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Simulation of urban development in the City of Rome

Framework, methodology, and problem solving

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Abstract: In Italy's case, the implementation of the UrbanSIM model involved the territory of Rome, including the municipalities of Rome and Fiumicino. The main goal was to build scenarios regarding the future of economic deconcentration. Rome is the largest municipality in Europe, with an inhabited surface area only slightly smaller than that of Greater London and almost double that of the inner Paris suburbs (the *Petite Couronne*). The spatial distribution of buildings within the municipality is distinctive. Unbuilt areas comprise 73 percent of the territory. These voids are often farmland (paradoxically, Rome is the largest rural municipality in Italy) or areas with high environmental, historic or cultural value. Fiumicino, previously part of the municipality of Rome, became an independent municipality in 1991. Its autonomy, made all the more significant because Fiumicino hosts the international airport, marked the start of an extensive process of economic deconcentration along the route connecting Rome to the airport. In Italy's case, the implementation of the UrbanSIM model posed several challenges, notably the availability, homogeneity and completeness of data. This paper uses four specific cases (land use, travel times, accessibility, and residential land values) to propose a general methodology to solve problems related to missing or non-homogeneous data. For the land use, we simply combine two different land use data sources, while for accessibility and travel time data, we propose the use of geostatistical methods in order to estimate missing and unavailable data, calculating also the accuracy of the predictions. For the residential land values, which are discrete data, we suggest the use of deterministic interpolation techniques. While it has not yet been possible to implement the calibration stage, some simulation outputs are presented. [1]

1 Introduction

The UrbanSIM model was applied to the City of Rome to build economic deconcentration scenarios with the goal of envisioning the future locations of businesses in various economic sectors throughout the study area. The premise of the experiment was that traditional planning tools alone do not suffice to manage sustainable urban expansion. Italy's traditional urban planning

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tools date back to the 1942 urban planning law (Law No. 1150). The law was based on the concept of a City Master Plan that identified the main communication and rail routes and divided the city into zones; the plan marked out zones subject to future expansion and specified the restrictions to be implemented in each zone for historic, environmental, or landscape-related reasons. From the 1970s on, the problems of a postmodern society made it increasingly difficult to apply this tool, for the implementation of the City Master Plan was outpaced by the social and economic changes taking place quickly and unpredictably as the result of a process that was both local and global. After the passage of Law No. 1150, the Rome municipality only managed to formulate a CMP in 1962, but even in those years of slower and more predictable change the plan had to be revised almost immediately. The revision should have been rapid but political; administrative, economic, and social changes led to a ceaseless process of modifications that lasted more than forty years and only ended with the approval in 2008 of a new CMP—the legitimacy of which has already been questioned. An urban simulation model such as UrbanSIM is better suited to the structure of society today and more sensitive to continuous economic and social changes deriving from a complex local system that is closely linked to global dynamics. However, the UrbanSIM tool has limitations as far as its application to Rome is concerned because of (i) the lack of territorial data suited to the model, (ii) the specific administrative organisation of the study area, and (iii) Italy's particular management policies, which differ from policies in the U.S. where UrbanSIM was created and has been applied for several years.

Figure 1: The study area: traffic zones, *suddivisioni toponomastiche*, and the metropolitan transport network.

The objective of this paper is to describe the Italian and local context in which UrbanSIM was applied, highlight the problems encountered in the implementation phase, and outline the solutions adopted and the preliminary output produced. The study area is situated in the central western part of the Italian peninsula, and includes the municipalities of Rome and Fiumcino (Figure 1). This area corresponds to the Central City identified by the SELMA project (Montanari *et al.* 2007), the core of which is delimited by a ring road approximately 68 km in length; this motorway is called the *Grande Raccordo Anulare* (GRA) (Fig.1).

The Fiumicino municipality covers an area of 209.50 km^2, while Rome is a large municipality covering 1291.11 km^2. The study area therefore extends over a total surface area of 1500.61 km^2. The population is mainly concentrated in the centre of Rome and around the Fiumicino airport (Fig. 2). In fact, the residential area comprises a mere 19.48 percent of the total metropolitan area (MA) (Table 1). It is important to analyze the main features of land use in the study area, since UrbanSIM considers the possibility that a certain type of development could be relevant for a small portion of the MA. The Tiber is Rome's main river. Together with other small streams and lakes, it covers an area of 7.48 km^2. Taking the wetlands into account, the total surface covered by water is 11.12 km^2, or 0.74 percent of the MA.

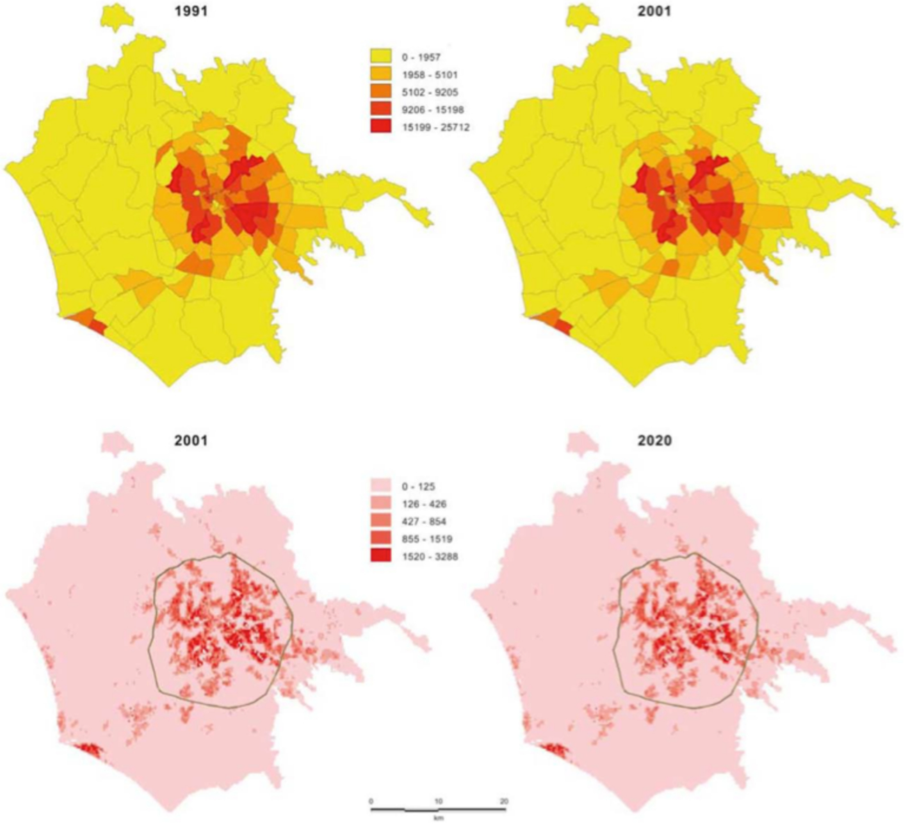

Figure 2: The Rome metropolitan area, population density by *Suddivisioni Toponomastiche*, 1991 and 2001, and population by gridcell, 2001 and 2020.

When considering non-developable areas, it is interesting to note that archaeological sites cover one square kilometre of the historical centre and that 68.60 percent of the MA is open space. In particular, a large section of land is agricultural, i.e. 424.55 km^2, equivalent to 28.40 percent of the MA (Table 1). Also, while there is a high concentration of activities in the core, there are many open spaces in the suburbs. Finally, the territory covered by public activities is 123.02 km^2, or 8.22 percent of the total area.

Table 1: Land uses (total area and percentages) in the Rome Metropolitan Area.

Land Use Type	km^2	(%)	Land Use Type	km^2	(%)
Water	7.48	(0.50%)	Open Space	559.63	(37.43%)
Wetland	3.64	(0.24%)	Open Space – Not built up	10.51	(0.70%)
Roads	16.01	(1.07%)	Open Space – Agricultural	424.55	(28.40%)
Public Space – Archaeological	1.00	(0.07%)	Open Space – Construction	7.37	(0.49%)
Public Space – Airport	19.63	(1.31%)	Open Space – Woods	14.81	(0.99%)
Public Space – Beaches	1.84	(0.12%)	Open Space – Shrubbery	8.83	(0.59%)
Public Space – Green Urban	67.90	(4.54%)	Residential – Continuous	147.67	(9.88%)
Public Space – Other Uses	24.28	(1.62%)	Residential – Discontinuous	143.50	(9.60%)
Public Space – Port Area	0.57	(0.04%)	Industrial	18.56	(1.24%)
Public Space – Sports Ground	7.80	(0.52%)	Industrial – Extraction	9.40	(0.63%)

In 2001, the municipality of Rome had 2 546 804 inhabitants and Fiumicino 50 535, for a total of 2 597 339 inhabitants in the MA. The total number of employees in the MA was 933 409 in the same year, distributed as follows among the main sectors: industry 132 132 (14.16%), commerce 166 612 (17.85%), services 370 091 (39.65%) and institutions 264 574 (28.34%). The implementation of the UrbanSIM model required the use of several data sources (1991 was chosen as the base year). Therefore, all the changes that have taken place in the planning system, the housing model, and traffic organization are relevant for the simulation. The grid cell size was set to 250 m by 250 m. The study area of 1500.61 km^2 was covered by a total of 23 933 grid cells.

This paper is organised into two parts. The first part examines the city of Rome in the Italian context with special attention to three main themes: the planning system, the housing situation, and the traffic and transportation system. The objective of the first part is to illustrate the general framework in which UrbanSIM was implemented. The second part goes into the core of the topic with a focus on the main problems encountered with implementing the model and the solutions adopted to tackle them.

2 The planning system

A report on urban policies in Italy by the Ministry of Infrastructure and Transports (which is in charge of national planning policies) points out “the lack of an integrated plan for interventions based on a clearly defined programme,” specifying that “another reason is the fragmentation of responsibility for intervention in urban areas among the various levels of government” (http://www.infrastrutturetrasporti.it and Nuvolati 2002). Faludi and Waterhout (2002) comment that traditional urban planning in Italy “places the emphasis on local planning and design”; as a result, “Italy does not have national spatial planning.” The EU Compendium on Italy (Commission of the European Communities 2000) concludes that “territorial planning is practically non-existent at the national level; it is merely a guideline at the regional level, and implemented at the local level," adding that the government "is only responsible for deciding the general direction of planning, and for coordination. In particular, it prepares guidelines for the layout of the national territory." Therefore, "there is no official territorial re-organisation strategy to refer to at the national government level."

The main tool of territorial government at the local level is Rome's City Master Plan. The deconcentration process in the 1991–2001 period took place while Rome City Hall was still using the old City Master Plan approved in 1962. In fact the new City Master Plan was only approved in 2008. In 1993, however, the Rome Master Plan was affected by the direct election of city mayors. One of the main effects of this law is that mayors are now directly responsible for implementing government programmes. In fact, government programmes are identified and largely oriented by mayors. Francesco Rutelli, Mayor of Rome from 1993–2000, started the process to create a new City Master Plan and introduced new planning elements such as the 1995 Posterplan, which outlined the administration's goals, and the 1997 *Piano delle Certezze* or Plan of Certainties, a series of changes and variations to the 1962 Master Plan that were necessary in the phase of transition to the new Plan. These two elements, which comprised the municipality's planning objectives, were implemented in the course of a long collaboration with all the stakeholders. The Plan of Certainties was primarily implemented in coordination with economic stakeholders with a view to completing projects that had already been initiated.

There were, therefore, several overlapping tools in use from 1991 to 2001, with the 1962 City Master Plan on the one hand and the Posterplan and Plan of Certainties on the other. The former, a legacy of the past, continued to have the binding force of a law but had been substantially modified by all the changes that had taken place in the interim, not to mention the implementation of *Piani di settore* (sector-specific plans) and *Piani Particolareggiati* (in-depth plans). The latter two contemporary plans were statements of intent providing the basis for the new Master Plan. The 1962 Master Plan created a city whose principal characteristic, according to Maurizio Marcelloni, the coordinator of the new Master Plan, was that it was without rules, where individual freedom and behaviour prevail over the limits imposed by a social organization (Marcelloni 2003). The 1962 Master Plan envisioned three main points: (i) Breaking down the city's compact, monocentric structure by creating a road route and moving the city centre eastwards through the establishment of the SDO (*Sistema Direzionale Orientale*), or Eastern Office District, in order to clear the historical centre of tertiary activities; (ii) Encouraging road travel and transport and (iii) Expanding the city by setting up self-sufficient residential districts with a focus on functionality. What has actually happened is the following: (i) Services have not abandoned the city centre; rather, they been strengthened and expanded, as the city centre and its cultural attractions are a major draw; (ii) The roads intended to increase road travel and transport have been only partially built and do not serve the residential buildings, which were not constructed in line with the Plan's recommendations; (iii) While self-sufficient residential districts have been developed, the problem is that although they are very efficient, with a good transport network within each district, they are not well-connected to each other or the rest of the city. The final result is a city that remains compact and monocentric, where the historical centre remains the most vibrant and attractive part, and a non-regulated and often degraded periphery with a uniquely residential function, poorly connected to the centre by an inefficient transport system. It is easy to understand why many observers agree that Rome is a city without rules. This statement also crops up regularly in political circles, where the objective of imposing rule and order on Rome is continuously mooted. From this viewpoint, too, Rome reflects the overall image of Italy as a society in which the enforcement of a law is an exception rather than the rule, and where the disorderly accumulation of laws makes it so difficult to enforce them that their very accumulation is an increasingly strong argument for nonenforcement (Marcelloni 2003).

The Posterplan and Plan of Certainties, as well as the new City Master Plan, start from the problems unsolved or generated by the 1962 Master Plan. While the new plans have no specific goals related to deconcentration, they prioritize the creation of new centres to generate a polycentric city. These new centres will be connected to residences as well as businesses. The Rome municipality has selected the most important infrastructures for the key metropolitan functions, such as the new *Centro Congressi* or Conference Centre in the Eur district on the outer edge of the core, the Fiera di Roma commercial fair grounds along the route connecting the rest of the city centre to Fiumicino and the airport, and the new *Polo Tecnologico* or technological pole along the Tiburtina road. The Rome municipality has also chosen to fill the urban empty spaces left over from uncontrolled and illegal building activity with green areas or new office districts.

3 Housing conditions

Italians are traditionally very attached to their place of residence and most Italians dream of owning the house they live in. Therefore, Italians tend to invest in bricks and mortar. Because they are rarely inclined to take risks, and possibly because of Italy's economic and political instability, Italians buy a house if they can afford it, and Rome is no exception: according to a 2002 estimate by CRESME, 70 percent of Rome's residents live in their own properties.

This attitude contributes to the static nature of Italian society. It is easy to change one's city of residence or neighbourhood when one lives in a rented flat, but it becomes much harder for a homeowner. A house has to be sold and another one bought. This is not an easy procedure and therefore happens very rarely, especially when moving from one neighbourhood to another in the same city. Italians are thus reluctant to move house, an attitude reinforced by their strong emotional and affective ties to their hometowns, where they have their family, friends, and acquaintances. Leaving home is no easy task for an Italian.

This typical Italian attitude must be taken into account when considering residential mobility in the UrbanSIM model. It is more common for an Italian to choose a workplace based on its distance from their home than the contrary. Changing jobs to be closer to home is far more common than moving home after changing jobs.

The Rome municipality has witnessed significant spatial changes over time. In 1871, the municipality comprised 212 386 inhabitants; in 2001, the number of residents was 2 546 804. In 1871, urbanized areas were spread over 479 ha, a figure that had increased to 25 000 ha by 2001. Thus, while the population increased 12-fold, urbanized space increased 52-fold. The largest expansion took place after the Second World War (Piroddi 2004).

At the end of the 1990s, the housing situation in Rome was very problematic, with a large unsatisfied demand for housing despite a continuous and incessant increase in construction after the Second World War (Brazzoduro 1997).

The urban sprawl problem is highly relevant in Rome today. In an article in the daily *La Repubblica* (5 November 2008), Alberto Statera points out that the new municipal government has decided to build 25 000 apartments covering an area of 750 ha in the *agro romano*, a rural area outside the ring road and one of the few remaining unbuilt areas around the city. The City Master Plan, approved in the winter of 2008 by the former government, had already provided 70 million m^3 and 15 000 ha to be covered.

The 1990s were years of big changes for the City of Rome (CRESME 2002):

1. The municipality experienced a population decrease in the first half of the decade, which changed to a trend towards growth at the end of the decade because of a significant increase in the foreign-born population.
2. Building activity decreased in the 1988–1999 period with only 5000 new houses built per year, the lowest figure since 1959.
3. There was intensive unauthorised construction in the first half of the decade as a result of the announcement by the central government of a new amnesty on the infringement of local building regulations.
4. Tertiary sector activities—particularly the most innovative ones, which had decreased in the first half of the decade—resumed strongly in the second half, making Rome a domestic and international hub once more for the tertiary sector.

As a result, the unsatisfied demand for housing was estimated at between 136 212 and 251 786 rooms in 2001.

Four interesting demand segments that will probably grow in the future can be forecasted in the current decade:

1. Demand from the "poor," i.e. disadvantaged people who do not have access to housing because of financial problems: this category includes numerous foreign-born residents.
2. "First-time" demand from young couples in search of small to medium apartments (1–2 rooms) and lacking substantial financial resources.
3. Demand for temporary stays from non-resident students, professors, professionals, and workers who visit the city for limited periods, as well as people who come to the city not on a daily basis, but rather for longer periods—a few weeks, a few months, or a year.
4. Demand for "quality" from individuals and households wishing to improve their housing conditions, and from elderly people. The latter often own apartments in downtown Rome that have become too big and architecturally unwieldy for them, and are therefore in a position to sell their downtown apartments to buy smaller houses of similar or better quality in more suitable parts of the city.

The average number of annual transfers went from 5200 in 1997 to 44 900 in 2005. In the same period, 1997–2006, there was a trend towards residential deconcentration, which turned into sprawl in many cases.

The average property value in the Rome metropolitan was €2650 per square metre in 2006 and up to €3000 in the Rome municipality. Property prices rose by 82.8 percent in the metropolitan area from 1998–2006. House prices increased all over Italy during this period due to the introduction of the euro and the government's failure to control prices. Over the past few years, prices have increased less markedly in the Rome municipality than in the outlying cities, where they have gone up steeply (BIR 2008).

4 The transport and traffic situation

The main Italian traffic rules are to be found in the 1991 *codice della strada*, or highway code, which assigns municipalities the task of controlling traffic in urban areas. Therefore, municipalities are free to create ZTLs (*zone a traffico limitato*, or limited traffic areas), decide on bus and taxi routes, pedestrian areas, and cycle paths, and implement measures to reduce air pollution (Mazza and Rydin 1997). Municipalities are also responsible for managing infrastructure, including parking lots; these are generally managed by companies that are partly government-owned. Public transport, also controlled by municipalities, is usually run by private companies with total or partial public control at the local or supra-local level (Bonnel 1995).

Common measures to regulate traffic in Italy include:

1. Limiting traffic to protect historic town centres
2. Reducing traffic to ensure a smoother flow
3. Restricting car use to reduce air pollution
4. Regulating car access in designated areas to encourage economic development.

Car ownership and use have increased in almost all European countries in recent years, to the detriment of public transport. In the Rome municipality, the number of cars increased from 1 675 058 to 1 891 032, i.e. an increase of 13 percent, in the 1996–2006 period. The number of motorcycles went up by 214 percent, from 114 719 to 360 424, in the same period.

Taking the total stock of vehicles in Rome into account, a change in the relative share of cars and motorcycles can be observed. If other vehicles such as buses, trucks, etc. are included, it can be seen that the share of cars dropped from 85.9 percent to 76.4 percent, while the share of motorcycles increased from 5.9 percent to 14.6 percent. The increased use of motorcycles is due to the need to move quickly through traffic despite increased congestion. In the 1996–2006 period, the number of buses increased from 6456 to 7269, although their relative share dropped from 0.33 percent to 0.29 percent (ATAC 2006).

Rome has the highest number of cars per inhabitant in Italy: 724.3 cars for 1000 inhabitants, compared to the Italian average of 600.8 cars per 1000 inhabitants. In 2004, 6 117 795 daily movements were registered in Rome. Nearly 1.5 million of these were systematic, for reasons of study or work; 56 percent took place by car or motorcycle, 25.8 percent on foot or by bicycle, and only 18.2 percent by public transport. Comparing figures for 1996 and 2004, we see a strong increase in the tendency to walk or bicycle (+30.27%), a significant decrease in the use of public transport (−24.25%) and a slight decrease in car or motorcycle use (−3%) (ATAC 2006).

The Rome municipality's public transport system covers an area of 1285 km^2. The urban network comprises 2217 km of surface lines (buses, trolley buses, and trams), with 103.8 km of reserved lanes, and a 37 km subway network. The bus lanes, which form a radial pattern reflecting the city's development over time, connect the suburbs to the downtown area.

The local government has attempted to encourage people to leave their cars at home and use public transport instead by creating ZTLs. Access to these areas is limited to only residents, people with disabilities (there were around 50 000 permits in 2006), and two-wheeled vehicles. The historic centre, which spreads over six kilometres or so in the city core, is a ZTL. Traffic restrictions are total in some areas (all day, every day, except for Sunday) and partial in other areas (access is forbidden only on some days and at some specific hours).

Another measure aimed at discouraging car use is the creation of large car parks in the central parts of the city. There are 30 car parks with a total capacity of 13 000 cars, all located near the main train and subway stations. Special parking lots for tourist buses also contribute significantly to traffic reduction (ATAC 2006).

5 The implementation of the model in the Rome metropolitan area

Data collection and management while constructing the base year database was the main problem during the implementation of the UrbanSIM model in the Rome MA. Problems related to data can be subdivided into four areas: (i) Availability (ii) Accessibility (iii) Homogeneity (iv) Completeness.

Several factors contributed to the difficulty of collecting and managing data. Chief among these was the division of the single municipality of Rome into Rome and Fiumicino in 1991. This made it very difficult to ensure the comparability and homogeneity of data.

While a large amount of data are sourced from the Italian National Institute of Statistics (ISTAT) and available on census tracts, many other sets of data come from the Rome municipality, which uses a different division of the area with districts called *Suddivisioni Toponomastiche* that are very different from census tracts. They are actually larger than census tracts, particularly in the centre of the MA, but since some data are only available at this level of spatial detail, we had no choice but to use them. This led to problems with regard to both data availability and data homogeneity. Furthermore, data from this kind of source are available only for the Rome municipality and not for the Fiumicino area, resulting in the problem of incomplete data.

As usual, it is indispensable to use different data sources (Table 2) when constructing a complex database such as the one required to implement the UrbanSIM model, and this caused problems related to data unavailability and incompleteness.

Table 2: Data sources.

ISTAT (Italian National Institute of Statistics)
  – National Census of the Population (1991, 2001)
  – National Census of Industry (1991, 2001)
CRESME research
Municipality of Rome
  – STA, Agency for the Mobility of Rome
  – Risorse per Roma (Resources for Rome)
BIR – Real Estate Stock of Rome
Bank of Italy – Survey on Household Income and Wealth (1991)
CNR – National Research Council
CORINE program

Another major problem concerned the travel model, an external model. Since traffic zones have only been assembled for the Rome municipality, we did not have these important data for the municipality of Fiumicino. In this case, the problem was to reconstruct the traffic zones in the Fiumicino area and, subsequently, to develop a procedure to estimate missing values for travel data, i.e. the values contained in the UrbanSIM "travel data" table, which contains information on accessibility. The UrbanSIM model also requires residential land values in the grid cells table. Unfortunately, this kind of data does not exist in Italy, where one can only find data on house prices. What is more, house price data from the BIR (Real Estate Stock of Rome) are far from complete: they are only available for some years and over some *Suddivisioni Toponomastiche*. In other words, besides not having direct data on residential land values, the only indirect information on house prices is only partially available. Therefore, as regards residential land values, we had problems with data availability to start with and then with incomplete data. We encountered many other problems during the implementation of UrbanSIM, but while these problems can be classed in the four previously mentioned categories, they are general situations that may be encountered when applying a complex simulation model to any metropolitan area using data from many different sources. Therefore, this paper only discusses the categories that we consider to be typical of the Italian situation. In the next section, we shall describe the methodologies used to solve these problems and show how they have allowed us to construct the full base-year database, the starting point for any kind of simulation with UrbanSIM. We shall focus in particular on the problems of land use, traffic data, and residential land values.

6 Methodological solutions

The base-year database contains the basic information for the simulation and one of the principal tables it contains is the grid cells table. This table stores all the geographic information used by the UrbanSIM model to simulate household and job choices and calculate, for each grid cell, a development event and its probability for each simulation year following the base year. Since much of the information comes from ISTAT census tracts, when defining the dimension of the cells we started by considering the distribution of census tracts within the study region. The size of the census tracts varies widely across the area; the core, in particular, contains the smallest subdivisions. Census tracts can be as large as 10 or 20 km^2 outside the city centre and as small as 1000 m^2 in the core. We decided to set the grid cell size to 250 m by 250 m to keep the information as detailed as possible. Using GIS tools, we created a grid of 250 m^2 grid cells. Consequently, the study area is covered by 23 933 grid cells, and this is the row dimension of the grid cells table.

We derived many of the data for the grid cells table from a Land Use GIS layer, but since we did not have a unique data source, the layer was made by combining two different land use data sources:

1. The CORINE (Coordination of Information on the Environment) programme;
2. The MEDASE project from the CNR (Italian National Research Council).

Both sources date to the late 1980s. The former is available for the whole Metropolitan Area; however, it is not very detailed and is insufficient (especially in the centre of the city) to distinguish features at a spatial resolution of 250 m. The MEDASE layer, on the contrary, is sufficiently detailed, but is unfortunately available for only part of the study area. It is worth noting, however, that the area covered by MEDASE is quite large (65.43%) and includes the central part of the city, i.e. the most populated and with the largest number of activities. We therefore used MEDASE data in the area where it is available and CORINE data in the residual part, joining the two layers with a merge operation using GIS software.

We then classified the two land uses to obtain a single classification for the study area to be used for the UrbanSIM implementation. The final coding scheme was arranged in one or two digits: in the latter case the first digit represents the principal class, the second a subclass. We defined seven principal classes: 1–Water; 4–Wetland; 5–Public Space; 6–Open Space; 7–Roads; 8–Residential; 9–Industrial. Since Medase and Corine were created for different purposes using different techniques and technologies, all the categories of the former do not necessarily have a corresponding category in the latter and vice versa. For example, the MEDASE codes 6 (archaeological areas) and 91 (areas for other uses) become codes 51 (public space–archaeological) and 55 (public space–other uses) respectively in our classification, but there are no related categories in CORINE. On the other hand, the CORINE codes 512 (water courses), 411 (inland marshes), 2 (agricultural areas) and 123 (port areas) have been classified using the new codes 4 (wetland), 62 (open space–agricultural) and 56 (public space–port areas), but there are no analogous categories in MEDASE. The GIS layer derived from this final classification was particularly useful in constructing the grid cells table. From codes 1, 4, 5, 6, and 7, we calculated the following fields for each grid cell by intersecting with the grid cell layer: percentage of water, percentage of wetland, percentage of public space, percentage of open space, and percentage of roads. Regarding codes relative to residential areas and public spaces (51, 52, 56, 57, 63, 81, 82, 91, and 92), we calculated the built-up area and the fraction of built-up area in each grid cell with respect to the census tracts. Then, using data from the 1991 Italian National Census on residential units per census tract, we obtained the residential units for each grid cell. From codes 81 (residential–continuous) and 82 (residential–discontinuous), by making GIS intersections, we calculated the fractions of residential land. Technically, each of those data corresponds to a column in the grid cells table.

As we explained earlier in this paper, the problem with the external travel model is that it is only available for the Rome municipality; we have no data for Fiumicino. In particular we obtained (STA 2002) the traffic zones in vector format and a related matrix X with travel times to and from every zone and data on accessibility. In the rows of the matrix X we have the origin zones and in the columns the destination zones, for a total of $n = 463$ zones. Note that the travel time between two zones is not symmetric; so, using x_{ij} to indicate the generic travel time from zone i to zone j, we can say that $x_{ij} \neq x_{ji}$. We know that these traffic zones were derived from the *Suddivisioni Toponomastiche* created before 1991; therefore, in the Fiumicino municipality area we do not have traffic zones but can use the *Suddivisioni Toponomastiche* to provide an approximation. The traffic zones are not exactly equal to the *Suddivisioni Toponomastiche* because the former are smaller, but all the *Suddivisioni* share common boundaries with the traffic zones (Fig. 1 and 2). Furthermore, moving from the core towards the periphery the two layers tend to be very similar, almost the same, and fortunately, we need to reconstruct some zones in one area that is far from the city centre. Thus, it would not be going too far to hypothesise that the traffic zones match the Fiumicino *Suddivisioni Toponomastiche*. Using a GIS editor tool, we have recreated eight new areas that coincide perfectly with Fiumicino's *Suddivisioni*, raising the total number of traffic zones from $n = 463$ to $n = 471$. However, this gives rise to a fresh problem, as we do not have data for these new areas.

The phenomenon of the time needed to move from one location to another can be considered a continuous one, and in fact the system of traffic zones is based on this assumption, given that for travel time, the same value is applied to an entire zone. In other words, the variable "travel time" (or accessibility) is conceptually spatially continuous, and we can consider the element of the matrix X as values sampled at a particular fixed point location, s_i, that is the centroid of each traffic zone. The UrbanSIM model requires a single value for the travel time between each pair of zones and subsequently these zones are rasterized by the grid cells, so we do not need to know the variable in every point of the study area. But we may treat travel times as spatially continuous for the purpose of predicting values at sites where we do not have measurements—namely the eight new zones in the municipality of Fiumicino—and in case there are missing data once a prediction model is set up.

Formally, given the generic origin zone i, the situation is one with a series of observations $x_{ij}, (j = 1, \ldots, 463)$ that are the travel times from the zone i towards all other zones. This is represented by one row of the matrix X, i.e. the $(1 \times n)$ vector $x_{i.} = (x_{i1}, \ldots, x_{in})^T$.

$$\begin{array}{cc} & \begin{array}{ccccc} 1 & 2 & 3 & \cdots & 463 \end{array} \\ \begin{array}{c} 1 \\ \cdots \\ i \\ \cdots \\ 463 \end{array} & \left[\begin{array}{ccccc} 0 & x_{1,2} & x_{1,3} & \cdots & x_{1,463} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ x_{i,1} & x_{i,2} & x_{i,3} & \cdots & x_{i,463} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ x_{463,1} & x_{463,2} & x_{463,3} & \cdots & 0 \end{array} \right] \end{array}$$

Generic row vector i

$$\begin{array}{cc} & \begin{array}{ccccc} 1 & \cdots & j & \cdots & 463 \end{array} \\ \begin{array}{c} 1 \\ 2 \\ 3 \\ \cdots \\ 463 \end{array} & \left[\begin{array}{ccccc} 0 & \cdots & x_{1,j} & \cdots & x_{1,463} \\ x_{2,1} & \cdots & x_{2,j} & \cdots & x_{2,463} \\ x_{3,1} & \cdots & x_{3,j} & \cdots & x_{3,463} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ x_{463,1} & \cdots & x_{463,j} & \cdots & 0 \end{array} \right] \end{array}$$

Generic column vector j

In the same way we can consider one destination zone fixed, let us say j, and use all the $x_{ij}, (i = 1, \ldots, 463)$ that are the travel times from all the zones towards the zone j. This is represented by one column of the matrix X, that is to say the $(n \times 1)$ vector $x_{.j} = (x_{1j}, \ldots, x_{nj})$. With these data and using statistical methods we can estimate the travel time (S_{kj}) from one of the new zones, let us say $k (k = 1, \ldots, 8)$, towards one generic existing zone j, by means of the vector $x_{.j} = (x_{1j}, \ldots, x_{nj})$. Or we can estimate the travel time (S_{ik}) from one generic existing zone i, towards one of the new zones, k, with the vector $x_{i.} = (x_{i1}, \ldots, x_{in})^T$. One of the simplest methods useful for our estimations is the Inverse Distance Weighted (IDW) interpolation technique. This method belongs to the group of the so-called deterministic interpolation techniques. The idea is to multiply the values of the points that fall within a specified neighborhood from the processing cell by a weight that is derived from the distance of the sample point from the processing location.

A second group of interpolation methods consists of geostatistical methods that are based on statistical models including autocorrelation, namely the statistical relationships among the measured points (Cressie 1993). Both deterministic and geostatistical methods are capable of producing prediction surfaces, i.e. continuous surfaces useful for prediction purposes. However, geostatistical techniques can also provide some measures of the accuracy of these predictions. The weights are based not only on the distance between the measured points and the prediction location, as in the case of IDW, but also on the overall spatial arrangement among the measured points. To use the spatial arrangement in the weights, the spatial autocorrelation must be quantified. The most commonly used geostatistical method is ordinary kriging, in which the weights depend on a model fitted to the measured points, the distance to the prediction location, and the spatial relationships among the measured values around the prediction location. Furthermore, it is easy to see that the travel time is strongly related to the road network (Fig. 1), and for this reason in our model we must also consider the influence of different directions when estimating the surface.

This is possible with kriging, taking into account the anisotropy, i.e. a characteristic of a random process that shows higher autocorrelation in one direction than another. Besides all the travel times for the accessibility model, contained in the "travel data" table, the UrbanSIM model requires the travel times from each traffic zone towards the zone containing the principal airport and towards the Central Business District (CBD), and these data are collected in the "zones" table. However, given that the most important airport in the Rome Metropolitan Area is situated in the municipality of Fiumicino, let us focus our attention on one of the new traffic zones—the one that includes the airport—to provide a practical example of the estimation process. We want to estimate the travel time from the CBD, which is in a commercial area of the city called E.U.R., to the Fiumicino airport: following our symbols, we are in the case where i = CBD and k = Fiumicino, and we must estimate S_{ik}. The first step is to calculate the empirical semivariogram, a means to explore the basic law in spatial phenomena, i.e. the basic principle that things that are close to one another are more alike than those farther away. With the empirical semivariogram, it is possible to see that pairs that are close in distance have a smaller difference than those farther away from one another. The empirical semivariogram provides information on the spatial autocorrelation of the n existing travel times from the CBD towards all the other $n-1$ traffic zones (vector $x_{i.} = (x_{i1}, \dots, x_{in})$ where i = CBD). The next step is to fit a model to the points forming the empirical semivariogram. This is because the empirical variogram does not provide information for all possible directions and distances. For this reason, it is necessary to fit a continuous function to the empirical semivariogram, and this model quantifies the spatial autocorrelation of the data. The variogram is based on the assumption of intrinsic stationarity, defined through a constant mean and a constant variance in the differences between values at locations separated by a given distance h and direction:

$$\mathrm{E}\left(X(s_i) - X(s_j)\right) = 0 \tag{1}$$

$$\begin{aligned} \mathrm{Var}\left(X(s_i) - X(s_j)\right) &= E\left(X(s_i) - X(s_j)\right)^2 \\ &= 2\gamma(s_i - s_j) \\ &= 2\gamma(h) \end{aligned} \tag{2}$$

where s_i and s_j are two different locations, $X(s)$ is the variable of interest in location s, and $2\gamma(h)$ is the variogram. For this application, we have chosen a spherical semivariogram model with anisotropy.

Finally, using the correlation values it is possible to calculate the kriging weights for the measured n values, and from these we can estimate a prediction for the location with the unknown value, i.e. for Fiumicino airport. The resulting estimated value for the time needed to move from the CBD to the airport is 19.916 minutes. We emphasise the fact that this result depends not only on the distance between the measured points and the prediction location, but also on the spatial autocorrelation among the measured points. Repeating this procedure for all the origin zones, we obtained estimates for all the other zones considered as origin and the zone of Fiumicino airport as destination. All the travel times concerning the eight new areas as origin zones and the Central Business District as destination have been estimated in the same manner (Fig. 3). Travel times to airport and to CBD are data contained in the "zones" table of the base year database, made up of 471 rows that correspond to the zones.

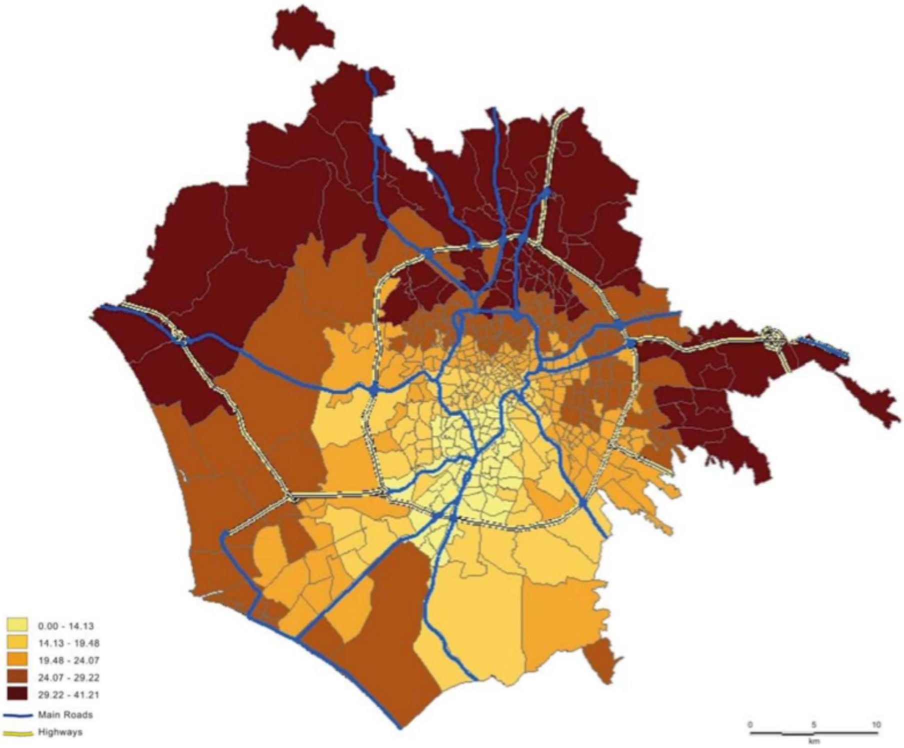

Figure 3: The Rome metropolitan area, travel time estimation (minutes) to CBD, by traffic zones.

One advantage of kriging is that it provides some measure of the accuracy of the prediction, i.e. some idea of how well the model predicts the values at unknown locations. Cross-validation helps to make an informed decision as to which model provides the best predictions. It consists of removing one or more data locations and then predicting their associated data using the data at the rest of the locations. In this way, it is possible to compare the predicted value to the observed value and obtain useful information about decisions—for example, about the semivariogram model. Further information is derived from the scatter plot of predicted values versus true values, which should be around the 1:1 line. Finally, the kriging prediction errors give us another important diagnostic tool. If the prediction errors are unbiased, the mean prediction error should be near zero. However, this value depends on the scale of the data and to standardize these, the standardized prediction errors give the prediction errors divided by their prediction standard errors. The mean of these should also be near zero.

Besides making predictions, the variability of the predictions from the true values is estimated and it is important to obtain the correct variability. If the average standard errors are close to the root-mean-squared prediction errors, the estimate of the variability in prediction is good. Another way is to divide each prediction error by its estimated prediction standard error. They should be similar, on average, so the root-mean-squared standardized errors should be close to 1 if the prediction standard errors are valid.

Table 3: Cross-validation results

Mean	−0.0223
Root-mean-square	1.666
Average Standard Error	1.807
Mean Standardized	−0.0029
Root-mean-square Standardized	0.9169

In our application, the cross-validation (Table 3) confirms that the model provides very good predictions (mean prediction error = −0.0223; mean standardized prediction errors = −0.0029; root-mean-squared standardized errors = 0.9169), and this is true not only for Fiumicino but also for all the other estimates.

As anticipated earlier, the problem of data availability for the municipality of Fiumicino also exists for the UrbanSIM "travel data" table, which contains data on accessibility in the form of logsums of travel times. In fact, in this case too we use an external model as input for UrbanSIM, and it is available only for the Rome area. The concept of accessibility for a given location is constructed considering the composite utility of all modes of travel to those destinations, defined as the logsum from the mode choice model for each origin-destination pair (Waddell *et al.* 2003). Therefore, in this case too we can consider this data a continuous variable and, once again using the geostatistical methodology, we have estimated all the missing values in the "travel data" table.

At this point it is important to consider that, in the context of the problems with data accessibility, we do not have the option of managing the travel model so as to extend the transport networks and calculate the missing travel times and logsums. All we have are the travel data on Rome, i.e. an origin/destination table with the logsums for four different modes of travel (public transport, car, motorbike, walking). We know that the geostatistical approach is not the best one, but considering the data we have, it seems the only way to overcome the problem. Furthermore, given that availability and accessibility of data seem to be the main obstacle to the application of the UrbanSIM model in Italy as well as other European countries, statistical methods can be used when other ways to obtain original and complete data are not possible. Finally, we should consider that the problems with travel data concern only the base year (1991); during the subsequent simulation years, the UrbanSIM models simulate the impacts of possible land use policies on travel. As we have shown in the previous section, another problem involving both unavailable and incomplete data is that of residential land value. This kind of data does not exist in Italy; however, we do have data on house prices. We started from the fact that the house price is decomposable into two quantities, namely the residential land value plus a residual quantity representing the improvement value derived from the construction value for residential buildings. So, for each grid cell, we can write the House Price P as

$$P = L + SC \tag{3}$$

where L is the Residential Land Value and SC the residential improvement value. The improvement value is calculated as a product of the construction cost per square meter C, and the surface of the house in square meters S. Data from BIR give us information about the housing price P in many *Suddivisioni Toponomastiche*; from the built-up area in each grid cell we have information on S; and, finally, we have data from the Rome Architects' Association on construction prices for the whole MA. All the data have been organized on a grid-cell level using GIS procedures, so since we have the quantities P, S and C for each cell, it is easy to derive the Residential Land Value by a simple subtraction:

$$L = P - SC \tag{4}$$

Regarding the further problem of missing data on this variable, we considered the core and the rest of the MA separately. In fact, outside the core there are many sparsely populated rural areas (Fig. 2) with fairly homogeneous house prices, so we simply considered a mean value of the existing values to reconstruct missing values.

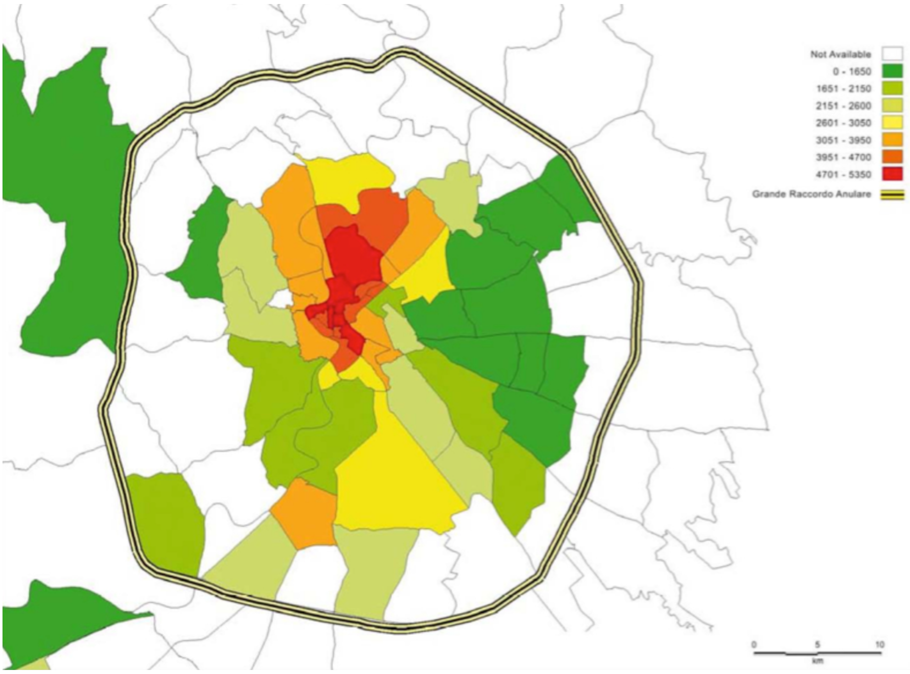

Figure 4: Rome metropolitan area, house price (Lit/m^2) by Suddivisioni Topomastiche.

Conversely, there is much greater variation in house prices in the core of the city (Fig.4), so we need a more sophisticated procedure to estimate missing values there. As in the case of travel data, we consider the value of a generic *Suddivisione* i as associated to the centroid of the same area, s_i, so that the available data are on scattered points. One of the most commonly used techniques for the interpolation of scatter points is the Inverse Distance Weighted (IDW) interpolation, based on the assumption that the prediction values should be influenced most by the nearby points and less by the more distant points. The interpolating value for a point is a weighted average of the scatter points and the weight reduces as the distance from the interpolation point to the scatter point increases. The general form of finding an interpolated value v for a given point s using IDW is the interpolating function:

$$v(s) = \frac{\sum_{k=0}^{N} w_k(s) v_k}{\sum_{k=0}^{N} w_k(s)} \tag{5}$$

where

$$w_k(s) = \frac{1}{d(s, s_k)^2} \ . \tag{6}$$

Here s denotes an interpolated point, s_k is a known point, d is the distance from the known point s_k to the unknown point s and N is the total number of known points used in interpolation. By means of IDW we estimated all the HP missing values in the core (Table 4) and, consequently, knowing the values of SC for the total MA, we reconstructed all the data regarding residential land values for each *Suddivisione Toponomastica* in the entire MA. Finally, by overlaying the *Suddivisioni Toponomastiche* with the grid cells layer, each cell received the corresponding real or estimated value; when a cell was between two different areas, we assigned it a value following the standard criterion of prevalence.

7 Results

We are still in the validation phase for the UrbanSIM model, but some interesting results have emerged from the simulations. Simulating up to the year 2020, we obtained an increase in the numbers of employees in all sectors. In particular, it is interesting to note the increase in the commerce sector: the system forecast is 349 323 employees, i.e. an increase of 59 742 units compared to the year 2001 (+20.63%). Through the GIS visualization of the data on a grid cells level, we verified that the increase is concentrated in some crucial areas of the city, which form the connection points between the ring road (GRA) and the main arterial roads connecting the MA with external areas, in particular in the eastern part of the MA. These are not highly populated areas but they do have a high concentration of shopping centres, and it is reasonable to believe that the areas will witness marked development in the commerce sector in future. Things are very different in the core: the number of jobs in the sale sector was 213 726 in 2001 and will be 228 369 in 2020, i.e. an increase of only 6.85 percent.

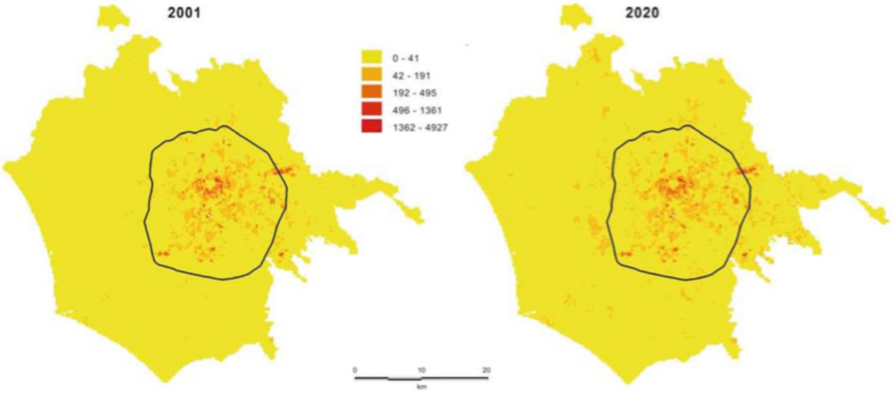

Figure 5: Number of industrial jobs by gridcell in the Rome Metropolitan Area, 2001 and 2020.

Regarding the industrial sector, starting from 260 536 jobs in 2001, 82 percent of which are within the core, (Fig.5), the UrbanSIM prediction for 2020 is 314 787 jobs (Fig.5), i.e. 54 251 additional workers (+20.82 percent). This figure may be surprising for an urban area but can be explained by the fact that the Rome MA covers a large space with many "voids," or empty

Table 4: Available and estimated house prices.

Code	Suddivisione Toponomastica	True Value	Est. Value	Code	Suddivisione Toponomastica	True Value	Est. Value
101	Monti	3600	3600	218	Tor di Quinto	2700	2700
102	Trevi	4450	4450	219	Prenestino-Centoc.	1350	1350
103	Colonna	5050	5050	220	Ardeatino	2800	2800
104	Campo Marzio	5350	5350	221	Pietralata	1250	1250
105	Ponte	5100	5100	222	Collatino	1400	1400
106	Parione	4500	4500	223	Alessandrino	1350	1350
107	Regola	4700	4700	224	Don Bosco	1650	1650
108	Sant'Eustachio	5300	5300	225	Appio Claudio	1950	1950
109	Pigna	5100	5100	226	Appio-Pignatelli	2550	2550
110	Campitelli	4900	4900	227	Primavalle	1600	1600
111	Sant'Angelo	4450	4450	228	Monte Sacro Alto	n. a.	2500
112	Ripa	4400	4400	229	Ponte Mammolo	1100	1100
113	Trastevere	3500	3500	230	San Basilio	1500	1500
114	Borgo	3600	3600	231	Giuliano-Dalmata	2300	2300
115	Esquilino	2250	2250	232	Europa E.U.R.	3650	3650
116	Ludovisi	4400	4400	301	Tor di Quinto	n. a.	2700
117	Sallustiano	4650	4650	307	Portuense	n. a.	2150
118	Castro Pretorio	2050	2050	308	Gianicolense	n. a.	2150
119	Celio	3500	3500	309	Aurelio	n. a.	2350
120	Testaccio	2800	2800	310	Trionfale	n. a.	2600
121	San Saba	3050	3050	311	Della Vittoria	n. a.	3900
122	Prati	3950	3950	401	Val Melaina	n. a.	2894
201	Flaminio	3350	3350	402	Castel Giubileo	n. a.	2447
202	Parioli	4150	4150	404	Casal Boccone	n. a.	2054
203	Pinciano	5000	5000	407	Tor Cervara	n. a.	1418
204	Salario	3400	3400	408	Tor Sapienza	n. a.	1464
205	Nomentano	2700	2700	412	Torre Spaccata	n. a.	1478
206	Tiburtino	1500	1500	415	Torre Maura	n. a.	1619
207	Prenestino-Lab.	1500	1500	418	Capannelle	n. a.	1787
208	Tuscolano	2000	2000	421	Torricola	n. a.	2159
209	Appio-Latino	2550	2550	422	Cecchignola	n. a.	2550
210	Ostiense	2050	2050	424	Fonte Ostiense	n. a.	2518
211	Portuense	2150	2150	427	Torrino	2250	2250
212	Gianicolense	2150	2150	439	Tor di Valle	n. a.	2051
213	Aurelio	2350	2350	440	Magliana Vecchia	1750	1750
214	Trionfale	2600	2600	444	La Pisana	n. a.	1881
215	Della Vittoria	3900	3900	450	Ottavia	n. a.	2139
216	Monte Sacro	2500	2500	453	Tomba di Nerone	n. a.	2692
217	Trieste	3600	3600	456	Grottarossa	n. a.	2453

spaces, since it is not totally urbanized. Spaces for economic activities are still available. Given its spatial distribution, the forecasted increase in the industrial sector could be attributed to an expansion of industries working in connection with Fiumicino airport and the Civitavecchia port. Given a process of intense residential and economic deconcentration in the Rome MA, these increases can be also linked to the building sector. The areas with the largest share of development in this sector are situated immediately outside the GRA, which delineates the core, especially in the western and northern parts of the MA. Again, the peculiarity of this MA is the strong difference between the core and the rest of the area and in fact, inside the core, the predicted increase is only 6.8 percent, from 213 726 to 228 369 units. This also means that at the end of the simulation period the percentage of industrial jobs situated inside the core compared to the percentage of industrial jobs in the MA as a whole drops to 72 percent.

The expected population of the whole MA in 2020 is 2 311 835 (Fig. 2), i.e. a decrease compared to the 2001 figure of 243 746 people (−9.54%). The population of the core goes from 2 047 279 in 2001 to 1 873 649 in 2020, an 8.48 percent decrease. However, we can also foresee an increase in the number of households in the same period, from 1 057 785 in 2001 to 1 118 425 in 2020. Those trends confirm a marked reduction in the average size of households, from 2.42 members in 2001 to 2.07 members in 2020.

8 Conclusions

In the current global economic crisis, there is increasingly heated debate about the social, economic and cultural development of the major Italian cities as a way to enhance growth. Investments in qualified services and infrastructure in metropolitan areas could represent the only option if we are to envisage the future with some amount of optimism at a time when economic performance is either stagnant or declining. Following large-scale industrial expansion in the 1950s and 1960s, Italian cities discovered cultural heritage, tourism, and the tertiary sector in the 1980s. Today, the economic crisis is affecting a metropolitan population whose growth is stagnant, except for immigrant families; where aging is a major phenomenon and where tertiary activities are in continuous development. Tertiary activities in Rome, for instance, account for 82 percent of the labour market, far more than the Italian average of 66 percent. With quantity no longer a priority after all these decades, this may be the time to start considering issues such as quality of life and the renewal of natural and cultural resources. In the period following the Second World War, planning in Rome mainly focused on safeguarding the integrity of the historic centre, partly because of policing by an international network of intellectuals (Montanari 1976) while more or less deliberately allowing for urban sprawl in the suburbs (Montanari 1993). A “development-led” urban policy continued during the years of the so-called “red administrations” (1976–1985) headed by Communist Party mayors and the “left-wing administrations” (1993–2008) headed by reformist mayors such as Messrs Rutelli and Veltroni. This analysis can also be found in the research of McNeil (2003), who highlights a project-driven approach over the past fifteen years in which private sector interests have overwhelmed and dominated those of the public. Even a huge event such as the 2000 Jubilee did not really change the development model, which still works in the interests of a lobby of property developers rather than those of the community. This experience has led the public administration to consider individual large-scale initiatives of its own. The public sector did not understand the need for a general background so as to forecast the impact of the huge Jubilee event. The result has been a process of "blind planning" and an inability to support appropriate decisions. Testing the UrbanSIM model is even more relevant in this situation because it would help reduce uncertainty, give clear development options to public sector stakeholders, provide local communities with a tool to support informed decision making, and contribute to the development of democratic planning processes.

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