interlinkages among activities and their physical support.

The remainder of the paper is organised as follows: section 2 offers a review of the methods for subcentre identification, a discussion on the necessity of the proposed approach and the theoretical framework of time-geography; section 3 illustrates the case study, data and methods; section 4 splits the results into two parts encompassing the presentation of the identified urban structure and its evolution; and the conclusion presents the analysis of the findings from an urban planning perspective.

2. Literature review

The majority of polycentrism literature has considered the concept of subcentre as equal to the employment concentration attracting commuters. Therefore, a convergent subcentre is defined as site with significant larger employment density than other nearby locations and which has a significant effect on overall employment density- as pointed by Roca *et al*. (2009). Such authors as well as Krehl (2016) have conducted comprehensive and critical reviews of "subcentre" identification methods based on this conceptualization. In brief, such methods are split into two approaches.

- The morphological method uses GIS to detect local peaks of employment (e.g. McDonald, 1987); density and absolute employment thresholds to identify subcentres sites that surpass them (e.g. Giuliano and Small, 1991); parametric methods to signal sites whose density is statistically superior to the reference provided by a regression in which density is a function of CBD proximity (e.g. McDonald and Prather, 1994); non-parametric methods based on locally-weighted-regressions to break the one-dimension symmetry implicit in conventional parametric models or flexible functional specifications such as splines (e.g. Muñiz *et al*., 2003).

- The functional approach identifies subcentres by using the ratio of travelers attracted by local jobs (Gordon *et al*., 1988), spatial models in order to identify zones that actually drive a higher flow than the one predicted by a gravity function (Camagni, 1994), as well as the interaction value in order to simultaneously detect centralities and their hinterlands (Roca *et al*., 2009). Other approaches combine mixed methods and incorporate the profile of economic activities located in subcentres (Solis *et al*. 2014).

Whether only employment concentrations can be regarded as subcentres is certainly the product of distinct urban conceptions. In U.S. cities, land use segregation has been portrayed since the first models of the Chicago School of Sociology assimilating the centre to a large concentration of employment (business) (Rauhut, 2017), further exacerbated by exclusive-zoning policies. Eventually, due to disexternalities and transport innovations suburban-employment concentrations (*i.e*. subcentres) and urban-sprawl emerged (Champion, 2001), thus generating a polycentric landscape. Nonetheless, in Europe such landscape is basically the product of the

coalescence of existing historical centers and planned subcentres (e.g. Parisian new-towns). In this latter process the Central Place approach focuses on the diversity of urban activities (not only work-related) and provides with a compelling method for center/subcentre identification (Veneri, 2013). This is mainly due to the fact that employment density does not always attract complementary activities and some of them exist even without employment. As Chen *et al.* (2017) point out, multiple nature activities combining work, shopping, socializing or leisure have rarely been systemically studied. Therefore the analysis of such activities rises to a more comprehensive definition of functional urban centers reflecting the actual usage of places. This paper aligns with this broader perspective with the following two contributions: 1) a complete set of activities coming from the same source of information (which allows to identify the coexistence of different urban structures and its diversity), 2) the amount of total time, and not only the number of people, allocated to perform such activities on each site. The time devoted to perform activities constitutes an excellent indicator of the importance people shed to the different sites, since this represents the most limited asset they have. Also, findings indicate that it is correlated with subtle characteristics of relevant sites such as urbanity and urban-quality (Marmolejo & Cerda, 2012) that are not necessarily present in all employment-concentrations (Jansen, *et al*., 2017). The suggested procedure can be considered as part of the time-geography framework.

Time-geography as an analytical framework to study urban structures

The fusion of time and space in a unified analytical framework for the study of social processes is quite recent. Although Randle (1965) recognized that the spatial-temporal displacement of people could bring an additional dimension to landscape, it was Hägerstrand (1970) who set the basis for the establishment of ‘time-geography’. His

main contributions were the shift in the subject of the study from zones to persons, whose life experiences are closely linked to time, as well as their capacity to overcome the friction of space. Individuals have different features and, therefore, different spatial-temporal possibilities; people move around the space through a smooth process, rather than in leaps, as is the case in a timeless analysis. Thus, time-geography relies on elements such as 'paths' that connect 'stations' where 'projects' occur, assembling an elegant framework to understand human activities and interactions (Shaws, 2012).

Not surprisingly, time-geography attracted not only followers (Pred, 1984) but also naysayers who mainly criticized the reductionist nature of reality, overloaded with physical features. Accordingly, Harvey (1989, p. 211-212) states that 'time-geography is a useful descriptor of how the daily life of individuals unfolds in space and time yet it reveals nothing about how stations and domains are produced, or why the friction of distance varies in the way it palpably does'. Maybe such criticism raised from the pretentious consideration of time-geography as a theory instead of a methodology: it constitutes a foundation for a general geographic perspective which attempts to consolidate the spatial and temporal perspectives of different disciplines. It is not a subject *per se*, or a theory in the strict sense, but rather an approach to gather knowledge from different scientific areas and reveal relations (Lenntorp, 1999). Thanks to the critics, Hägerstrand made great efforts to extend his original framework gradually replacing *Choros* with *Topos*, *i.e.* space with the place; and *Chronos* with *Kairos*, *i.e.* time objectively measured at the right moment to act judiciously.

Theoretical criticisms aside, time-geography was pushed forward with great effort due to the high cost that the gathering of spatial-temporal information entailed back at that time, as well as to the lack of affordable computational techniques. It was not until the 90's, with the advent of new spatially-aware technologies, in addition to

the development of geospatial science and Big Data processing, that the costs of data gathering and processing/modelling/visualizing decreased, at the same time as spatial-temporal dimension representation was made easier (Buliung & Kanaroglou, 2006), see a comprehensive review of such location-aware technologies in Spangenberg (2014), the diversity of applications/analysis-methods directly linked to time-geography in An *et al.* (2016) and implementations for Barcelona in Delclòs *et al*. (2017).

Despite the revolution of location-aware technologies, origin-destination-surveys constitute adequate sources of information to study the spatial-temporal behaviour of people (Delfino, 2009).

3. Case study, data source, and methods

The Metropolitan Region of Barcelona (MRB), comprising 164 municipalities (3,236 sq. km, 4.79 million inhabitants in 2006 according to the National Institute of Statistics-INE), serves as the case study. The analysis is carried out on a municipal level, which is the standard unit in the studies of urban structure in Barcelona (see a comprehensive review in Ureña *et al.,* 2013) given the relatively small size of municipalities (4.5 sq.km on average). The inclusion of a 5-year period (*i.e.* 2001-2006) allows for the identification of any shifts within a booming economic cycle. According to the INE, Barcelona, and Spain in general, experienced the end of the economic boom during that period: the GDP grew by an annual average rate of 8%, while 5 years before it was 7%, and 5 years later it dropped to 1%. This growth translated directly into job creation and the decrease of the unemployment rate from 11.5% to 9.03%. The subsequent downturn brought the unemployment rate up to 21.08%. Therefore, the period under review

constitutes a booming cycle both in terms of economic growth and employment rate. After this five-year period, the crisis arrived.

The spatial-temporal behaviour of people is studied departing from a trip-chain analysis derived from ATM's Enquesta-de-Mobilitat-Quotidiana (EMQ) origin-destination-household-surveys for the years 2001 and 2006. This latter was the last year that the EMQ was conducted in Barcelona and, consequently, it is not possible to track the evolution of urban structures after that period using this source of information. However, it could be postulated that the effect detected during the period of economic boom would be inversely reflected (like a mirror) in a period of crisis. Unfortunately, there are no exactly equal empirical data to be used as backing evidence for this mirror behaviour even though it is somehow endorsed by research departing from the working-day-survey (Marquet & Miralles-Guasch, 2017).

Table 1 contains: 1) all the details of the EMQ surveys (*i.e.* coverage, universe, sample, collection method, etc.); 2) the depuration process implemented as to eliminate inconsistent spatial-temporal data, and 3) the selection criteria of cases used in this paper. The change in methodological approach in EMQ-2006 suggests the analysis of proportions and average-times instead of absolute figures, as well as a relative-based subcentre-identification method, as explained below.

Tab.1

The methodology comprises 3 stages.

1) *Trip-chain analysis to compute time devoted to perform activities as well as attracted trips*

A trip-chain is the time-ordered sequence of trips made during a day by each respondent in the survey. For each trip the EMQ registers its origin-zone/time, destination-zone/time, mode of transport, respondents' (*i.e.* travellers) sociodemographic information and activity inducing the trip (*i.e.* activity to perform at the destination zone). The supplementary file offers a comprehensive list of EMQ-activities and how they have been grouped into the 6 types analysed in this paper: work, study, shopping, health care, socializing and leisure. Home activities are not considered since the interest lies in identifying activity-subcentres. Using each respondent's trip-chain as a basis it is possible to calculate the amount of time devoted to undertake each activity in any zone using the following formula (1):

$$T_{jkz} = Dt_{jnm} - At_{jkz} \qquad (1)$$

Where T_{jkz} stands for the amount of time (*i.e.* minutes) devoted by respondent-*j* to perform a *k*-activity in a *z*-zone (*i.e.* municipality for the purpose of this paper); Dt_{jnm} represents the departure-time of the same *j*-respondent to perform the next *n*-activity in an *m*-destination-zone (in case of self-contained trips the *z* and *m*-zones coincide); At_{jkz} corresponds to the arrival-time of respondent-*j* to perform the *k*-activity in *z*-zone. The sum of T_{jkz} for all *j*-respondents ($j=1...n$) for a given *k*-activity in a *z*-zone amounts to the total time allocated to perform such activity in that zone by the total number of respondents throughout a working day. The sum of all *j*-respondents ($j=1...n$) arriving to perform a given *k*-activity in a *z*-zone represents the total number of people carrying out such activity in that zone throughout the same working day. This process is repeated for all 6-*k*-activities and 164-*z*-zones and then broken down into 3 different educational levels of *j*-respondents.

2) Time density and diversity

Time density is calculated using the following formula(2):

$$TD_{kz} = \frac{\sum_{j=1}^{n} T_{jkz}}{Ua_z} \quad (2)$$

Where TD_{kz} stands for the total number of hours divided by the developed area reported by all *j*-respondents performing a *k*-activity in a *z*-zone. Ua_z represents the urbanised area of a *z*-zone. The higher this indicator is, the larger the intensity of use (Marmolejo & Cerda, 2012). Urbanized land comes from the artificialized areas from the CORINE remote sensing project (retrieved from IGN) for the years 2000 and 2006.

In order to identify activity and socio-educational diversity levels of zones Shannon's H-entropy-index is used:

$$H_z = -1 \cdot \sum_{k=1}^{n} P_{jkz} \cdot \ln(P_{jkz}) \quad (3)$$

Where H_z is the level of diversity of activities at a *z*-zone; P_{jkz} represents the probability to find a *j*-respondent performing a *k*-activity in *z*-zone. The socio-educational diversity, which acts as a proxy indicating the socioeconomic profile of the respondents, is similarly computed using the 3 levels of education registered in the survey (*i.e.* basic, intermediate and university). The larger the *H*, the higher the diversity in zone *z*.

3) Subcentre identification

This paper uses the method developed by García-López (2007) which relies on the double cut-off threshold. Accordingly, a subcentre in a *k*-activity is: 1) a municipality that has a time-density level for that *k*-activity which is higher than the respective

metropolitan time density; and 2) 'time spent' makes up more than 1% of the overall time devoted to that activity in the metropolis. This method offers two advantages: on the one hand, it does not rely on *ad-hoc* threshold criteria, which facilitates replicability; and on the other, it remains robust to changes in the structure of time use since it renders both thresholds relative at a determinate moment. Therefore, it is useful for the comparison of two moments, which is precisely what has been done in this paper.

The comparison between the situation in 2001 and 2006 allows us to identify changes in the subcentre structure, diversity of activities, time allocated in each territory (*i.e.* centrality/periphery) and activity. The supplementary file offers a comprehensive descriptive statistical analysis for each indicator.

4. The urban structure of Barcelona from a spatial-temporal perspective

Fig.1 represents the spatial distribution of time-density, differentiating working-time density from leisure-time density. . By comparing both densities different spatial trends in the allocation of non-home activities across the city can be identified. For example, *while working tends to concentrate in few nuclei, other social activities have a more sprawled and polycentric pattern*. These latter activities are more present in coastal (*e.g*. Maresme-leisure area) and peripheral locations (*e.g*. Montseny-mountain area), where outdoor amenities make up for the relative absence of buildings (and employment).

Regarding subcentres, 17 activity centralities (including the CBD–Barcelona municipality-) are identified in 2006: 5 of them located within the central-conurbation around the CBD, while 11 of them correspond to outer subcentres. As a whole, these 17 centralities concentrate 72% (43% in the CBD) of all non-home time spent in the

metropolis. There are only 11 working nuclei that capture 69% of all working-time, *as a matter of fact, this is the least concentrated activity*, while the most polycentric pattern is to be found in health care, where 13 centralities account for 88% of the total amount of time devoted to health-care. Study-time is the second most concentrated activity, 83% takes place in 11 centralities. Shopping-time also has a relatively high concentration in 11 centralities, followed by leisure and socializing, which tend to be less concentrated due to the fact that some of these activities take place outdoors or even in the home of relatives and friends. Overall, we can say that the MRB is more polycentric for non-work-related activities. *As a result, by taking into consideration only job concentrations, which seems to be usually the case in literature, the polycentric structure of cities may be underestimated*. And, most importantly, it may hide meaningful zones capable of stepping beyond the frontier of 'work-concentration-zones' to become 'places' as originally defined by Augé (1992).

Fig.1

One distinctive feature of centralities is the widespread variety of activities that takes place in them. The number of activities for which a given municipality is to be accounted as a centrality can be understood as an indicator of hierarchy, since the higher the amount of activities, the more attractive that place is (Veneri, 2013; Chen *et al*., 2017). In that sense, a select set of centralities are ranking in the top positions of nuclei-activity, such as Barcelona, Badalona and L'Hospitalet (all of them in the central-conurbation area), as well as also other centralities with a historic development parallel to that of Barcelona, such as Granollers, Mataró, Sabadell and Terrassa. These latter 'mature' subcentres are, in fact, formerly independent centres that have coalesced into the MRB as transport costs have decreased, and new infrastructures have been built (García-López & Muñíz, 2010). Interestingly enough, decentralized subcentres (*i.e*.

those generated as a result of employment decentralization) show a lower level of diversification. For example, Barberà, Cerdanyola, Martorell, Mollet or Viladecans are mono-activity subcentres. In all of them, the public distribution of assembled land devoted to manufacturing premises (e.g. land developed by the Catalan Land Institute) seems to have played a role attracting industrial/logistic activities. Another feature of such centralities is the fact that they act as outer subcentres, which are located well beyond the central-conurbation.

How has the urban structure changed between 2001 and 2006?

As for time distribution, the data included in Fig.2 suggest that working time decreased during the period of study. Conversely, the share of time devoted to activities related to social reproduction and consumption increased. This temporary trend is compatible with the fact that within a growing economic scenario people can invest more time in activities linked to private consumption, such as shopping or eating/drinking out. Interestingly enough, this trend is more important in suburban municipalities where the loss of time share for working activities is remarkably larger than in centralities, whilst the gain in leisure activities is the largest.

Fig.2

According to Fig.3, work is the activity with the largest average duration, i.e. 5.9 hrs/person/day, followed by study. On the opposite extreme is shopping and socializing with a total of 1.3 hrs/person/day for both. In general, longer activities take place in the CBD and shorter ones in the suburbs, which may imply a lower degree of specialization.

In the period studied the average duration of activities was reduced. The reason is partly due to the number of activities per day, which increased by approximately 30% between 2001 and 2006. As a result, people undertake more activities (and travels) in the same daytime. Nonetheless, the average duration of activities related to work and study witnessed a more significant reduction than those related to social reproduction, which is consistent with the change in the time share between the different activities.

Fig.3

From 2001 to 2006 the diversification of activities and socioeconomic profiles has changed (Fig.4). Overall, all the territories included in the study are more diverse, in terms of activity and socioeconomic profiles, in 2006. This trend is particularly clear in the suburbia, which witnesses the most important increase of all zones in terms of diversity. Centralities saw a more moderate increase of their diversity, probably due to the fact that the activities conducted there tend to be more consolidate. In spite of that, in 2006 they continue to boast the highest level of diversity in terms of activity and education compared to the suburbs.

Fig.4

Fig.5 details the change in the urban structure understood as number of subcentres and, for each activity, it shows the municipalities that maintain (M) in 2006 the status they had in 2001, appear (A) as nuclei in the concentration of a given activity and those that fail to meet the double cut-off criteria to be considered as a centrality and end up disappearing (D). Overall, polycentricism (*i.e.* number of centralities) has increased by a total of 2 new subcentres. As a matter of fact, 5 municipalities emerge as subcentre. Out of those, Vilafranca is a special case since it appears as a nucleus for 2

activities, *i.e*. shopping and health-care, thus consolidating its role as a county capital as well as its historical tradition as a retail county-centre. 2 of them disappear. From them, Vilanova is the most affected municipality as it ceases to concentrate 3 activities, all of them related to social reproduction. All mature centralities (*e.g*. Barcelona, Granollers, Sabadell, Terrassa and Mataró) maintain their role as nuclei for all the activities under study, reinforcing their position as historical centralities. Conversely, emerging centralities (*i.e*. those acting as nuclei for few activities) show more instability, such as Gavà and Pineda, which lost their power to concentrate socializing time, or Mollet, whose loss in socializing activities is partially compensated by its emergence as a study nucleus.

Regarding the different activities, health care emerges as the one boasting the largest number of new centralities, most of them located beyond the central conurbation. This trend may be associated to the suburbanization of the population in new urban fabrics since urban planning legislation in Catalonia requires land to be reserved for local facilities such as primary health care centres in new developments. Working is the second most important activity considering the number of new centralities. On the other hand, activities such as shopping and leisure have witnessed a modest growth and, in the case of socializing activities, even a decrease in the number of nuclei.

Fig.5

Fig.5 also depicts the change in time concentration. Overall, centralities have lost share in time concentration, moving from 78% in 2001 to 72% in 2006; the CBD has lost more share (53%->43%) than subcentres (29%->25%). The CBD has lost share in all activities, mainly in socializing and leisure activities, followed by health-care and shopping. It is worth noting that peripheries have gained share in their spatial

concentration for all of these activities. Thus, it can be said that social reproduction activities have given rise to a decentralization pattern compatible with that of the urban sprawl, with the exception of health-care activities, which boast a balanced decentralization pattern: half of them concentrated in subcenters; and the other half, in peripheries, such is also the case of working time. This latter finding is consistent with the fact that work and health care are the activities boasting the largest number of new centralities, as mentioned before.

A complementary perspective is provided by the importance of subcentres, understood as the proportion of people attracted to carry out different activities. Fig.6 illustrates how the CBD has lost its power to attract flows in all activities. Nonetheless, the drop is larger for health care and leisure, while milder for study. The case of health care is particularly interesting since the suburbs witness a significant increase in the number of people attracted, but not in the time devoted to perform this activity. This suggests that *the sprawling of activities contributes to reducing their duration.*

Fig.6

5. Discussion and conclusions

Urban structure is understood as the spatial distribution of activities and population. As a result of the lack of data, rather than out of conviction, most of the attention has been drawn in the literature only to employment as a means to identify the nodes of such structure, despite the fact that in times of maximum employment it only accounts for 63% of non-home-time in Barcelona. This paper takes one step forward to identify centralities and the changes they undergo in a short period of time by departing from the analysis of temporal-spatial behaviour of population, which is linked to the Time-

Geography framework. The novelty of the approach consists in the simultaneous analysis of both time and space coordinates, since 'human experience can only occur in, and through, movement over space and time' (An *et al*.; 2015:16) for *all* daily-activities. In doing so, a trip-chaining analysis derived from origin-destination-surveys has been implemented. This information provides an extensive scope of coverage in terms of spaces, activities and demographics and depicts a comprehensive picture of daily dynamics in cities (Delfino, 2009), as opposed to the GPS approach, which is expensive or entails large efforts to make it significant for large populations (Delclòs *et al*., 2017).

Using a simple double-threshold methodology a number of municipalities have been identified as subcenters in the metropolitan Barcelona.

In brief, Barcelona emerges as a polycentric metropolis which is more polycentric for social-reproduction activities (*i.e.* socializing, leisure, shopping, health care). In 2006, 69% of the overall working time in the metropolis is concentrated in only 11 employment centralities, while 75% of the total time devoted to social reproduction activities is concentrated in up to 13 nuclei. *Failure to detect these hidden divergent location patterns by merely taking into consideration employment concentrations, which seems to be the case in the literature, can render the analysis of urban structures incomplete*. On the other hand, spatial-temporal behaviour of population is more informative than the number of jobs, since it allows us to quantify the intensity of use of a given zone (*i.e*. number of hours spent in a zone) not only in terms of number of people. This, in turn, adds a layer of *meaning in terms of urban richness*, as we can identify 'places' or *topos* rather than simple zones in the Time-Geography language.

In Barcelona, centralities concentrate long-lasting activities, which suggests that the citizens deem them interesting and attractive; on the contrary, peripheries concentrate slightly shorter-term activities. Centralities also stand out as diverse points in terms of concentration of activities, in fact, there is a clear correlation between consolidation of nuclei and diversity in terms of the number of activities conducted as well as the socio-educational profile of the population undertaking them. Historical subcenters that witnessed an endogenous development parallel to that of the CBD stand out as more diverse than emergent decentralizing centralities. This finding challenges planning policies aimed at creating *urban* centres from scratch while providing infrastructure and land assembly.

One key feature of the spatial-temporal analysis has to do with its ability to easily identify changes in the daily urban dynamics; this feature is far from present in other approaches such as the analysis of employment or population densities. In Barcelona polycentrism and sprawl increased during the end of the booming economic period 2001-2006. According to Marquet & Miralles-Guasch (2017), both personal and labour mobility increased greatly during that period, highly dependent on cars, while, at the same time, residential location choices gained independence from job places, favouring residential suburbs. In short, increased familiar budgets allowed for the extension of the length/number of trips (and activities). Evidence compatible with the influence of highways on land-use patterns and location of housing found by García-López *et al.* (2015). In 2001 centralities concentrated 78% of all the stay-time people spent outside from home, while in 2006 this figure barely reached 72%. This decline is especially relevant in the CBD. In spite of this decrease, the number of subcentres increased, namely for activities such as health care, work or shopping, while others like

socializing have witnessed a decrease in the number of nuclei. Also, there is an increase in time concentration in the suburbs. Only time devoted to activities such as work or health-care offers a well-balanced decentralization: roughly half the share lost by the CBD is gained by subcentres; and the other half, by peripheries. Nevertheless, the duration of the activities taking place in suburbs is witnessing a more significant reduction than CBD; *this finding suggests that sprawling activities are incapable of attracting time as CBD does*.

Overall, the decentralization process can be portrayed as follows: 1) although the number of centralities has increased, these have lost importance in terms of the time-concentration for daily-life activities, with CBDs witnessing the sharpest decline in time share among all centralities; 2) personal activities such as leisure or socializing have the highest level of deconcentration, which may be linked to the rise of residential sprawl; 3) both processes are increasing the diversity of both activities and socioeconomic profiles of the people carrying them out in the suburbs, whilst shortening the duration of those activities in that territory. This latter finding is compatible with the larger increase in number of trips, travel-time (constricting activity-time) and travel-distance in suburban Barcelona identified in the period 2004-2007 by Marquet *et al*. (*Op.Cit*)

Implications for planning-policy and limitations of our study

Both traditional and emergent spatial-temporal data sources constitute the new frontier for urban planners. The analyses carried out here, allow to identify important elements on the construction of the city, since some centres emerge as diverse, compact and socially diverse (a prerequisite for social cohesion). Interestingly, the Spatial Planning Policy initiated in 2003 in Catalonia urges to base urban development/redevelopment on the aforementioned elements embedded in the

'compact-city model'. Nonetheless, no methodological aid is provided in such policy. Therefore, the analysis of the spatial-temporal behaviour of population is of primary interest since it is the result of the interaction of land uses, transport and mobility, and, thus, it allows us to streamline a more comprehensive approach to urban planning. Furthermore, non-working activities (*i.e* social reproduction) and permanence, recently recognized as fundamental for the urbanity and dynamism of cities, can be incorporated into the analyses.

Our study is necessarily exploratory and limited in nature, yet it lays the groundwork for future and complementary analytical research aimed at 1) verifying whether time-density centralities stand out in the identification of structural urban nodes in relation to the traditional employment-density approach as studied by Marmolejo & Cerda (2012, 2017); 2) identifying the determinants of time density as researched by Marmolejo *et al.* (2012) and railway services as researched by García-López *et al.* (2015, 2017); 3) incorporating more spatial-temporal elements in the construction of a centrality index as done by Marmolejo & Cerda (2017); 4) exploring the urban features that impact territorial resilience in the context of economic shifts (Marquet & Miralles-Guasch, 2007). A bigger challenge is posed by the inclusion of human decisions, with behaviourism playing a paramount role in the spatial-temporal patterns of population.

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Table. 1 EMQ survey details, depuration process and selection criteria

	EMQ 2001	EMQ 2006	Notes
1) General data from EMQ			
Spatial coverage	ATM Jurisdiction (296 municipalities)	Catalonia (947 municipalities)	
Reference population	>3 years old	>3 years old	
Universe population	4,345,435	6,830,755	
Sample population	30,740	106,091	
Collection methodology	In-home paper based diary	Telephone survey	
Collection dates	1st-15th Oct. 2001; 15th Jan.-15th Feb. 2002	28th March-2nd Jun.; 27th Sept.-1st Dec. 2006	
2) Depuration process			
Time-sequence errors	0.60%	0.09%	a
Space-sequence errors	20.30%	0.28%	b
Valid trips after depuration and applying the expansion factor for each zone	39,162,672	27,271,519	c
3) Selection criteria used in this paper for the 164 municipalities of the MRB after depuration process			
Trips of population over 16 years old (since travels require autonomy) during an average working day.			
The average working day is provided by EMQ 2006, and computed as the average from the 5 working days in EMQ 2001			

Notes and depuration process details

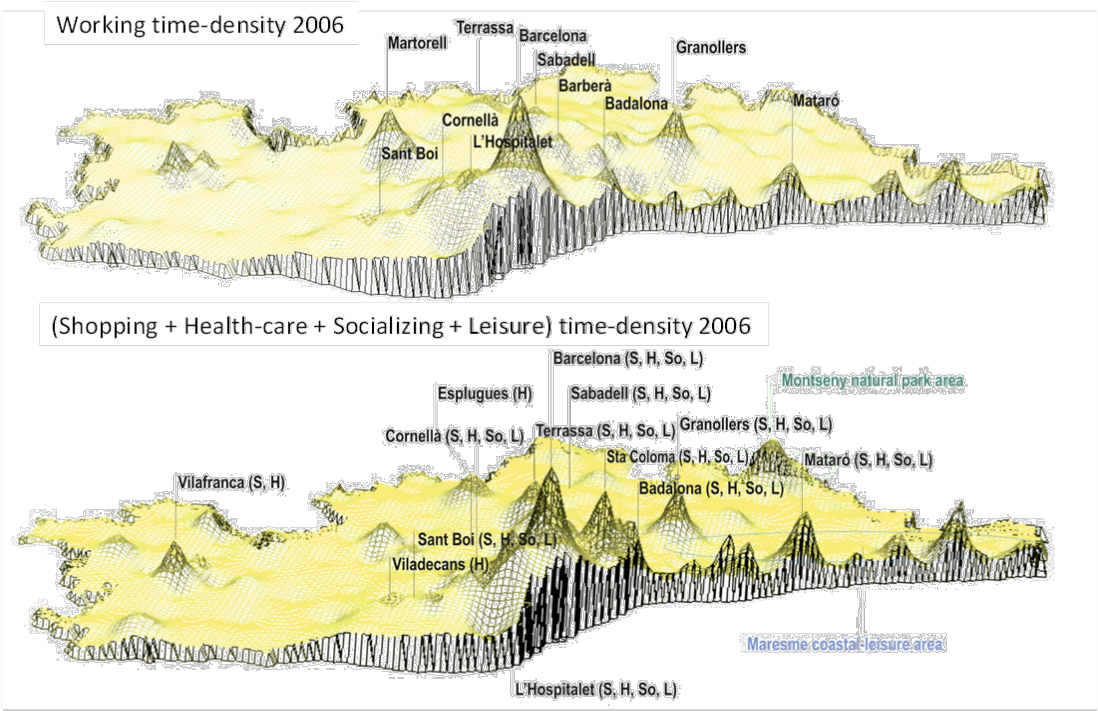
a) There is a time-sequence error when the starting-time of a given trip occurs before the arriving-time of the previous trip in the trip-chain sequence of a given respondent

b) There is a space-sequence error when the originating-zone of a given trip occurs in a different place from the arriving-zone of the previous trip in the trip-chain sequence of a given respondent

c) The expansion factor (EF) extrapolates the total number of journeys for each transport zone. The EMQ provides a EF for each transport zone

Data sources. Quotidian mobility (EMQ in its Catalan abreviature) origin destination survey (Autoritat del Transport Metropolità-ATM-) 2001 & 2006.

Fig. 1 Time density and subcentres identified in 2006



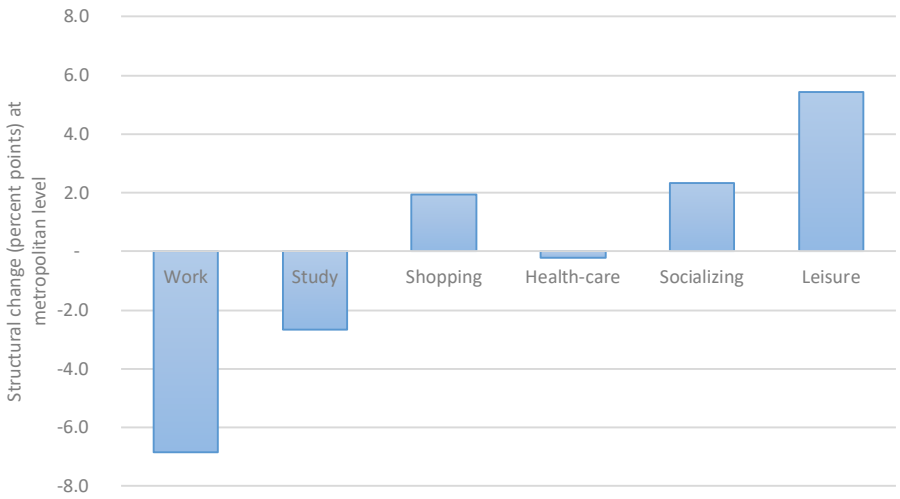
Municipality	centrality type	SUB	Work	Study	Shopping (S)	Health-care (H)	Socializing (So)	Leisure (L)	SUM
Barcelona	CBD	1	1	1	1	1	1	1	6
Badalona	Outer CBD subcentre	1	1	1	1	1	1	1	6
Cornellà de Llobregat	Outer CBD subcentre	1	1	0	1	1	1	1	5
Esplugues de Llobregat	Outer CBD subcentre	1	0	0	0	1	0	0	1
Hospitalet de Llobregat	Outer CBD subcentre	1	1	1	1	1	1	1	6
Santa Coloma de Gramenet	Outer CBD subcentre	1	0	1	1	1	1	1	5
Barberà del Vallès	Out Subcentre	1	1	0	0	0	0	0	1
Cerdanyola del Vallès	Out Subcentre	1	0	1	0	0	0	0	1
Granollers	Out Subcentre	1	1	1	1	1	1	1	6
Martorell	Out Subcentre	1	1	0	0	0	0	0	1
Mataró	Out Subcentre	1	1	1	1	1	1	1	6
Mollet del Vallès	Out Subcentre	1	0	1	0	0	0	0	1
Sabadell	Out Subcentre	1	1	1	1	1	1	1	6
Sant Boi de Llobregat	Out Subcentre	1	1	0	1	1	1	1	5
Terrassa	Out Subcentre	1	1	1	1	1	1	1	6
Viladecans	Out Subcentre	1	0	0	0	1	0	0	1
Vilafranca del Penedès	Out Subcentre	1	0	0	1	1	0	0	2
MRB		**17**	**11**	**10**	**11**	**13**	**10**	**10**	
Time concentration									
CBD (a)		43%	41%	51%	44%	52%	40%	45%	
Subcentre (b)		29%	28%	32%	31%	36%	32%	29%	
Centralities (a+b)		72%	69%	83%	75%	88%	72%	74%	
Peripheries		28%	31%	17%	25%	12%	28%	26%	
MRB		**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	

Notes: 1 means that the municipality is identified as a centrality, in the case of subcentres it meets the double cut-off criteria of having a larger time-density than the metropolitan average of a given activity; and has more than 1% of metropolitan time of such activity

Data sources. Quotidian mobility (EMQ in its Catalan abreviature) origin destination survey (Autoritat del Transport Metropolità-ATM-) 2001 & 2006
Urbanised land: CORINE land cover project (Instituto Geográfico Nacional -IGN-), 2000, 2006. Municipality delimitation: Institut Cartogràfic de Catalunya

Source: own elaboration

Fig. 2 Outside-home time distribution change 2006-2001



Change 2006-2001 (p.p.)

	Work	Study	Shopping	Health-care	Socializing	Leisure	All activities
CBD	- 7.1	- 1.7	1.9	- 0.3	1.8	5.4	-
Outer_CBD	- 3.4	- 5.0	0.8	- 1.1	3.3	5.4	-
Out-Subcentres	- 5.6	- 4.2	2.4	0.6	1.2	5.6	-
Suburbia	- 12.9	- 0.2	2.6	0.3	4.1	6.1	-
MRB	- 6.8	- 2.7	1.9	- 0.2	2.3	5.4	-

Notes: Outer-CBD is made up from the following central conurbated municipalities: Badelona, Cornellà, Esplugues, L'Hospitalet, Montgat, El Prat, Sant Adrià, Sant Feliu, Sant Joan, Sant Just and SantaColoma (some of them are outer-cbd-subcentres)

Data sources. Quotidian mobility (EMQ in its Catalan abreviature) origin destination survey (Autoritat del Transport Metropolità-ATM-) 2001 & 2006. Municipality delimitation: Institut Cartogràfic de Catalunya

Source: own elaboration

Table. 2 Average time per outside-home activities

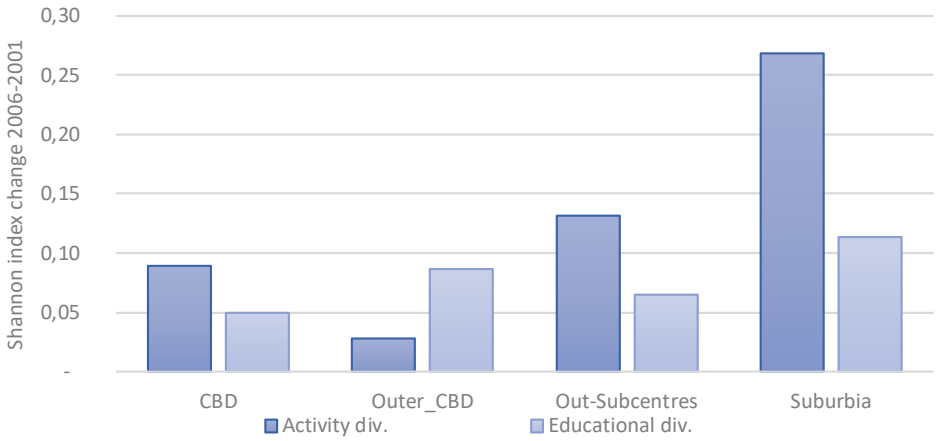
2006	Hours/person/day					
	Work	Study	Shopping	Health-care	Socializing	Leisure
CBD	5.9	4.3	1.4	1.7	1.6	2.0
Outer_CBD	6.1	3.9	1.2	1.6	1.2	1.6
Out-Subcentres	5.8	4.2	1.1	1.5	1.2	1.8
Suburbia	5.9	3.6	1.2	1.2	1.1	1.7
MRB	5.9	4.1	1.3	1.6	1.3	1.8
Change 2006-2001 (p.p.)						
CBD	- 0.7	- 0.6	- 0.3	- 0.5	- 0.4	- 0.1
Outer_CBD	- 0.2	- 0.5	- 0.3	- 0.8	- 0.0	- 0.1
Out-Subcentres	- 0.6	- 1.0	- 0.5	- 0.3	- 0.6	- 0.4
Suburbia	- 0.7	- 1.3	- 0.1	- 0.7	- 0.1	- 0.1
MRB	- 0.7	- 0.8	- 0.3	- 0.6	- 0.4	- 0.2

Notes: Outer-CBD is made up from the following central conurbated municipalities: Badelona, Cornellà, Esplugues, L'Hospitalet, Montgat, El Prat, Sant Adrià, Sant Feliu, Sant Joan, Sant Just and SantaColoma (some of them are outer-cbd-subcentres)

Data sources. Quotidian mobility (EMQ in its Catalan abreviature) origin destination survey (Autoritat del Transport Metropolità-ATM-) 2001 & 2006. Municipality delimitation: Institut Cartogràfic de Catalunya

Source: own elaboration

Figure. 3 Activity and socioeducational diversity 2006 and 2006-2001 change



2006 (Shannon index)

	Activity div.	Educational div.
CBD	1,64	1,09
Outer_CBD	1,63	1,02
Out-Subcentres	1,65	1,04
Suburbia	1,54	1,04
MRB	1,62	1,08

Change 2006-2001 (Shannon index)

CBD	0,09	0,05
Outer_CBD	0,03	0,09
Out-Subcentres	0,13	0,07
Suburbia	0,27	0,11
MRB	0,11	0,07

Notes: Outer-CBD is made up from the following central conurbated municipalities: Badelona, Cornellà, Esplugues, L'Hospitalet, Montgat, El Prat, Sant Adrià, Sant Feliu, Sant Joan, Sant Just and SantaColoma (some of them are outer-cbd-subcentres)

Data sources. Quotidian mobility (EMQ in its Catalan abreviature) origin destination survey (Autoritat del Transport Metropolità-ATM-) 2001 & 2006. Municipality delimitation: Institut Cartogràfic de Catalunya

Source: own elaboration

Figure. 4 Change in the number of centralities and share of time concentration 2006-2001

Municipality	Type	SUB	Work	Study	Shopping	Health-care	Socializing	Leisure
Barcelona	CBD	M	M	M	M	M	M	M
Badalona	Outer CBD subcentre	M	M	M	M	M	M	M
Cornellà de Llobregat	Outer CBD subcentre	M	A	M	M	A	A	A
Esplugues de Llobregat	Outer CBD subcentre	A	M	M	M	A	M	M
Hospitalet de Llobregat,	Outer CBD subcentre	M	M	M	M	M	M	M
Santa Coloma de Gramenet	Outer CBD subcentre	M	M	M	M	M	M	M
Barberà del Vallès	Out subcentre	A	A	M	M	M	M	M
Cerdanyola del Vallès	Out subcentre	M	M	M	M	M	M	M
Gavà	Out subcentre	D	M	M	M	M	D	M
Granollers	Out subcentre	M	M	M	A	A	A	A
Martorell	Out subcentre	A	A	M	M	M	M	M
Mataró	Out subcentre	M	M	M	M	M	M	M
Mollet del Vallès	Out subcentre	M	M	A	M	M	D	M
Pineda de Mar	Out subcentre	D	M	M	M	M	D	M
Sabadell	Out subcentre	M	M	M	M	A	M	M
Sant Boi de Llobregat	Out subcentre	M	A	M	A	A	M	M
Terrassa	Out subcentre	M	M	A	A	M	M	M
Viladecans	Out subcentre	A	M	M	M	A	M	M
Vilafranca del Penedès	Out subcentre	A	M	M	A	A	M	M
Vilanova i la Geltrú	Out subcentre	D	M	M	D	M	D	D

Number subcentres change (2006-2001)

	CBD	0	0	0	0	0	0	0
	Outer CBD subcentre	1	1	0	0	2	1	1
	Out subcentre	1	3	2	3	5	-3	0
	MRB	2	4	2	3	7	-2	1

Time concentration change (2006-2001)

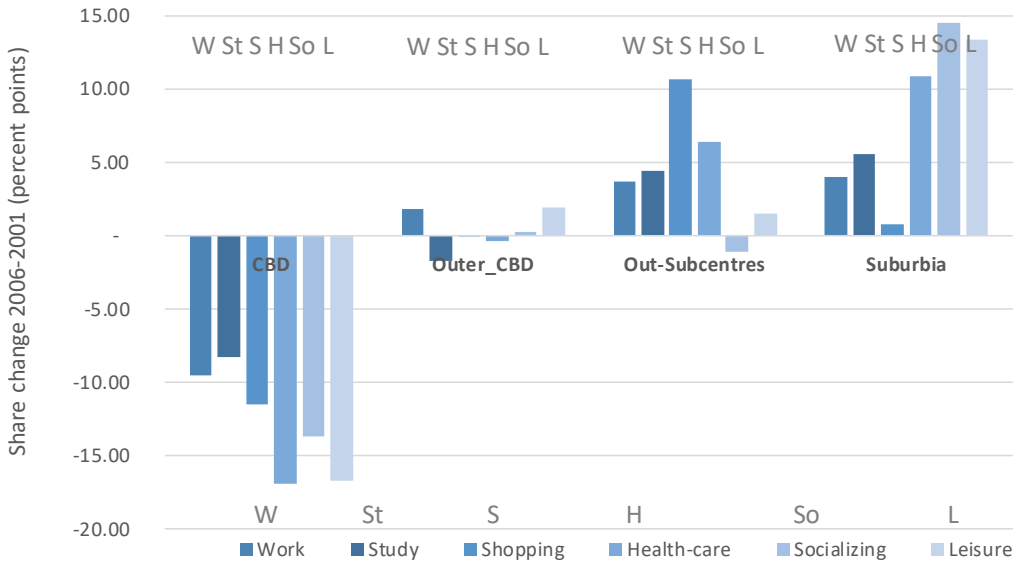
CBD	- 10.2	- 10.2	- 6.2	- 11.0	- 13.9	- 14.7	- 14.6
Subcentre	4.0	5.0	0.0	1.6	7.4	1.3	2.1
Peripheries	6.3	5.2	6.1	9.4	6.6	13.4	12.5

Note: M= mantains the 2001 subcentre status; A= appears as a subcentre in 2006; D= dissapears as a subcentre in 2006

Data sources. Quotidian mobility (EMQ) origin destination survey (Autoritat del Transport Metropolità-ATM-) 2001 & 2006
Urbanised land: CORINE land cover project (Instituto Geográfico Nacional -IGN-), 2000, 2006. Municipality delimitation: Institut Cartogràfic de Catalunya

Source: own elaboration

Figure. 5 Flows of attraction 2006-2001



2006	Work	Study	Shopping	Health-care	Socializing	Leisure
CBD	41%	48%	40%	48%	34%	41%
Outer_CBD	13%	12%	17%	17%	17%	16%
Out-Subcentres	15%	19%	19%	14%	16%	13%
Suburbia	31%	21%	23%	21%	33%	30%
MRB	100%	100%	100%	100%	100%	100%

Change 2006-2001 (p.p.)

CBD	- 9.57	- 8.25	- 11.47	- 16.88	- 13.67	- 16.74
Outer_CBD	1.84	- 1.69	- 0.01	- 0.37	0.28	1.88
Out-Subcentres	3.71	4.42	10.64	6.38	- 1.13	1.46
Suburbia	3.99	5.51	0.80	10.87	14.45	13.36
MRB	0	0	0	0	0	0

Notes: Outer-CBD is made up from the following central conurbated municipalities: Badelona, Cornellà, Esplugues, L'Hospitalet, Montgat, El Prat, Sant Adrià, Sant Feliu, Sant Joan, Sant Just and SantaColoma (some of them are outer-cbd-subcentres)

Data sources. Quotidian mobility (EMQ in its Catalan abreviature) origin destination survey (Autoritat del Transport Metropolità-ATM-) 2001 & 2006. Municipality delimitation: Institut Cartogràfic de Catalunya.

Source: own elaboration

Supplementary file providing more details on data used

Figure 1 Detail of activities within each activity group analysed in this paper

Activity group	Activity detail as it stands in EMQ 2001	Activity detail as it stands in EMQ 2006
Work	Work	Work
	Work-related activities	Work-related activities
Study	Study	Regulated education
		Non regulated education
Shopping	Shopping	Daily shopping
		Non-daily shopping
Health-care	Hospital and physician visits	Hospital and physician visits
	Personal care	Diagnostic visits
		Rehabilitation visits
		Personal care
Socializing	Friends and relative meetings	Friends and relative meetings
	Come along with friends and relatives	Come along with friends and relatives
Leisure	Leisure, fun, sports, take a walk	Cultural leisure (museums, conferences, cinema, theatre)
	Eat out	Other leisure (wine & dine, ludic activities)
		Non-leisure eat out
		Take a walk
		Sport

Note: the survey also considers other activities such as in-home activities, second-home, religious services, agricultural duties, political involment, "other activities", etc.

Data sources. Quotidian mobility (EMQ in its Catalan abreviature) origin destination survey (Autoritat del Transport Metropolità-ATM-) 2001 & 2006.

Figure 2 Descriptive statistics of used variables

			2001				2006				Notes	Source
Variable		Units	Min	Max	Average	Std Dev	Min	Max	Average	Std Dev		
Time devoted to	Work	Hrs. ('000)	-	19,483	232	1,529	-	30,061	448	2,371	a, b	I
	Study		-	4,138	44	329	-	6,308	76	501	a, b	I
	Shopping		-	1,928	21	152	-	4,283	60	339	a, b	I
	Health-care		-	736	7	58	-	1,114	13	89	a, b	I
	Socializing		-	1,427	16	113	-	3,339	50	266	a, b	I
	Leisure		-	1,334	14	105	-	4,989	68	393	a, b	I
Urbanized area		sq. km.	0.1	82.0	4.3	7.2	0.1	82.1	4.5	7.3	c	II
Time-Density	Work	Hrs. per sq. km.	-	237,469	23,688	30,414	-	366,265	51,186	53,344	a, d	I, II
	Study		-	68,607	3,040	8,099	-	87,408	6,224	11,812	a, d	I, II
	Shopping		-	23,500	1,837	3,649	-	52,186	6,173	8,147	a, d	I, II
	Health-care		-	8,971	316	1,219	-	13,573	917	2,036	a, d	I, II
	Socializing		-	22,518	1,517	3,342	-	40,688	5,815	7,177	a, d	I, II
	Leisure		-	21,737	1,246	2,787	-	60,787	8,023	10,376	a, d	I, II
Diversity	Activities	H index	-	1.68	0.97	0.41	-	1.66	1.24	0.53	a, e	I
	Socioeducati		-	1.09	0.70	0.28	-	1.10	0.85	0.36	a, e	I
Attracted flows	Work	People ('000)	-	2,925	35	230	-	5,076	76	400	a, f, g	I
	Study		-	829	9	66	-	1,453	18	115	a, f, g	I
	Shopping		-	1,147	14	91	-	3,138	47	250	a, f, g	I
	Health-care		-	338	3	27	-	665	8	53	a, f, g	I
	Socializing		-	718	9	57	-	2,134	39	172	a, f, g	I
	Leisure		-	650	7	51	-	2,495	37	198	a, f, g	I

Notes

a Refers only to people over 16 years considering their activities during a working day

b refers to the total number of hrs for each activity comming from all sampled population along an average working day

c Refers to categories Level 1 (artificial areas) from Corine Land Cover Project

d the same than b but in terms of density

e Diversity takes into account the number of people classified by activity or education level

f it also includes trips originating in the same destination zone

g it is important to note that the same person can compute more than one time as an attracted flow

Data sources. I) Quotidian mobility (EMQ in its Catalan abreviature) origin destination survey (Autoritat del Transport Metropolità-ATM-) 2001 & 2006; II) Urbanised land: CORINE land cover project (Instituto Geogràfico Nacional)