Sustainable Urban Metabolism for Athens

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ABSTRACT: In this article an attempt is made to analyze and assess urban dynamics through a sustainable urban metabolism approach. The study is focused on the metropolitan area of Athens for which a number of alternative development scenarios are postulated and evaluated in terms of sustainability. The scenarios in this analysis do not present forecasts, but rather the range of realistic options from a business as usual perspective to a more ambitious development policy considering metabolic interdependencies.

1 INTRODUCTION

1.1 *The Concepts of Urban Metabolism and Sustainable Urban Metabolism*

The concept of urban metabolism helps to understand and analyze the way societies use resources, energy and land and other elements of the environmental system, for maintaining and reproducing themselves. The way cities and urban areas are being built is greatly influencing the quantities and qualities of resources being used in maintaining urban life. Urban development includes processes of growth in new areas, decay and abandonment and also restructuring and rehabilitation in parallel. While the dynamics of urban development in these components have been studied and debated for a long time (Urban Audit, 2007), the interrelation between urban development and urban metabolism in the sense of physical interaction with the environment is far less understood (McDonald & Patterson 2007),.

While demographic growth in European cities is rather moderate and mainly due to migration, the most significant factors effecting urban spatial growth are the growing number of smaller households and the increasing space consumption by households, business units and transportation infrastructures. Today, these dynamics extend far beyond urban centers and heavily affect rural areas (ESPON 2007). While the drive for spatial expansion continues even in demographically stagnant areas, the environmental consequences and the potential economic and societal risks of such a growth pattern give reason to substantial concern (European Environmental Agency, 2002).

Present patterns of resource and energy consumption are associated to three main factors, namely: the physical and technological qualities of buildings, the urban (spatial) structures – together forming the built environment – and the consumer lifestyles, greatly depending on the level of economic development. If these flows and consumption patterns can be transformed to quantitative levels and qualities less damaging to the ecological system, the long-term sustainability of urban systems can be improved.

1.2 *Scope and Context of the Article*

Based on the urban metabolism approach, the "Sustainable Urban Metabolism for Europe" (SUME - http://www.sume.at/) FP7 Collaborative Research Projects analyzes the spatial qualities of built urban systems and the impacts of these "urban forms" on the quality and quantities of resources needed to maintain them. The analysis is conducted in five European cities (Athens, Munich, Oporto, Stockholm and Vienna) with different development scenarios assumed in order to assess what types of urban forms and built structures can lead to a reduction of resource and energy consumption. This article presents the Athens case study. .

The basis for the analysis undertaken rests in the existing building stock and urban form of Athens and the population of two different development scenarios. It must be pointed out that the scenarios in this analysis are not actual forecasts in the sense that they depict the expected situation of the urban area in the future. Instead, the aim is to demonstrate the range of potential development paths between a trend scenario (baseline scenario or BASE scenario) and a more ambitious scenario (SUME scenario), geared to improve the metabolic performance of the urban region. In doing this, the two scenarios should not be perceived as extreme stand points, but rather as the range of realistic options from two different perspectives; one assuming that existing development trends are continuing in the future and another one that envisions a more ambitious development policy considering metabolic interdependencies.

Drawing up different scenarios, attempts to answer the question: *"Is it possible to considerably affect the metabolic performance of urban regions by urban development policies and planning, and how much?"*.

2 SCENARIOS POPULATION

2.1 *Urban Data*

The Athens Urban Metropolitan Zone (UMZ) – 221 km^2 & approximately 3.5 million population – was segmented in 238 cells for which an overlay of several information sources allowed an analysis of densities, the mix of uses (residential vs. economic), the building typology and age structure and the accessibility to the main transport lines. Supplementary information was collected with regards the limitations for further development, such as protected zones, historic areas, parks etc. Most data were obtained from the 2001 Census of Population and Housing and for simplicity reasons it was assumed that they correspond to year 2000 as well. More specifically, the datasets used include information on the following characteristics:

- population and number of households (Census 2001)
- number of jobs (Census 2001)
- number of dwellings tabulated by the year they were constructed (Census 2001)
- number of non-residential buildings (Census 2001)
- area of continuous and discontinuous urban fabric (km^2, source: CORINE 2000)

Estimation of population and number of jobs for each cell for year 2050 was made in two steps. For year 2020 population and jobs for each cell were obtained from Attiko Metro S.A. that performed a study on the future of the Athens area back in 1996. These figures were then modified based on different assumptions leading to a more sustainable structure of the city. For year 2050 the growth of population between 20020-2050 total population of the Athens area available from the Hellenic Statistical Authority was allocated to the various cells using the methodology described below. .

2.2 *Methodological Approach*

Allocation of population and jobs within the UMZ is performed in 2 steps. In each of the steps, a portion of the estimated population and jobs change was allocated. It is assumed, that this allocation takes place within the UMZ; only a remaining surplus of future population (and jobs) which cannot be accommodated within the UMZ according to the density rules is to be allocated outside of the UMZ.

More specifically, Step 1 calculates the portion of the changes in population and employment for 2000-2020 (as estimated by the Attiko Metro) that can be hosted in existing dwellings on a cell basis when we assume that there is a 10% increase of floor space per person. This assumption is made for bothe the BASE and SUME scenarios. In the following Step 2, for the allocation of residual population and jobs within the total UMZ (that is the remaining population and jobs from Step 1 plus the estimated change for 2020-2050), the existing housing characteristics are considered as important while no further change in floor space per person is assumed.

For the allocation of population in Step 2, the characteristic average “on-site-density” (OSD - which is defined as (population + jobs/2)/km² - urban fabric as defined by CORINE) was defined as an upper limit for future densification. In this classification, 7 classes are defined: single family house, Mixed area (low density), Mixed area, Dense mixed area, Low multi storey, Multi-storey and Dense multi-storey.

The rationale for the algorithm used in Step 2 is that prevailing conditions in an area with respect housing types usually remain stable over long periods and change only through major development impulses (e.g. accessibility increases due to new transport infrastructure, changing (higher) land values, specific development projects etc.). As a general assumption, cells with a distinct housing type (i.e. mainly single-family houses) will not change fundamentally over time, without a specific reason. Thus, without a major impact (e.g. accessibility provided by new high-capacity transport lines) each cell is expected to host as much population as possible without moving to a higher density class or to exceed its maximum density threshold.

On the other hand, under certain assumptions, housing density in some cells may exceed the current values (thresholds) by allowing the cell to upgrade its class thus permitting the accommodation of more population and jobs. It was assumed that this could happen in areas where there is:

- Existence/anticipation of large urban development projects,
- Proximity to existing transport axes and/or future high-level public transport infrastructure

The result of the scenarios is the spatial distribution of population and jobs within the UMZ and an estimate of the population which will be settling in the urbanized areas outside the UMZ.

2.3 *BASE and SUME Scenarios*

The purpose of the scenarios calculations is to demonstrate the potential differences between the starting situation of the urban region (year 2001) and the two future structures in 2050, which are the result of different development strategies. The BASE scenario is viewed as a continuation of current planning policies supporting past spatial development trends (densities and configurations of the urban fabric). On the other hand, the SUME scenario is defined as a path of sustainable spatial development. This takes place by changing current planning policies towards a clear guidance of urban development on major transport routes, providing compact and integrated new developments and aim at densification in areas of good accessibility.

The BASE scenario was set up, using the building typology and densities throughout the UMZ as a reference. As for an alternative SUME scenario, urban development policies were assumed that would:

- allow the spatial distribution of population and jobs in new developments to have a clear focus on public transport lines, spatially contained, thereby going beyond foreseen projects
- increase densities in existing built-up areas, if there is or will be good accessibility of public transport
- speed up the renovation and replacement of existing buildings, relevant for the building energy calculation

BASE and SUME scenarios are differentiated – as the result of the development strategies applied in Step 2– in terms of the:

- size of population spreading beyond the UMZ border,
- densities applied (for the newly urbanized areas),
- spatial distribution/proximity to the lines of public mass transport.

The BASE scenario provides this estimate under a trend-like development strategy, while the SUME scenario shows the potential magnitude of policy effects to reduce development outside UMZ until 2050. It also provides the basis for evaluating the effects of focusing development close to transport lines.

2.4 *Evaluation of the Scenarios – the UDP Indicator*

The two scenarios generate the distribution of population and jobs among the cells within the UMZ and estimate the population and jobs to be located outside the UMZ for year 2050. These spatial patterns are evaluated with respect their potential impact on transportation and the energy consumption needed for transport. The approach is a qualitative rating of each cell's location with respect to its proximity to the center of the metropolitan area where there is a heavy concentration of jobs and access to high-capacity public transportation. To quantify these , the Urban Diversity Pattern (UDP) indicator was defined which is composed of the following three sub-indicators:

- Indicator 1: Accessibility to high-level public transport infrastructure
- Indicator 2: Centrality (proximity to centre functions)
- Indicator 3: Diversity (mix of economic and residential functions)

The accessibility to high-level public transport infrastructure (Indicator 1) is analyzed by implementing different circular catchment areas (<5, <10 and >10 km), which have their midpoint in the centre of the city. Each cell in the UMZ is evaluated according to which catchment area belongs to and according to its proximity to public transport. Cells touching directly a metro or urban railway line are evaluated with more points than those without direct connection since it can be assumed that there will be higher share of car use (Newman & Kenworthy 1989).

Indicator 2 is also composed by different catchment areas (<2.5, <5 and <10 km) which have the centre of a city as midpoint. The closer a cell is situated to the historical centre, the more functions are located in this cell. Therefore, the population will have to cover less distances to reach attractive destinations in a city. As a result, the closer a cell to the historical center is, the higher its rank.

The OSD impacts the urban diversity pattern as higher densities raise the number of potential users (demand) of functions. A high job and population density is evidence of an enlarged number of functions available for users in short distance (ECOTEC, 1993) and therefore an indicator for a larger variety of the offers and attractiveness of a cell. In this respect, the density is linked with urban functions and therefore Indicator 3 uses four density categories which allow to rate the diversity pattern of a city. In general the cells with the highest density get the best rating.

Each cell in the UMZ is evaluated for each indicator through a rating procedure. The highest ratings a cell can reach for each of the sub-indicators are 4 points. The highest ratings a cell can reach for the UDP-indicator therefore are 12 points as from the aggregation of the three sub-indicators. Due to the aggregation of the three sub-indicators, the UDP-indicator combines the quality of high public transport access, centrality and diversity for each cell. Weighting of the UDP-indicator with the residences of each cell, takes into account the amount of population which lives in a high quality area.

2.5 *Results*

The 221 km^2 of urban fabric within Athens UMZ are very densely inhabited; 65 % of the population (2001 data) lives in areas with primarily multi-storey buildings while only 2 % of the population living in areas with primarily single family houses. The rest of the population lives in areas where there are both multi-storey and single family housing. During the period 2000-2050 a total of 300,000 people (9% growth) are allocated in the two scenarios. Due to the high average densities and land availability, all population is allocated within the UMZ for both, BASE and SUME scenarios.

Thus the maps referring to density patterns in BASE and SUME scenario (Figure 1) do not show major differences. Nevertheless, noticeable differences appear when the percentage densification is compared for the two scenarios (Figure 2). As a result of these small differences, the SUME scenario scores a high UDP indicator which is higher than both the BASE scenario and the actual urban form of Athens in 2000 UDP.

On the other hand, while the BASE scenario scores a lower UDP compared to 2000, the differences between the three UDP's (actual 2000, Base and Sume scenario) are small (Table 1). This indicates that the high existing densities and the land availability in Athens allow the area to host the population development until 2050 in a rather sustainable way regardless of the development path followed. It also indicates that the same high densities allow a number of development options that should be further investigated.

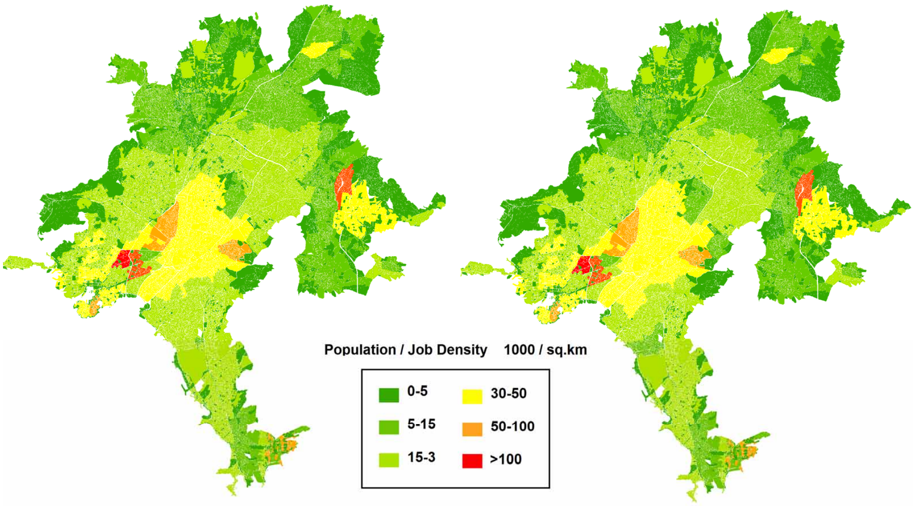

Figure 1.Population & Job densities for the Base (left) and the Sume scenario (right).

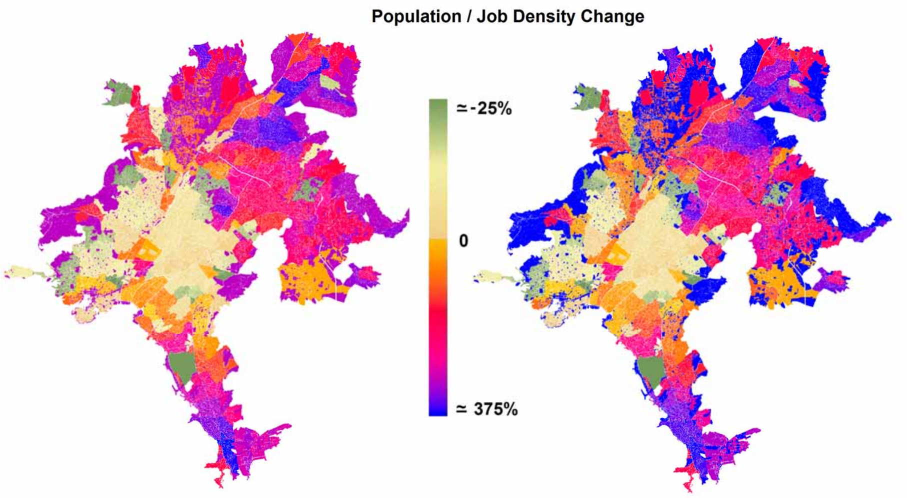

Figure 2. Population & Job densities change for the Base (left) and the Sume scenario (right).

Table 1. The values of the UDP indicators.

	Indicator 1	Indicator 2	Indicator 3	UDP
2000	3.29	2.95	3.60	9.85
BASE	3.23	2.75	3.42	9.26
SUME	3.46	2.91	3.72	9.87

3 ALTERNATIVE SCENARIOS

3.1 *Changes in Methodology*

The dense and compact form of the Athens UMZ appears to be a guarantee for the sustainable development of Athens if sustainability is defined in terms of proximity to public transportation. However, there are also issues of quality of life and access to green areas. Many areas lack any open space. Hence, a question that arises is whether it is *possible to redistribute the population within the Athens UMZ in such a way so that lower densities and more urban green areas can be achieved thus leading to a more sustainable development path.* In an attempt to answer this question, four additional scenarios were populated.

The common characteristic in all four scenarios is that it is assumed that 10% of the built areas (urban fabric in CORINE) of each cell is used as urban green areas. Although the assumption of 10% green area in each cell is unattainable in reality it permits the estimation of "green" scenarios.

Additionally, an overall maximum population density value is defined for all cells regardless which OSD class they belong to. This means that no cell can exceed this value during the process. As a result, the "redundant" population from all cells that (according to 2001 data) have higher densities has to be reallocated to other less dense cells. Finally, an assumption with respect change in floor space was introduced.

3.2 *Results*

Four alternative scenarios were calculated (Figure 3) with different assumptions concerning the floor space per person and the maximum density threshold parameters. The results obtained show that the later appears to influence the final allocations more heavily. This can be partially explained by the fact that 30% of the 2001 population live in areas with OSD greater than 30.000 and the average OSD for all cells is 80.0000. In all four of scenarios it is assumed that 10% of the urban fabric will be used as urban green areas which means that approximately 10% of the 2001 population (340.000 people) have to relocate.

Scenarios A and C that assume a threshold of 20.000 population per km^2 but different change in floor space per person from the base year, force 775.000 (20% of total population) and 1.550.000 (40% of total population) people to locate outside the UMZ and score the same UDP indicator (Table 2) which is lower than the 2000 UDP since people are relocated to areas which are less central.

Scenario D on the other hand, that assumes a 30.000 density threshold, allocates only 230.000 people outside the UMZ and scores a high UDP indicator. While scenario D assumes a 10% increase on floor space per person, scenario B assumes an equal decrease. As a result, the whole of the population is distributed within UMZ while a high – yet lower than scenario D – UDP indicator is scored. An interesting observation is that scenario B scores a higher UDP indicator than both the Base and the Sume scenarios. This indicates that theoretically population within Athens UMZ can be redistributed resulting to less dense cells with more green urban areas and high sustainability levels. Of course, the necessary adjustments in real world will require more or less demolishing and rebuilding a vast portion of the city and would require massive relocation of the population.

Table 2. The values of the UDP indicators for the alternative scenarios.

	Indicator 1	Indicator 2	Indicator 3	UDP
Scenario A	3.47	2.95	3.30	9.73
Scenario B	3.47	2.95	3.73	10.15
Scenario C	3.47	2.95	3.30	9.73
Scenario D	3.47	2.95	3.80	10.23

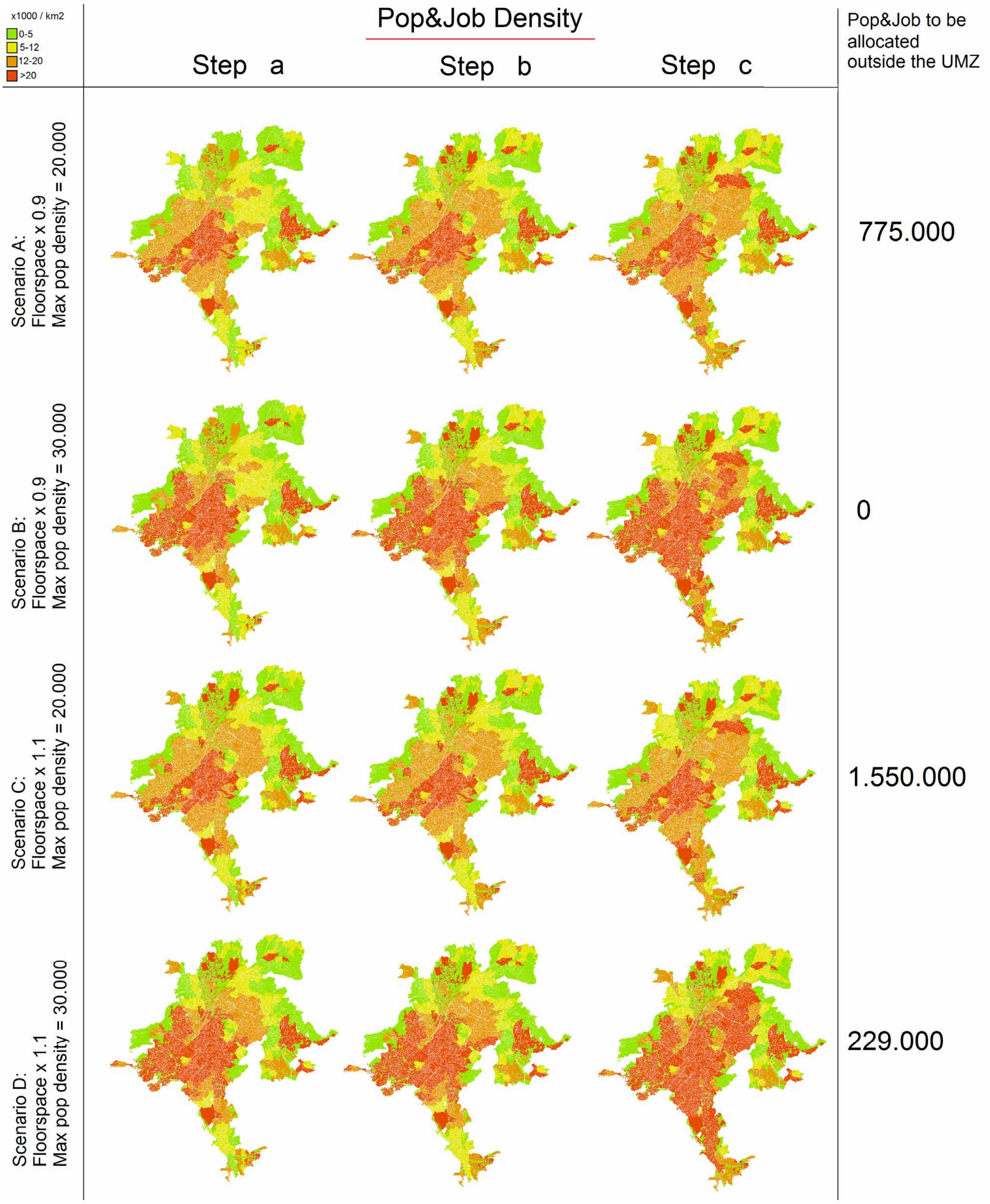

Figure 3. Population & Job densities for the alternative scenarios populated.

4 CONCLUSIONS

It is a well acknowledged fact that high population densities and compact urban forms are considered to be sustainable in terms of energy consumed in the transportation sector. For the case of Athens as discussed in this paper for year 2050, the existing high densities already support a relatively efficient transportation energy locational pattern. Changing the densities of some parts of the city and using available land results in locational patterns which based on the indicators used, describe and improved situation in terms of sustainability.

However, the issue in Athens is that existing densities are already high and most important there is lack of open space and green areas in most parts of the city. The city can be considered sustainable in terms of energy consumption in transportation but there is a need for a better environment for its citizens. As shown by the alternative development scenarios that were populated, by 2050, 10% of the built area of each cell in the UMZ can be used as urban green areas and despite the population growth, population densities can get lower than 2001 without allocating population outside the UMZ. At the same time this can be achieved while improving the performance of Athens' urban configuration as shown by the change in UDP indicators.

On a higher level of analysis, the concept of sustainable urban development appears to be a key instrument in shaping sustainable cities. Nevertheless, its concept should be expanded in order to provide a more holistic view of the urban development process. To this end, various aspects concerning the quality of life, socioeconomic and cultural conditions should be analyzed in order to design urban environments that are not only efficient and sustainable but desirable as well.

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References

ECOTEC, 1993. Reducing transport emissions through land use planning, HMSO, London

EEA – European Environment Agency. 2002. Towards an urban atlas. Assessment of spatial data on 25 European cities and urban areas. Environmental issue report N°30. Copenhagen

ESPON, 2007. Scenarios on the territorial future of Europe. ESPON Project 3.2 Final report, 60pp.

McDonald, Garry W. & Patterson, Murray G. 2007. Bridging the divide in urban sustainability: from human exemptionalism to the new ecological paradigm. In: Urban Ecosystems. DOI: 10.1007/s11252-006-0017-0.

Newman, P. & Kenworthy, J. 1989. Cities and automobile dependence: An international sourcebook. Gower, Aldershot, England

Urban Audit. State of European Cities Report, Adding value to the European Urban Audit, May 2007.