Aldea, M., Alpopi, C. (2022). Land observations and management in the outlook of urban growth. *Administratie si Management Public*, 39, 189-212. DOI: 10.24818/amp/2022.39-11

Land observations and management in the outlook of urban growth

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***Abstract*:** Urban growth is a specific phenomenon to the evolution of cities, which exhibits over time through the fact that cities, from the moment they emerge, go through a continuous process of development and expansion. Urban growth means the spatial multiplication of the built-up (or otherwise valorized) land surfaces inside and outside the city boundary. Our research objective is to better understand all the dimensions affected by urban growth and their relationships, thus being necessary to use remote sensing techniques to identify the type of satellite imagery processed output that is best related to the economic and social indicators recorded statistically and historically. In the present paper, following the research carried out, the authors present the progress that they have made in terms of monitoring and studying the urban growth phenomenon for the city of Bucharest, based on the spatial patterns of the land use/land cover surfaces obtained through remote sensing of Landsat satellite imagery that emphasize the changes in the built-up land surfaces in more than four decades. Thus, the authors identified the changes at the macro scale of the city using the techniques of satellite remote sensing and established the most effective relationships to the historic, spatial, economic, and social statistical determinants. The results show which factors are decisive and which are the best land observations and forecasting techniques that can help the urban management of the city and its future development. The forecasting can be used both to estimate the chronological evolutions and future changes in urban surface and to think about city development policies and to surmount the absence of statistical socio-economic data.

Keywords: urban growth, remote sensing, urban management, land observations.

JEL: R11, R58, O18

DOI: 10.24818/amp/2022.39-11

Introduction

Analysis of a city and its component elements differs from case to case, depending on the area of concern of the person studying the matters of urban development.

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Various specialists in various fields have perceptions about the city according to the activities in which they are involved. Some analyse at the level of detail and study the aesthetic aspect of the structure and the component elements of the urban buildings, from the point of view of the resistance of the construction.

Others study the city as a whole in terms of its design and development, mobility, and energy security. Regardless of the approach, however, these perceptions can be passed on through the prism of urban management towards more efficient use of urban resources, attracting public funding to increase the quality of life and demographic revitalization. Regardless of the scale at which the city is viewed, elements of its development can be identified either concretely on a micro-scale (for example by identifying an actual building or park) or by observing spatial patterns of macro-scale growth. These spatial patterns are indications that can be observed on a macro scale to characterize urban development and can be monitored for changes over time. From the point of view of urban development, one can observe the phenomenon of urban growth, a phenomenon specific to the evolution of most cities manifested over time, since their appearance (Chandler *et al*., 2013; Stobart, 2004; Bretagnolle, *et al*., 1997).

An equally natural phenomenon encountered during the history of urban centres, but especially in recent years, in the context of population decline, industrial decline, etc. is also urban contraction (Ducom, 2008). The existence of the two phenomena, growth and contraction, makes it possible to talk about the dynamic of urban systems. Because the conversion of land from rural to urban is a difficult reversible or irreversible process (Wise *et al.,* 2007), in the case of urban contraction, spatial patterns are difficult to identify. On the other hand, spatial patterns are very useful in the case of urban growth, so the multiplication of areas of land used/built, both inside and outside the city limits.

The aim of this paper is to advance the possibility of monitoring and studying the phenomenon of urban growth based on spatial patterns manifested by changes in land use over the past 45 years and which at the macro scale of a city can be identified by satellite remote sensing technology and the ability to estimate chronological developments in the absence of data or to predict future changes by analysing historical, spatial, economic and social determinations.

1. The phenomenon of urban growth and monitoring methods

Urban growth, as a quantum of the growth of capitalized/built land areas, manifests itself in various forms, one of these forms being “urban expansion” (Bhatta, 2010). From the point of view of characterizing the phenomenon of urban growth in general, it is distinguished primarily by a dimension related to space and a dimension related to time. Spatial changes can be monitored over time using satellite remote sensing techniques. Also, the analysis of changes in land use in the case of urban growth, in terms of socio-economic changes, introduces a new dimension that can be correlated with previous dimensions and can serve as a possibility to simulate and forecast possible dynamics in the future.

1.1. The spatial dimension

Due to the advent of satellites and the development of Earth observation programs, and free access to satellite imagery, a new approach to surveying the evolution of the emerging forms of urban growth has become available, namely satellite imagery monitoring and the identification of so-called spatial patterns at the macro scale of analysis of a city or rather of an urban area. Patterns can be observed by identifying land use classes. The terminology of "spatial pattern" means the spatial arrangement or distribution of the built environment in order to ensure socio-economic functions at the urban level (Inostroza, *et al.,* 2013). The city's growth way can thus be analysed based on the information generated by processing satellite images and grouping pixels recorded in various classes of land use/land cover. Through the image classification process, each pixel is identified and placed in a certain category (class). These classes can be chosen by an analyst before applying image processing (supervised classification), or they can be automatically produced by an algorithm following the unsupervised classification process (without human intervention).
Urban growth monitoring based on satellite remote sensing involves a trade-off between the spatial resolution of images - the pixel, the smallest identifiable element in an image - and the number of varieties of identifiable elements in the field. The higher the resolution, the more easily the elements in the land become identifiable by the analyst, but the number of categories they can fall into becomes so high that an automatic (unsupervised) or even supervised classification could have unsatisfactory results (Moeller, 2005). For this reason, the preferred satellite images for monitoring urban dynamics (Moeller, 2005) are those with a resolution of 4 - 50 m and Landsat sensors fall into this category, starting from the first Landsat-MSS sensors with a spatial resolution of 60 m to the most recent Landsat-7-ETM and Landsat 8/9 OLI with multispectral sensor with a spatial resolution of 30 m/15 m in panchromatic and thermal with 60/100 m resolution.

1.2. The temporal dimension

Over time, cities' grow or decrease in size, is characterized by a continuous dynamic, being determined by the social, economic, and administrative-political context. Until the 19th century, the study of the spatial development of cities was not necessarily a priority for documentary and research concerns (Chandler, *et al.,* 2013). Even studies over the past 40 years have looked at urban dynamics in relation to the demographic evolution of the population rather than urban areas, which may be irrelevant as long as statistical data collection is a recent activity on a historical scale (Chandler, *et al.*, 2013). For this reason, statistical data on the population or building stock does not always have a high degree of certainty or is not partially or fully available. But satellite images recorded in time series can be additional data sources that can document the evolution of urbanization by identifying the areas that cover the land.

Urban growth monitoring based on satellite remote sensing thus implies, in addition, this new parameter, namely the temporal resolution - the number of images taken during a year. The physical conditions of orbiting the Earth by satellites impose such circumstances that as the temporal resolution is higher, the spatial resolution is lower. Geosynchronous satellites have a period of rotation equal to that of the Earth and orbit at high altitudes, which means that the spatial resolution is very low (1 pixel covers an area of the order of kilometers) but can record images covering a large part of the planet, for example, every 30 min (Moeller, 2005). Satellites orbiting at lower altitudes have better spatial resolutions and rotation periods of the order of hours to orbit the Earth. In addition, heliosynchronous satellites cross the same point on Earth at the same time of day and having no inclined angles is the best suited for the study of urban areas (Moeller, 2005).
Given these time-related conditionings, Landsat solar-synchronous satellites with revisiting periods of approx. 16 days to the same land surface and images were taken continuously since 1972, which means that the evolution of urbanization can be traced over the last 50 years. This is the reason why, in this paper, we chose them for monitoring the urban dynamics of Bucharest. In addition, the Landsat 9 satellite was launched on September 27, 2021 in the same orbit as Landsat 8 but with a phase shift of 8 days so that the combined time of the two satellites Landsat 8 - Landsat 9 to revisit a terrestrial surface is only 8 days, which doubles the temporal resolution, which is also true for the Landsat 8 - Landsat 7 set, but not so functional due to the technical problems of the Landsat 7 satellite (NASA, 2021).

1.3. Socio-economic dimension

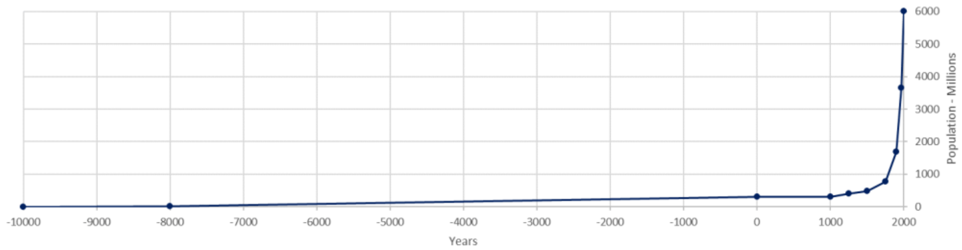
1.3.1. Economic data

Economic growth is closely related to the valorisation of land in the form of built-up surface and GDP growth is the most fundamental factor in the expansion of urban land use. Gross domestic product (GDP) is the main macroeconomic indicator that reflects national revenues over a year, and for Romania is estimated by the National Institute of Statistics (National Institute of Statistics, 2021). This indicator is especially useful insofar as the GDP of the Bucharest-Ilfov Region is also available, which is the regional correspondent of GDP (National Institute of Statistics Metadata 1.0, 2014; Directorate of National Accounts and Macroeconomic Synthesis, 2009). GDP is a good indicator of the level of production but not of material well-being when it is defined in terms of consumption of goods and services individually/in households. To indicate the level of material well-being, it should be supplemented with more appropriate indicators for measuring it. GDP per capita is frequently used to compare this welfare (OECD/Eurostat, 2012). Real GDP takes into account the effects of inflation over time so that different periods can be compared (US Bureau of Economic Analysis, 2022). Thus, an important economic indicator that can be taken into account additionally is the inflation rate. Another statistically recorded economic index that can be analysed is the nominal house price index (house cost) and can be used in order to relate it with the remotely sensed built-up areas as an important factor in purchasing a household or not. The nominal house cost covers both the sales of newly built and already existing dwellings (OECD, 2022), showing the residential property prices over time.

1.3.2. Social data

The evolution of the human population had a significant increase especially in the last hundred years, as can be seen from the historical data (United Nations, 1999; Durand, 1974) presented in Figure 1.

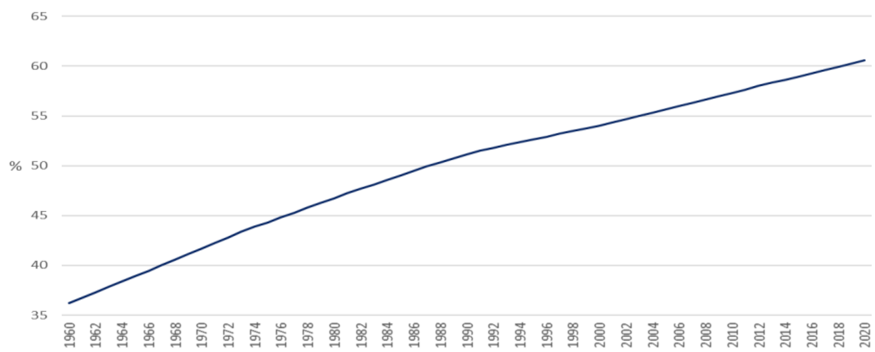
Figure 1. The estimated historical evolution of the world's population



(*Source:* Durand, 1974; United Nations, 1999)

This sharp increase in world population in the last century has had a definite influence on the evolution of cities, especially since the percentage of the population living in urban areas is estimated to have increased significantly over time, as shown in Figure 2 according to World Bank estimates based on the United Nations World Urban Development Outlook - Revision 2018 (World Bank, 2021).

Figure 2. Percentage of urban population in total population



(*Source:* World Bank, 2021)

In view of the above, it can be assumed that there may be a correlation between population growth in an urban area and the increase in urban areas in relation to it, and such an indicator of social statistics can be used.

2. Methodology

In our study of the relationship between spatial patterns of urban growth and statistical indicators' evolution, three techniques namely remote sensing, socio-economic-statistics of events and statistical regression and correlation were used.

2.1. Research methodology

The present paper introduces three methods of analyse which were used as tools for our research. The first tool is based on remote sensing techniques of processing the satellite images with approximative decadal recurrence in order to obtain the principal land use/land cover types with emphasis on the built-up surfaces. Thus, using this first tool, we were able to calculate the coarse values of the areas of built-up land at each decadal change in the Bucharest-Ilfov Region. The second research tool we used was the documentation regarding the available sources of socio-economic statistical data and the historical events references followed by the analysis of their suitability for the research objective. The necessary data for the use within the second tool was obtained from both national and international organisations that provide such statistical recordings: United Nations Statistics Division, OECD, Eurostat, Romanian National Institute of Statistics, Bucharest Regional Directorate of Statistics, and the Romanian, Regional or Bucharest's Statistical Yearbooks. The historical references consisted of information contained in laws and regulations together with the documented events such as significant natural hazards which took place and could have had a potential influence on the urban dynamics. The third research tool we applied was the statistical analysis based on regression and correlation. The third tool was used in order to integrate the previous two research tools and to show the relationships that can be established between the parameters resulting from the use of the first couple of tools.

2.2. Methodology for change detection analysis by processing multitemporal satellite remotely sensed images

Change detection analysis of land use/land cover (LULC) obtained from the processing of multitemporal satellite remotely sensed images is one of the main steps in comparing the statistical recordings regarding the chronological evolution of a city and its actual spatial form. Taking advantage of the opportunity of being able to use the Landsat satellite imagery available as open data, we chose this sensor also due to the fact that it provides the spatio-temporal resolution necessary for LULC change detection. Currently available Landsat images start from 1972, but must meet the requirements for remote sensing of urbanized areas for the detection of changes in time series (Aldea, *et al*., 2016) as presented in sections 3.1 and 3.2 for the use in monitoring the phenomenon of urban growth, specifically:

a) Landsat images downloaded from the USGS archive must have the minimum processing Level 1, so processed at complete ground accuracy correction (L1TP).
b) the preferable season when the image was recorded is one in which most of the deciduous trees in Bucharest, as well as most of the other types of vegetation, are in the latent vegetation period.
c) images without cloud cover in the study area
d) images recorded as close as possible to the dates on which the events occurred which may generate changes in the land cover in the sense of expanding the built surfaces.

The first such image to meet the four criteria mentioned above dates from 1976. As for the last criterion, the events that can generate evolutions in land use were those of a socio-economic nature closely related to the statistical indicators in this sphere but also of historical evolutions not statistically recorded but only documentary such as regulations in the field of urban planning or natural disasters which took place. The satellite images were chosen for processing and analysis that meet the selected criteria from a) to d) are presented in Table 1 and have a spatial and temporal resolution corresponding to the study of urban dynamics.

Table 1. Satellite images selected according to the criteria of selection from a) to d)

Temporal resolution	Sensor	Season/Month	Spatial resolution
1976	Landsat MSS	13 January	60 m
1986	Landsat TM	06 October	30 m
1990	Landsat TM	26 February	30 m
2000	Landsat TM	31 December	30 m
2009	Landsat TM	29 November	30 m
2019	Landsat OLI	19 February	30 m

(*Source*: USGS, 2022)

In order to determine the land use/land cover (LULC) classes in the Bucharest-Ilfov Region, the unsupervised K-Means algorithm for classification was used. The K-means algorithm calculates the initial class means as evenly distributed then iteratively groups the pixels into the nearest class using a minimum distance technique (Tou, *et al*., 1974). This method can be applied in a simple way due to the unsupervised algorithm of classification in a few iterations (less than 20) and with minimised human intervention, detection of correct classes thus being more objective. Post-classification and corrections were performed by human interpretation of the obtained classes.

2.3. Methodology for socio-economic analysis

2.3.1. Economic data

The Gross Domestic Product of Romania is estimated by the National Institute of Statistics (2021), based on three methods. In the last couple of decades, Romania's economy has been developing rapidly, with Bucharest as the most economically developed city in Romania. In 2009 at purchasing power parity, producing more than 20% of the country's GDP, Bucharest had a per-capita GDP more than twice the Romanian average while only accounting for 9% of the country's population (Eurostat newsrelease, 2009). The GDP macroeconomic indicator is especially useful to the extent that the GDP of the Bucharest-Ilfov Region is also available and statistically recorded as the regional GDP correspondent, calculated by the production method - as the sum between the regional Gross Value Added and the taxes on the product plus the customs duties on imports minus the subsidies on the product (National Institute of Statistics Metadata 1.0, 2014). Since the macroeconomic indicator will also be used in the forecast of the future evolution of built-up surfaces, in order to simplify the forecast and to reduce variability, the main indicator used in the analysis will be the GDP, not GDP per capita which would depend on both the GDP forecast and the population forecast. Economic data available from the Romanian National Statistics Institute statistics are usually related to nominal GDP. The Ministry of Finance provides the data for real GDP.

The values used for the selected economic indicators were those recorded in the statistical databases of the international platforms of the United Nations and of the Organisation for Economic Co-operation and Development. The GDP was obtained from the United Nations database (United Nations Statistics Division, 2022). The nominal house price index (house cost), was obtained from the OECD data platform (OECD, 2022).

2.3.2. Social data

Due to the coverage with data over a longer period of time (1956 – 2011) the Stable Census Population was chosen as a demographic indicator, a reference that includes both persons who have their permanent residence in the locality in the census year and persons who have temporary residence in the locality, with the exception of persons with temporary residence in other localities (Bucharest Regional Directorate of Statistics, 2012).

In order to fill in the needed data with the values for the periods of time between the census years, the data were extracted from the Romanian, Regional or Bucharest's Statistical Yearbooks which have their own methodology for the population indices, but mainly the Legally Resident Population. This indicator, according to the methodology of the Romanian National Institute of Statistics (National Institute of Statistics, 2014), represents the number of persons with Romanian citizenship from the address they declare as the main residence in the Romanian administrative units

and it does not contain information about other residences or about the number of absent people who left for work, studies or even for tourism purposes in the country or abroad. This statistical indicator can be analysed in relation with the newly built-up areas and its degree of usefulness in the study of the development of the Bucharest-Ilfov Region can be established. Another social statistical indicator that can be analysed is the dwelling number index, especially the ones built with the population’s own funds, being perceived as their main investments.
Statistical indicators were obtained from multiple sources to best cover the selected time periods. Thus, data on the population were taken from the census of 1956-2011 (Romanian National Institute of Statistics, 2022) and from the statistical yearbooks of 1977, 1986 and 2021 (Central Directorate of Statistics, 1977; 1986; Bucharest Regional Directorate of Statistics, 2021) and the number of completed homes from private funds of the population were obtained from the statistical database available on the platform of the National Institute of Statistics of Romania and completed where appropriate with data from Romania's statistical yearbooks from 1977 and 1986 (National Institute of Statistics, 2021; Central Directorate of Statistics, 1977; 1986).

2.4. Methodology for statistical analysis – regression and correlation

The analysis is performed with the support of historical statistics data through socio-economic statistical indicators such as those demographic ones as stable population according to domicile and those economic ones such as housing situation and GDP. Convenient socio-economic statistical indicators are linked to the time factor by means of a linear regression together with the built-up land areas identified through satellite remote sensing tools. Thus, the relationship between social and economic indicators such as dwellings, GDP etc., and the urban area can be established by regression analysis using surface measurements from satellite images and socio-economic indicators from statistical data. Finally, it is possible to forecast the newly built land area in the coming forecast years based on the socio-economic indicators registered or forecasted in the studied perimeter (in this case the Bucharest-Ilfov Region). Bucharest, from the point of view of the conversion of land into built/capitalized surfaces over the last 50 years (Aldea, *et al.*, 2015), it is possible to present an evolution in accordance with demographic evolution.
For a better understanding of the relationships for each pair made from the built-up area metrics and each of the other statistical indicators, a correlation analysis is performed. The value of the correlation coefficients is between -1 and +1 and determines whether the pair of variables tend to change together:

- positive correlation if large values of one variable tend to vary with large values of the other,
- negative correlation - whether small values of one variable tend to move with large values of the other
- correlation near zero - both variables tend to be unrelated.

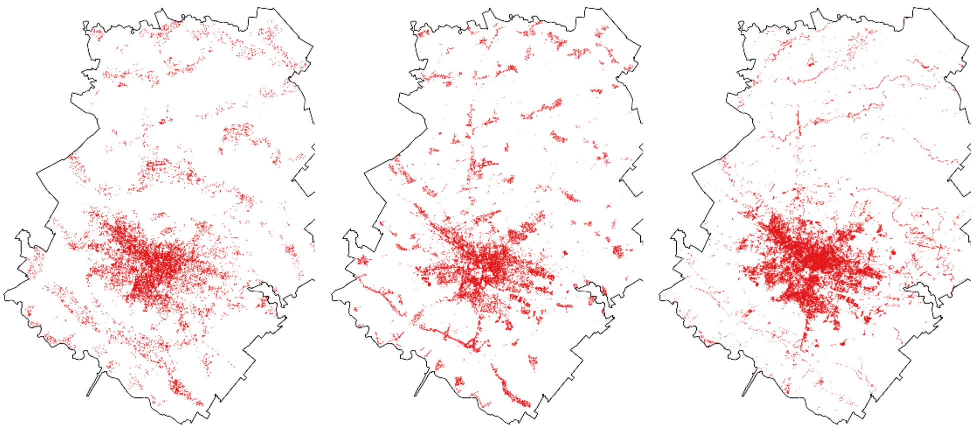
3. Interpretation of the results

The results obtained after performing the previous analysis and applying the three research tools as mentioned in the anterior chapter will be presented in the next subsections. The results are separated into three subsections based on the type of analysis on which the data were subjected. The first research tool implied satellite imagery processing and resulted in obtaining the visual land use spatial cover and obtaining calculated built-up areas in the Bucharest-Ilfov Region including their evolution over the last four decades. The second research tool emphasized the main events driving the major changes in socio-economic statistical indicators over the studied period of time such as the regulation that promoted the increase of built-up space, the growth of population and natural disasters such as floods and earthquakes which determined reconfigurations in the urban form and distributions of population or other types of events (such as the admission in the EU) that determined economic evolutions. The third research tool integrated the previous tools and resulted in the identification of the statistical socio-economic indicators that present a strong relationship with the evolution of the urban built-up surfaces determined from the satellite images.

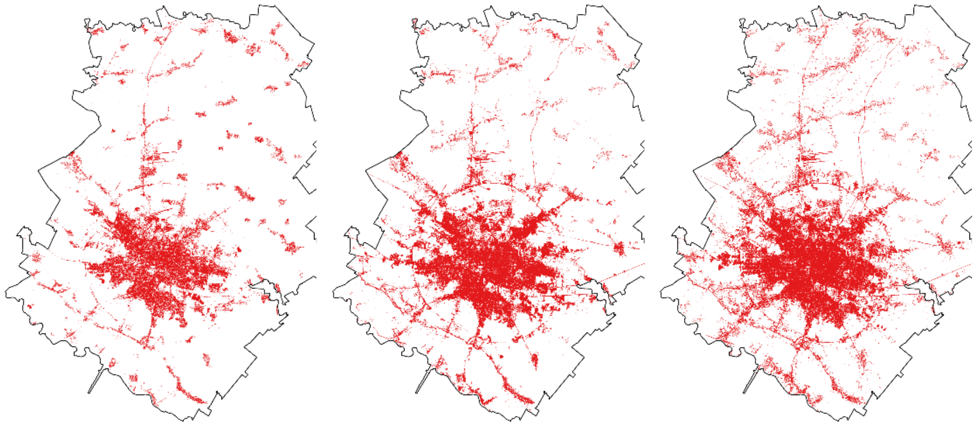
3.1. Results of the change detection analysis based on satellite imagery

Following the processing and analysis of the time series of satellite images, the resulting spatial patterns for the built-up areas of the perimeter and the immediate vicinity of Bucharest, as they are presented in Figure 3 (a) to (f), are much more extensive and segregated in the last 20 years than in previous decades, a fact that also applies to the built-up area of the entire Ilfov county.

Figure 3. The built-up class - evolution in Bucharest-Ilfov Region between 1976 and 2019 resulted from our processing of the six Landsat satellite images



a - 1976 *b - 1986* *c - 1990*



d - 2000 *e - 2009* *f - 2019*

Observing the spatial and temporal growth patterns of the class of built-up surfaces resulted through remote sensing, we were able to identify the following stages in the spatial patterns of the development of the Bucharest-Ilfov Region:

- The 1976-1990 development - Figure 3 (a) to (c): a stage marked by a relatively low growth, with small patterns of segregation and expansion beyond the city core, but marked by a more compact form with more and more dense built-up space.
- The 1990-2000 development - Figure 3 (c) to (e): this phase is characterised by a continued low growth but with increasing patterns of expansion and segregation and with a low increase in the compactness of the city core.
- The 2000-2019 development - Figure 3 (e) to (f): at this point these last two decades of development are marked by a period of fast growth, with more segregated built-up surfaces emerging at the Bucharest-Ilfov Region level, with the distinguished pattern of expansion of the settlements alongside the main transport corridors and also marked by an important enlargement and contraction of the city core.

The spatial metrics and their rate of change have also been calculated for the Bucharest-Ilfov Region from the change detection analysis of remotely sensed images performed over a time period between 1976 and 2019 (Figure 34 and Figure 5) which emphasizes a continuous expansion and contraction of the built-up areas. The resulted built-up class area metrics allow us to perform the following spatial metrics analysis by grouping the chronological evolution of these areas in a few phases of development:

- The 1976 – 1986 development phase – with an increase in the built-up area by less than 2%.
- The 1986 – 2000 development phase – with an increase in the built-up area by about 20% every 10 years.

- The 2000 – 2019 development phase – the built-up area increased by 50% in the last two decades with more than 100 km^2 of newly built-up areas and doubled in the last 30 years with over 150 km^2.

Figure 4. Built-up areas – changes in km^2 in the Bucharest-Ilfov Region determined by our classification of land use/land cover of the six Landsat satellite images

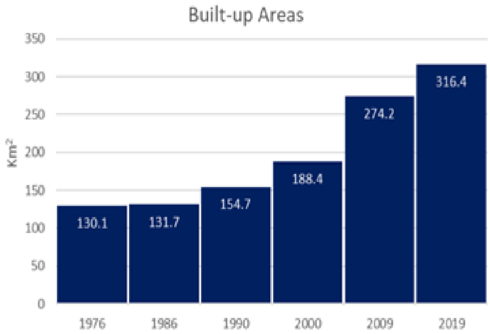
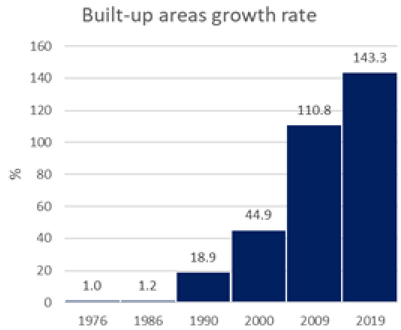


Figure 5. The growth rate of built-up areas in Bucharest-Ilfov Region from the reference year of 1976, areas determined by our classification of land use/land cover of the six Landsat satellite images



3.2. Results of the socio-economic analysis

The timestamp of the historical context at which the socio-economical analysis has its starting point is characterised by the urban and rural planning regulations of the communist regime in Romania.

Thus, the first snapshot of our analysis is around the period of 1975-1977, when we could pick up the main effect of this planning regulation, the 2448/1952 Resolution which stated that the Bucharest capital city to be kept on artificial growth limit: both as a perimeter and as a controlled number of inhabitants (Aldea, *et al*., 2015). Subsequently, Law 58/1974 on the systematization of localities introduced a plan to reconfigure the urban and rural environment, based on compacting urban areas by limiting their development and major reduction of built space in rural areas by relocating people to cities (Aldea, *et al*., 2015). Against the background of significant floods in July 1970 and 1975 that severely affected both a large part of the country and Bucharest too situated in the Argeș-Vedea river basin according to the current classification (National Institute of Hydrology and Water Management, 2015) and the earthquake of March 4, 1977, of 7.2 magnitude Gutenberg - Richter which largely damaged the old buildings (Lungu, *et al*., 2014), there were excesses in the application of this law. New technical regulations have been introduced regarding the seismic protection of buildings, which justified the demolition of old, single-family buildings and their replacement by the construction of new, collective housing, built according to standard projects. The vision of this type of regulation was the relocation of entire rural populations in urbanized areas.

Therefore, the period 1975-1989 bears the imprint of this law that led to an increasingly compact form of urban areas in Romania in parallel with urban population growth. This is the case of Bucharest, including its central and historical area, where demolition began in 1984, the year in which the disappearance of an entire neighbourhood can be seen. In the following years, mega-buildings were erected in a grouped manner, identifiable by their size in 1990 Landsat images.

After the period 1975-1989, the major events that brought important changes of a socio-economic and administrative-political nature are those of 1989, 2004, 2007 and 2009.

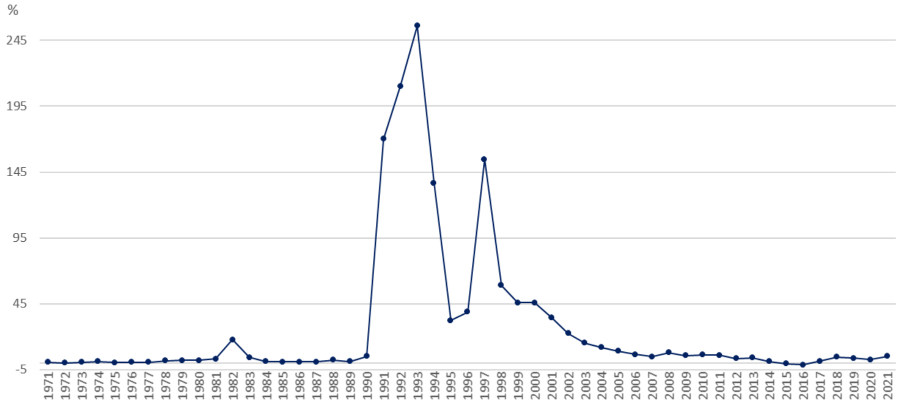
At the end of 1989 there was the fall of the communist regime and the establishment of the democratic system, characterized by the transition from a centralized economy to a market economy. This fact led to a long period of transition marked by economic decline, with economic indicators recording the worst values in the periods 1991-1994 and 1997-1998, periods of the electoral cycle type in which the economy went through two economic cycles: expansion-recession (Alpopi, *et al*., 2014; Săvoiu, 2006). As can be seen in Figure 6 and Figure 7, the inflationary periods, with the real GDP lower than the nominal one, were 1981-1983, 1990-1994, 1996-2000, 2008-2009 and 2018 (National Institute of Statistics, 2022). In 2004, Romania's accession to NATO marked a period of macroeconomic stability and internal balance (Săvoiu, 2006) marked by a slight economic recovery. The next event, corresponding to 2007, was Romania's accession to the European Union, the beginning of the transition to a capitalist economy. That was a period of economic growth amid a "real estate bubble" at the international level, followed shortly by the financial crisis of 2008-2009 (Eurostat, 2022), events highlighted by the indicators in Figure 6 and Figure 7 (National Institute of Statistics, 2022; United Nations Statistics Division, 2022). Against the background of the fragile recovery, in 2012 (Eurostat, 2022) GDP indicators fell again compared to the previous year. The same can be seen in Figure 7 for 2015. Economic recovery to the level before the crisis (2007) can be noticed only from 2017, an increase that is slightly capped at 2019-2020.

The economic analysis accentuates the following periods of development:

- The 1975 – 1990 phase – the communist period largely marked by very low inflation and a linear increase in the GDP.
- The 1990 - 2000 phase - almost the entire decade is characterised by an unfavourable economic development.
- The 2000 - 2009 phase - the period in which there was a first surge in economic growth marked by the significant decrease of the inflation rate and an exponential rise in the GDP levels.
- The 2009 – 2020 phase – this last decade is demarcated by relatively low inflation rates and oscillating GDP values with a large jump in GDP started in 2015 and curbed in 2019, at an all-time high.

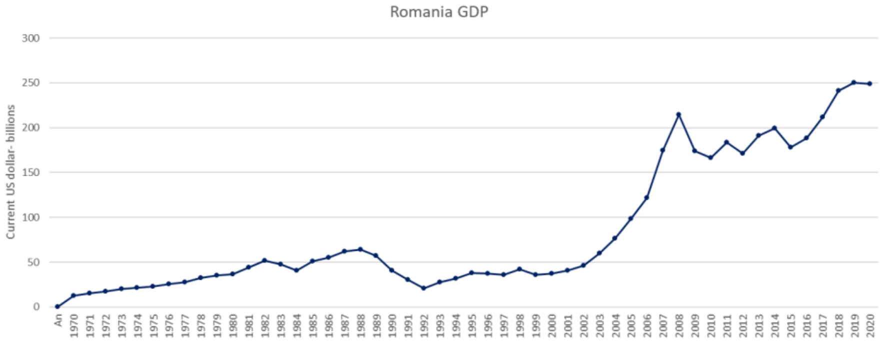
The last two phases can be grouped together as one phase of economic growth in GDP and of stabilisation of the inflation rates at relatively low levels.

Figure 4. Romanian Annual Inflation Rate Evolution



(*Source*: National Institute of Statistics, 2022)

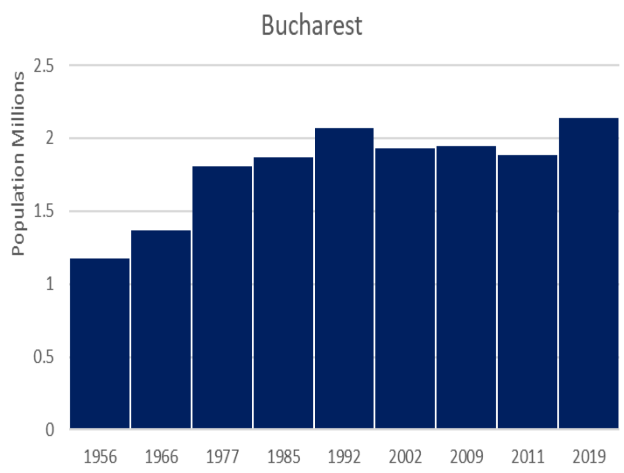
Figure 5. Romanian Gross Domestic Product evolution in current billion US dollars



(*Source*: United Nations Statistics Division, 2022)

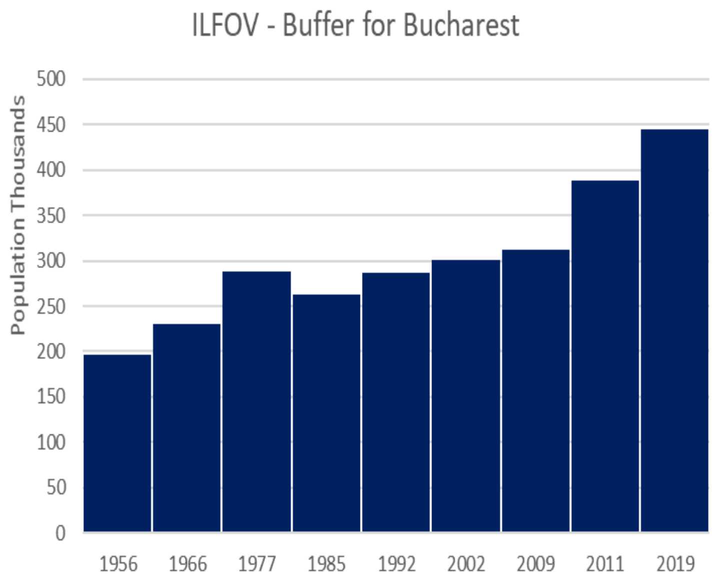
From a demographic point of view, as can be seen from **Error! Reference source not found.**, the statistically registered population of Bucharest has not increased significantly in the last four decades, in contrast to the doubling of the urban population in the two decades after 1956 (Romanian National Institute of Statistics, 2022; Central Directorate of Statistics, 1977; 1986; Bucharest Regional Directorate of Statistics, 2021). In contrast to this, it can be seen from Figure 9 that the population in the buffer zone of the capital - Ilfov County - almost stagnated registering small variations during the communist period, being then marked by a significant increase, almost doubling compared to 1985, the strongest increase being observed in the last decade with a spectacular leap after 2009 (the year of the end of the financial crisis). Despite the demographic growth in the Ilfov area, the population registered at the regional level and especially at the level of Bucharest has registered an obvious increase only in the last decade (Figure 10 and Figure 11).

Figure 6. The resulted evolution of the population of Bucharest



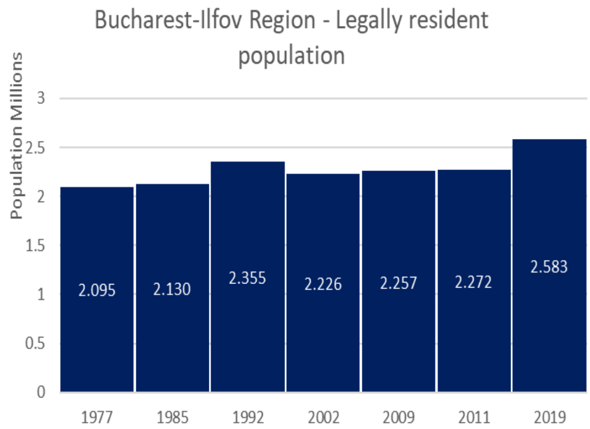
(*Source*: adapted from the Census data between 1956-2011 and Statistical Yearbooks of 1977, 1986, 2021)

Figure 7. The resulted evolution of the population of Ilfov – the buffer county



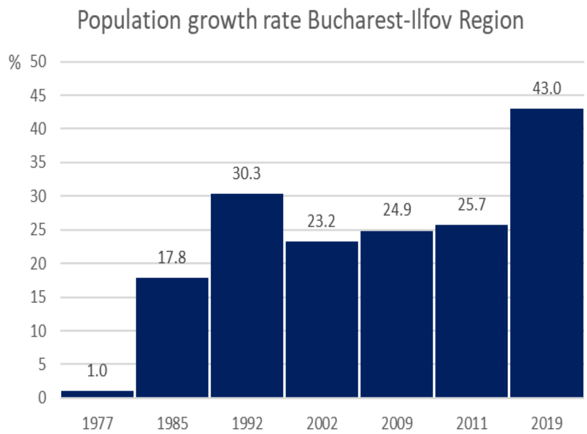
(*Source:* adapted from Census data between 1956-2011 and Statistical Yearbooks of 1977, 1986, 2021)

Figure 8. Legally resident population – resulted dynamic for Bucharest-Ilfov Region



(*Source:* adapted from the Census data between 1956-2011 and Statistical Yearbooks of 1977, 1986 and 2021)

Figure 9. The resulted population growth rate in Bucharest-Ilfov



(*Source*: adapted from the Census data between 1956-2011 and 1977, 1986 and 2021 Statistical Yearbooks)

The main phases in the demographic evolution statistically registered which resulted from the analysis performed in this direction for the Bucharest-Ilfov Region are presented next:

- The period between 1956-1977 – this period was marked by a rapid growth in population and it precedes the time-series of the change detection analysis but it explains through the statistical recordings the state of the population number at the beginning of the study
- The period between 1977 – 1985 period – this period presents a few small oscillations but overall, it is a rather stagnant demographic decade

- The period between 1985 – 2009 – it is a period which largely marks the end of the communist regime with many changes in the structure of population, characterised by a predominantly slow growth
- The period between 2009 – 2019 – this last decade distinguishes by an accentuated growth, one of the largest increases in population since 1977.

3.3. Results of the statistical analysis – regression and correlation

Regression analysis was used to find the best matching relationship between the built-up areas and the associated social and economic factors. After a satisfying relationship between a socio-economical factor and the built-up area was found, then the forecasted economic or social indicators (like the projected GDP or the anticipated number of dwellings to be erected) were added in the regression expression in order to extend the forecast towards the future developments of the built-up areas in the Bucharest-Ilfov Region for as many years as are available in the forecasts. The spatial metrics of the built-up areas for the Bucharest-Ilfov Region were calculated from the remote sensing analysis of the satellite images performed previously and presented in the section 3.1 (Figure 4 and Figure 5). Thus, the changes in km^2 of the Region's built-up areas were analysed in relation with the relevant socio-economic indicators as resulted from their examination and presented in section 3.2.

From the point of view of statistical records, as can be seen from Figure 10 and Figure 11, in the area currently covered by the Bucharest-Ilfov Region, the way in which the number of people varied over time and the percentage of population growth do not seem to be significantly related to the situation of land areas transformed into built-up areas (Figure 4) and nor with the growth rates over time of the built-up areas (Figure 5), as determined by the analysis of satellite images in point 3.1 and the resulting spatial sizes. The result of the regression analysis between the evolution of the built-up areas obtained from the satellite images and the evolution of GDP, population, dwelling number and the nominal house cost over the last four decades is presented below in Table 2.

Table 2. The relationship between the evolution of the remotely sensed spatial land use/land cover surfaces and the GDP, population, dwelling number and the nominal house cost in terms of the regression and correlation results

Variables	Regression expression with coefficients	R Square
Remotely sensed built-up area in relation with the statistically recorded national GDP Correlation coefficient = 0.95	$y_n = 0.0011x_n - 126754$, *where* y_n = GDP in the year n x_n = Built-up area in year n	$R^2 = 0.9067$
Remotely sensed built-up area in relation with the statistically recorded	$y_n = 0.001753\ x_n + 1{,}924{,}923.868389$, *where* y_n = Population - Bucharest - Ilfov Region x_n = Built-up area in year n	$R^2 = 0.600659$

Variables	Regression expression with coefficients	R Square
Population of the Bucharest - Ilfov Region Correlation coefficient = 0.77		
Remotely sensed built-up area in relation with the dwellings' number recorded statistically Correlation coefficient = 0.98	y_n = 0.000052 x_n - 7,190.897262, *where* y_n = Dwellings' number x_n = Built-up area in year n	R^2 = 0.975714
Remotely sensed built-up area in relation with the nominal house cost recorded statistically Correlation coefficient = 0.97	y_n = 0.00000049 x_n - 36.36512230, *where* y_n = Nominal house cost x_n = Built-up area in year n	R^2 = 0.92028824

According to the results obtained from the regression analysis and presented in Table 2, the GDP indicator proves to be a relatively good indicator for the evolution of built-up areas, with R^2 greater than 0.9 (Figure 12 and Figure 15), together with the nominal house cost with correlation coefficients of 0.95 for GDP and 0.97 respectively for house cost. Dwellings' number is the best fit for the built-up area variation with a 95% match and a correlation coefficient of 0.98 (Figure 14 and Table 2). The dynamics of the population recorded at the level of the region and especially at the level of Bucharest registered a sharp increase only in the last decade and it does not correlate with newly constructed areas recorded by remote sensing, the value of R^2 is 0,6 (Figure 13 and Table 2) and the correlation coefficient is about 0.77.

Figure 10. Romanian GDP in relation with the built-up areas obtained from satellite images for the Bucharest-Ilfov Region - results from our regression analysis

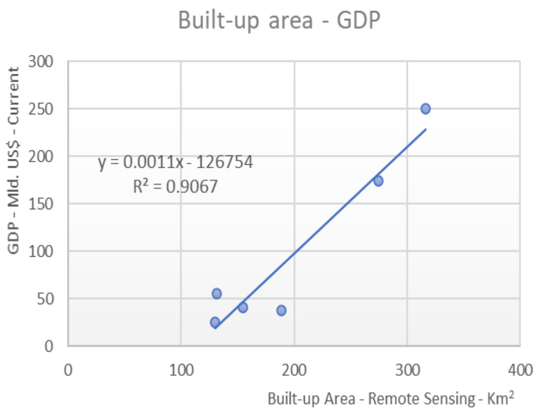


Figure 11. Population in relation with the built-up areas obtained from satellite images in the Bucharest-Ilfov Region - results from our regression analysis

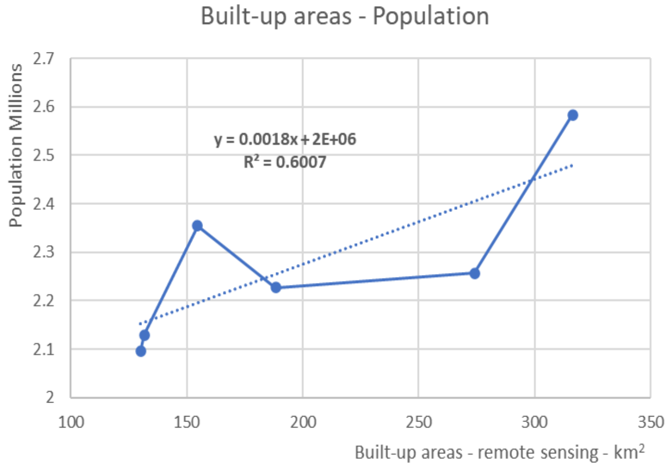


Figure 12. Number of dwellings completed in the current year with population funds recorded statistically in relation with the built-up areas obtained from satellite images - results from our regression analysis

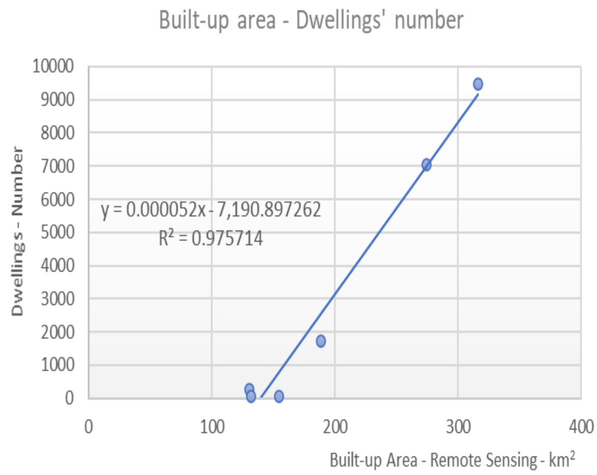
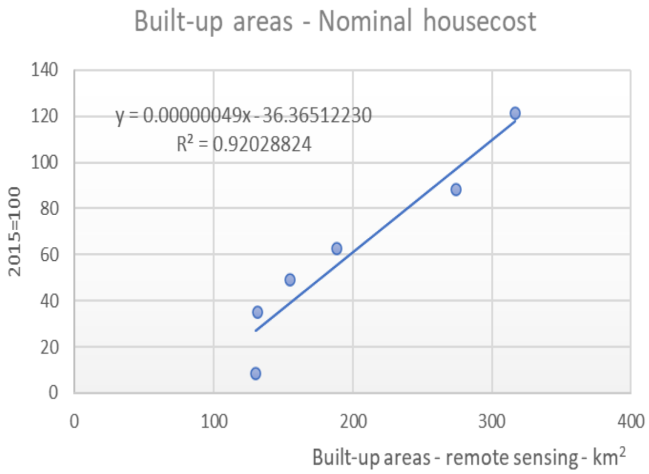


Figure 13. Nominal house prices statistically recorded in relation with the built-up areas obtained from satellite images - results from our regression analysis



Forecast of the future built-up areas' development was conducted based on the regression analysis as the linear regression is one of the best ways to analyse data and make predictions on it. Thus, using the GDP and the construction price forecasts for estimation of the nominal house prices (National Commission for Strategy and Forecasting, 2021) the prognosis resulted in an increases in the built areas in the Bucharest-Ilfov Region by 2024 that will end up occupying between 380 km2 and 384 km2 respectively (Figure 16 and Figure 17).

Figure 14. Forecast of built-up areas based on our regression analysis and the forecasted GDP from the forecast report of National Commission for Strategy and Forecasting (2021)

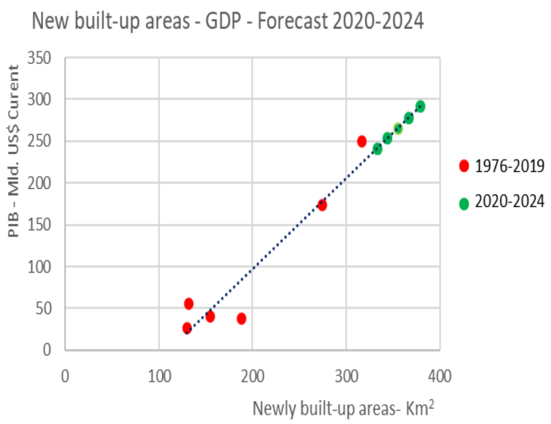
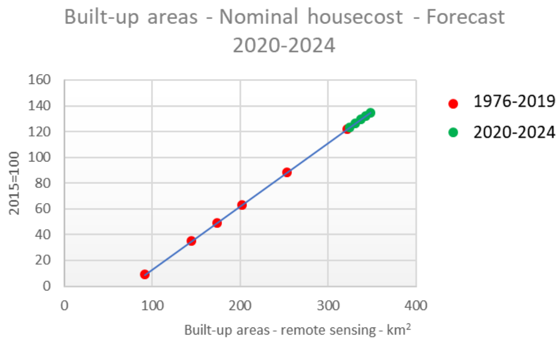


Figure 15. Forecast of built-up areas based on our regression analysis and the forecasted house cost by the National Commission for Strategy and Forecasting (2021)



4. Limits of the research and future research

It should be noted that there is another indicator that can be added to the second and third research tools in regard of the analysis of the economic factors influences on urban development apart from GDP and this indicator is the Purchasing Power Parities (PPP) index. This is assimilated to monetary conversion rates that equalize the purchasing power of different currencies and which in simplified form are relative prices that show the ratio of prices in national currencies of the same good or service in different countries (OECD/Eurostat, 2012). Romania is not part of the OECD (but it's a candidate for the accession) and for this reason certain statistical records related to this indicator are missing and posed a limitation on our present paper. PPPs can be used in future economic analyses in the eventuality that statistical records are or become available in order to generate price and volume indices in which the latter can be used to compare levels of savings, material well-being, consumption, investment, etc. (OECD/Eurostat, 2012).

Although in this paper the considered values of the GDP were the values of the national GDP, given that Bucharest's contribution to it is quite significant, it could potentially be used in the future, since it maintains the same relation. Since another limitation for the present paper was that the available data for the Bucharest GDP did not cover the entire study period, future research can be performed using the local GDP of Bucharest or the entire Bucharest-Ilfov Region once it becomes available.

The last event of the nature of previous disasters (earthquake and floods) was the Covid-19 pandemic declared in March 2020. This generated social and economic implications on a global scale, influencing consumption patterns and those of urban development indirectly, as a result of the migration of housing options to low-density residential areas, of single-family homes, as a result of the imposition of the "lockdown" at home for a significant percentage of the population, of school closures, and of the imposed "telework" etc. Future research can therefore consist in analysing the effects of the pandemic event of 2020 on the city's economy and evolution and a new forecast thus determining whether changes in one variable tend to be followed by changes in another variable, as a test for the limitation of the theory.

5. Conclusions

The analyses and results obtained from the statistical processing performed at the population level and the built-up areas identified through satellite remote sensing show a different evolution of the number of people compared to the dynamics of the built-up areas. The analysed data showed that both in the case of the urban city core of Bucharest and in the case of the aggregation of the buffer zone Ilfov county, so of the entire Bucharest-Ilfov Region there is a weak correlation between the evolution of built areas and the demographic evolution, with a rather poor fit of approx. 60%. Instead, the regression analysis showed the existence of a strong linear relationship between the newly built surfaces as they resulted from the processing of time series of satellite images and various statistical indicators, the value of R^2 being in all analysed cases over 0.90, which means that the model has an accuracy of over 90%, a relatively good fit for macroeconomic indicators. The close relationship between GDP and the evolution of built-up areas may represent a preference of the population and firms to invest in real estate, considered likely to be a safe acquisition of assets. As the study area has at its core a large metropolitan city, the growth in built-up areas for the overall Region is a result of a process that can be associated with the availability of financial resources, infrastructure, and policy factors.

Conflict of Interest Statement

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Acknowledgment

Not the case

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