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The Use of Sholl and Kolmogorov Complexity Analysis in Researching on the Sustainable Development of Creative Economies in the Development Region of Bucharest-Ilfov, Romania

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Abstract: Nowadays, creative economies stand as a relevant indicator of the sustainable development of local and regional ones. The study aims to highlight the spatial behaviour of creative economies in the Bucharest-Ilfov Development Region, the most dynamic and complex regional economy in Romania. In order to assess the spatial dynamics of creative economies in the region, an economic database was created, at the level of the territorial administrative unit, for the two economic indicators considered important for the study, number of employees and turnover, under the auspices of the Classification of National Economy Activities (NACE). The establishment of creative economies was made following the Government Decision no. 859 of 2014, with 66 codes for this sector. Annual cartographic models were developed for each indicator in QGIS (a free and open–source cross–platform desktop geographic information system application that supports viewing, editing, and analysis of geospatial data), for the period 2000–2016. For a relevant analysis of spatial behaviour, we used Sholl and Kolmogorov complexity, which highlighted specific patterns of spatial dynamics that help us to understand the role of creative economies in the sustainable development of regional economies. The results highlighted the role of accessibility corridors in the development of the regional economy.

Keywords: Sholl analysis; Kolmogorov complexity; spatial patterns; creative economies

1. Introduction

The creative economy generates jobs and wealth, and is also a remarkable tool for urban and regional revitalization. Its significance, role and importance are being studied more and more lately [1]. The basis of the creative economy is the capital of creative ideas and not necessarily physical capital [2], so it offers the potential for growth and the development of new, creative, intangible products, service experiences and markets. Howkins mentions that creativity becomes an economic activity only when an idea becomes a business [3].

Lately, more and more studies have analysed the growth of economic policies based on the development of cities' creativity [4–7]. This interest accompanies a transition to a new economy [8] based on creativity, which includes creativity, the culture industry, the creative class and the urban environment as fundamental conditions [9]. Nowadays, these conditions are part of programs that underlie urban planning and are generally associated with urban entrepreneurship [10]. Creativity promotes urban economic growth, the competitiveness of cities and their vitality [11]. In this context, there is a need for regional and local policies that promote the creativity and culture of cities, with advantages for the urban economy if the regeneration of urban sites can be achieved. It should be noted, however, that these policies should include different axes, namely culture, art, industry and urban design, in order to create a comfortable city/urban environment that stimulates creativity [12].

Different spatial models of the creative economy have been analysed by geographical economists and regional researchers and their concentration has been noticed especially in metropolitan areas [13], giving the cities economic and social benefits [14–16]. The growth of the creative economy in today's cities is largely a process of self-strengthening beyond the initial stage of cluster formation. This is because the high number of creative product companies offers different benefits that help them continuously grow. Benefits include both specialized funds and diversity of employability, as well as networks and knowledge exchanges, common providers and support services, institutional infrastructures and brand identity [17–20].

It has been found that the urban environment factors associated with the creative economy cover the demographic, social, economic and quality of life dimensions. The population represents the advantages of urbanization economies for professionals in the creative sector, in particular due to the high demand for creative activities and network effects, especially in large cities [21]. It is also considered that the density of the specialized employability in different activities of the creative sector is a positive factor explaining regional variations in creative economies. Another factor associated with the creative activities is related to the urban facilities or the quality of life associated with the place [13,17]. The causal relationship between facilities and the creative economy is complex. On the one hand, creative activities, favoured by many residents of the city, directly contribute to the facilities in the cities [15]. On the other hand, employees in the creative sector, in general, will have a greater demand for facilities, as they tend to remain in urban centres that have more facilities and a greater openness to diversity and new opportunities. Big cities are considered to have a higher concentration of creative economies [22]. In order to attract and maintain the creative class, in the cities, "the conversion of historic neighborhoods with mixed destination" took place, to promote "vibrant art scenes and outdoor activities", "highlighting their cultural diversity" [23].

The complexity of the processes in emerging territorial systems structured around big cities, developed above, encouraged the scientific world to develop new methodologies that would help with understanding the patterns of their evolution. We opted for Sholl analysis and Kolmogorov complexity because they complement the familiar classical approaches. Sholl analysis provides information on the degree of branching, allowing the quantification of the dynamics on the development colour of some spatialized economic phenomena. The aim of our study was to identify these aspects in their dynamics. The benefit of Kolmogorov complexity lies in obtaining information about the complexity of the spatial distribution of creative economies, classified into five grey levels, at the level of the territorial administrative unit.

The proposed algorithms can contribute to a greater knowledge of the spatial behaviour of the regional economy, with the results obtained being consistent supports to aid decision-making.

2. Materials and Methods

2.1. The Scope of the Research

The study aimed to analyse the distribution of the creative economy in the Bucharest-Ilfov Development Region, on the basis of two economic indicators—turnover and number of employees.

The Bucharest-Ilfov Development Region is one of the eight development regions of Romania, made up of Bucharest and Ilfov county, nine cities, 32 communes and 91 villages in total, and is the most developed development region in Romania (Figure 1).

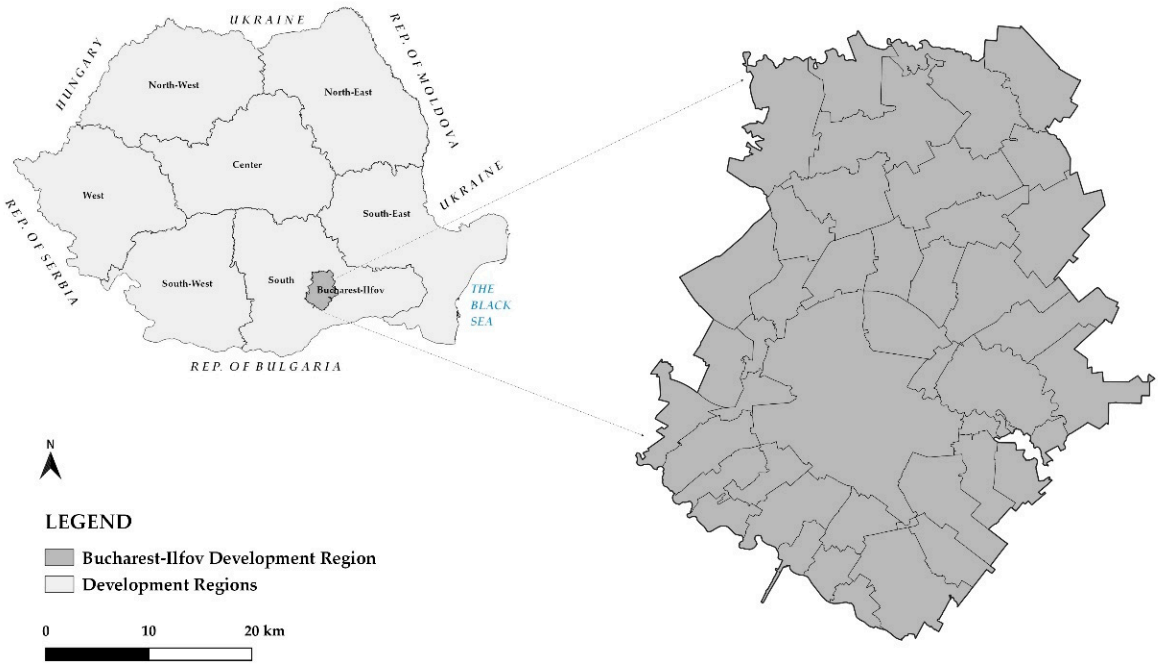

Figure 1. The geographical location of the Bucharest-Ilfov Development Region within Romania.

The region was chosen for this study because it is in first place in terms of the development of creative economies, making it a particularly attractive economic environment; in addition, the services sector is well developed and there is a high degree of accessibility. In 2016, the region accounted for 55% of the turnover in the creative sector in Romania, and 127,406 employees out of the 268,429 employees trained in this sector.

2.2. Data Analysis

The time span for the study of the dynamics and distribution of creative economies at the Bucharest-Ilfov Development Region was 2000 to 2016. An economic database has been created at the level of the administrative-territorial unit, highlighting two economic indicators relevant to the analysis of creative economies (number of employees and turnover), according to the Classification of National Economy Activities (NACE). The NACE codes belonging to the creative economies (Table 1) were chosen accordingly to the Government Decision no. 859 of 2014, regarding the approval of the "Government Strategy for the development of the sector of small and medium-sized enterprises and the improvement of the business environment in Romania Horizon 2020". The values for turnover, for a better analysis, are expressed in the national currency (Ron); according to the National Bank of Romania, 1 euro equals 4.75 Ron.

Table 1. NACE codes for the creative activities established by H.G. 859/2014.

NACE Codes	Creative Activities	Field of Activity According to NACE
5811	Book publishing	Information and Communication
5812	Publishing of directories and mailing lists	
5813	Publishing of newspapers	
5814	Publishing of journals and periodicals	
5819	Other publishing activities	
5821	Publishing of computer games	
5829	Other software publishing	
5911	Motion picture, video and television programme production activities	
5912	Motion picture, video and television programme post-production activities	
5913	Motion picture, video and television programme distribution activities	
5914	Motion picture projection activities	
5920	Sound recording and music publishing activities	
6202	Computer consultancy activities	
6203	Computer facilities management activities	
6209	Other information technology and computer service activities	
6311	Data processing, hosting and related activities	
6312	Web portals	
6391	News agency activities	
6399	Other information service activities n.e.c.	
7111	Architectural activities	Professional Scientific and Technical Activities
7112	Engineering activities and related technical consultancy	
7120	Technical testing and analysis	
7211	Research and experimental development on biotechnology	
7219	Other research and experimental development on natural sciences and engineering	
7220	Research and experimental development on social sciences and humanities	
7311	Advertising agencies	
7312	Media representation	
7320	Market research and public opinion polling	
7410	Specialised design activities	
7420	Photographic activities	
7430	Translation and interpretation activities	
7490	Other professional, scientific and technical activities n.e.c.	
8510	Pre-primary education	Education
8520	Primary education	
8531	General secondary education	
8532	Technical and vocational secondary education	
8541	Post-secondary non-tertiary education	
8542	Tertiary education	
8551	Sports and recreation education	
8552	Cultural education	
8553	Driving school activities	
8559	Other education n.e.c.	
8560	Educational support activities	
8610	Hospital activities	Human Health and Social Work Activities
8621	General medical practice activities	
8622	Specialist medical practice activities	
8623	Dental practice activities	
8690	Other human health activities	
8710	Residential nursing care activities	
8720	Residential care activities for mental retardation, mental health and substance abuse	
8730	Residential care activities for the elderly and disabled	
8790	Other residential care activities	

Table 1. *Cont.*

NACE Codes	Creative Activities	Field of Activity According to NACE
9001	Performing arts	Arts Entertainment and Recreation
9002	Support activities to performing arts	
9003	Artistic creation	
9004	Operation of arts facilities	
9101	Library and archives activities	
9102	Museums activities	
9103	Operation of historical sites and buildings and similar visitor attractions	
9104	Botanical and zoological gardens and nature reserves activities	
9311	Operation of sports facilities	
9312	Activities of sports clubs	
9313	Fitness facilities	
9319	Other sports activities	
9321	Activities of amusement parks and theme parks	
9329	Other amusement and recreation activities	

2.3. GIS Analysis and Graphical Models

Using QGIS 3.4 (Grüt, Switzerland), open-source software, maps were created for each year, for the period 2000–2016, for both the number of employees and the turnover, in a sequential colour scheme, at the level of territorial administrative unit.

The graphical models show the evolution of the two indicators, with the highlights being the years 2000 (the beginning of the analysis time span), 2008 (when the maximum was reached in Romania for the two indicators), 2009 (the first year in which the economic crisis was registered) and 2016 (the last reference year). Combo-type charts analyse the evolution of the share of the creative sector in the Bucharest-Ilfov Region in terms of the total economy of the Bucharest-Ilfov Development Region (A) and the evolution of the share of the creative sector in the Bucharest-Ilfov Region in the total creative economy of Romania (B), as well as the matrix trend with reference to 2016, for the two indicators—presenting the first 20 creative codes with the most significant value of the share of the creative economy in the region, in terms of the total creative economy at the country level.

2.4. Pre-Processing Images

In order to perform the Sholl and fractal analysis (Kolmogorov complexity), the colour gradient maps were turned into grey tones in five classes: for turnover—I (the white class has the highest values, over 60,000,000 Ron), II (a very light grey class with values between 10,000,000 and 60,000,000 Ron), III (the light grey class with values between 1,000,000 and 10,000,000 Ron), IV (the dark grey class, with values of 100,000–1,000,000 Ron) and V (the darkest colour, almost black, with values below 100,000 Ron) and for the number of employees—I (the white class has the highest value, with over 500 employees), II (the very light grey class with 250–500 employees), III (the light grey class with 100–250 employees), IV (the dark grey class with 50–100 employees) and V (the darkest colour, close to black, with under 50 employees). The built analysis was based on binary images, with the specific results due to segmenting the five classes of the image into grey tones and analysing the 8-bit greyscale images. The analysed images had a resolution of 2162 × 2552 pixels.

2.5. Sholl Analysis

Sholl is a quantitative analysis method that is usually the basis of neuronal studies to describe the morphological characteristics of an imaged neuron [24]. Mainly, Sholl analysis is used to measure the number of intersections per concentric shell at different distances from the centre. Sholl analysis is a binary analysis; the analysis is performed in ImageJ (Bethesda, MD, USA) through the Sholl analysis plugin [25–27]. In addition to the number of intersections per concentric shell, Sholl also calculated the average diameter of the dendrites or axons within each concentric shell. Mainly, Sholl analysis is used

to measure the number of intersections per concentric shell at different distances from the centre. In our article, we propose using Sholl analysis to highlight the spatiotemporal dynamics of turnover and the number of employees in creative economies. The Sholl analysis plug-in is an improved algorithm for retrieving data from bitmap images with regression analysis, curve fitting and statistical inference, so an automatic estimation of the values of the arborization (branches) based on the Sholl analysis is possible. The plugin can perform Sholl analysis directly on 2D images of the objects to be analysed separately, isolated from the others. We should mention that this plugin can also perform 3D analysis using greyscale images; instead of circles, it uses spheres, and instead of pixels it uses voxels.

The study proposes using Sholl analysis to highlight the spatiotemporal dynamics of turnover (Figure 2) and the number of employees (Figure 3) for the creative economies of the Bucharest-Ilfov region. The analysed binary images comprise the two classes with the highest values (white and very light grey for turnover: class I with values over 60,000,000 Ron and class II with values of 10,000,000–60,000,000 Ron, and again for employees: I with over 500 employees and class II with 250–500 employees. The sum of intersections (sampled), mean of intersections (sampled) and ramification index (fit) were analysed.

a. Sum of intersections represents the sum of all intersections.

b. Mean of intersections is given by Equation (1):

$$Mean\ of\ intersections = \frac{Sum\ of\ intersections}{Intersecting\ radii}, \tag{1}$$

where "intersecting radii" is the number of sampling radii that intersect the (arboreal) object at least once.

c. Ramification index allows the quantification of the degree of branching and is given by Equation (2) [28]:

$$Ramification\ Index = \frac{Max\ intersections}{Number\ of\ primary\ branches}. \tag{2}$$

The ramification index is calculated only when the primary branches are valid and not equal to zero.

The points of intersection were obtained when the "directions of development" intersect the concentric circles created with the help of Sholl analysis. The number of intersection points increases when new propagation directions appear or when the analysed phenomenon is spatially extended. The number decreases when it is compacted, disappearing from the propagation directions or when the analysed phenomenon goes into decline, shrinking.

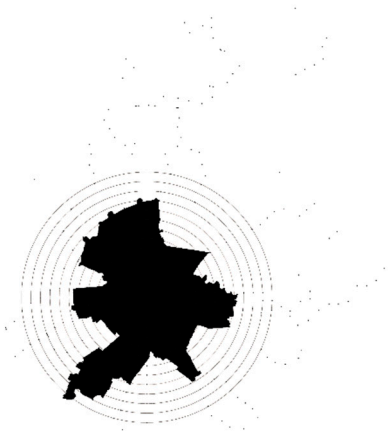

Figure 2. Spatiotemporal dynamics of turnover, 2000–2016.

Figure 3. Spatiotemporal dynamics of the number of employees, 2000–2016.

In this study we start from pixel 0 (the centre of Bucharest) to pixel 1790 (the maximum outside); the intersecting radii numbered 179, and the radius step was 10 pixels. The mean intersections were obtained by dividing the number of intersections by 179 circles.

2.6. Fractal Analysis-Kolmogorov Complexity

Fractal analysis has been used since the 1980s as a tool to understand the complexity of the system, and has been applied in spatial analysis to study the phenomenon of urban agglomeration [29], forest dynamics [30] or economic phenomena [31]. It can be compared to classical approaches to binary fractal analysis such as Ruler Dimension [32,33] BoxCounting [29,34–36], Dilation Dimension [29,37], Mass Dimension [38], Local Connected Fractal Dimension [39], Perimeter-Area Dimension [40,41], Information Dimension [42], Minkowski Dimension [43], Multifractal Dimension [44,45] or recently Fractal Fragmentation Index [46–48]. Kolmogorov complexity is the indicator by which the degree of complexity of the turnover and the number of employees for the Bucharest-Ilfov Development Region was established. Starting from Shannon entropy [49], Kolmogorov proposes a new theory of complexity. According to this theory, the Kolmogorov complexity of an object represents the length of the shortest computer program that produces that object as output (being a measure of the computing resources needed to reproduce the analysed object). The KC full image analyses the degree of complexity for all five classes of values.

Kolmogorov complexity analysis was performed using open-source IQM 3.5 software (Graz, Austria) [50], and the complexity of the message is given by the size of the program needed to allow the receipt of such a message (Equation (3)).

If x (t) is the trajectory of a dynamic system in a sampled space of n-dimensional phase at discrete time intervals Δt (for $t > 0$), the generalized Kolmogorov entropy, K_q, can be defined in this space and divided into the n-dimensional hypercubes of the side r (at time intervals Δt) through the following equation [51]:

$$K_q X = -\lim_{r\to 0}\lim_{\Delta t\to 0}\lim_{N\to\infty}\frac{1}{N\Delta t}\frac{1}{q-1}\ln\sum\nolimits_{i_1,i_2,\ldots,i_N}^{m(r)} p_{i_1,i_2,\ldots,i_N}^{q}, \quad (3)$$

where $\{X = xi\}$ is the discrete random variable and $xi = x\ (t = i\Delta t)$; $p_{i_1,i_2,\ldots,i_N}$ is the common probability that the trajectory $x\ (t = \Delta t)$ to be found in the box i_1, $x\ (t = 2\Delta t)$ to be found in the box i_2 si $x\ (t = N\Delta t)$ to be found in the box i_N.

Complexity 0 means Kolmogorov complexity $\cong 0$. As the image complexity increases, the Kolmogorov complexity grows.

This method has been implemented in various algorithms by using the routine length required for storing or reproducing images. Some algorithms were the basis of the JPEG or ZIP format for image compression [52]. In this study, the PNG format was used, with 10 iterations that required system bias corrections.

3. Results

3.1. The Spatial Dynamics of Creative Economies

3.1.1. The Economic Dynamics of Turnover

The analysis of the turnover of the creative sector at the level of the Bucharest-Ilfov Development Region presents a positive trend, with an upward evolution during the 17 years analysed. In 2000, the first year of the analysis, we observe a concentration of the highest values of the turnover in the municipality of Bucharest (with a maximum value of 2,112,885,299 Ron), followed by neighbouring localities such as Măgurele (11,113,383 Ron), Buftea (4,763,041 lei), Volunteers (3,438,509 Ron) and Pantelimon (2,899,094 Ron) (Figure 4). Until 2008, a progressive trajectory and values of 13,649,703,013 Ron for the main growth pole, the municipality of Bucharest, followed by Voluntari, Măgurele, Buftea, Mogoșoaia and Corbeanca, are highlighted.

Significant increases are observed at the end of the analysis (2015 and 2016), with maximum values for the analysed period reached by Bucharest in 2016, with a turnover value of 27,598,264,903 Ron, being followed by the surrounding areas: Volunteers (1,149,679,236 Ron), Măgurele (300,4411,850 Ron), Mogoșoaia (166,098,459 Ron) and Otopeni (141,161,282 Ron) (Figure 5). The codes with the most significant values are those for advertising, architecture and the IT field, respectively: 7311 (advertising agencies, with a value of 449,419,320 Ron in 2000, reaching 2016 with 5,041,850,886 Ron), 7112 (engineering activities and related technical consultancy, with values of Ron 244,020,034 in 2000 and Ron 4,458,934,256 in 2016), and 6202 (computer consultancy activities totalling Ron 138,029,029 in 2000 and Ron 3,244,752,653 in 2016).

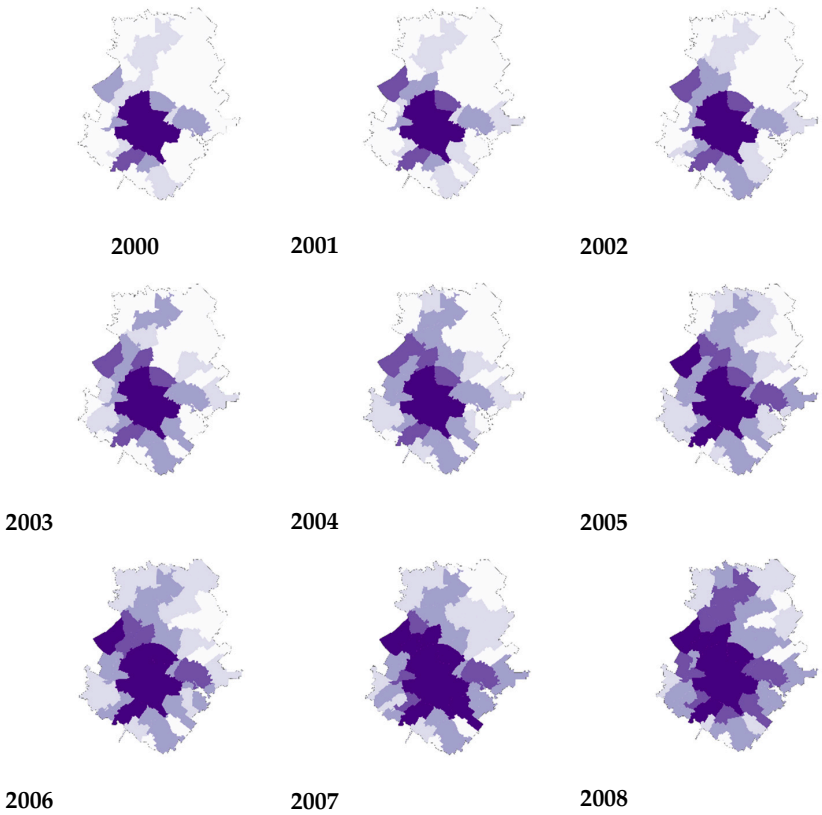

Figure 4. *Cont.*

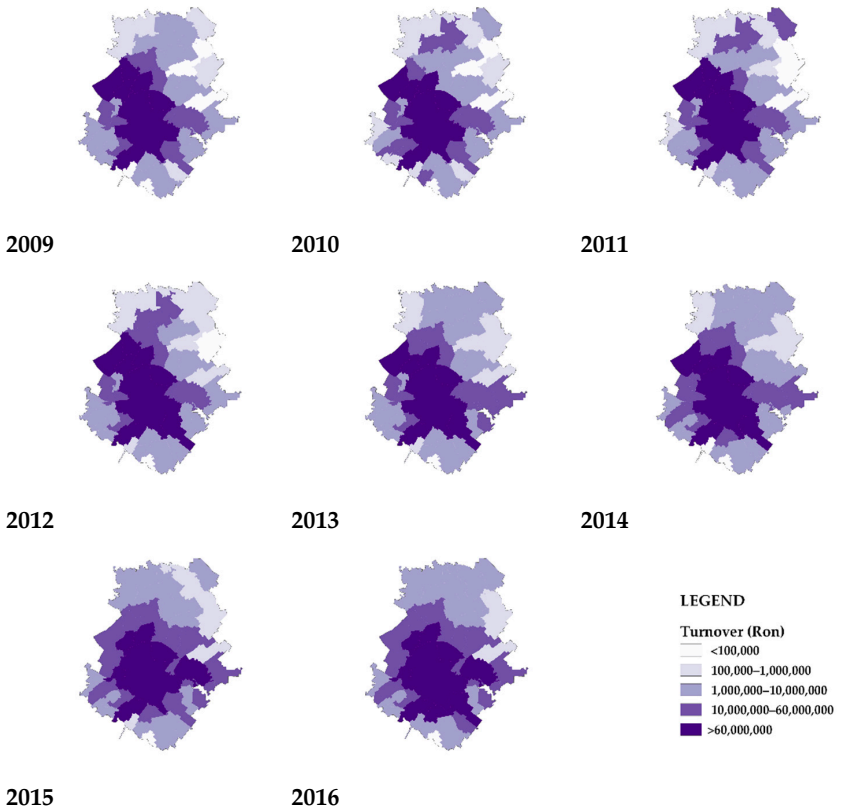

Figure 4. Distribution of turnover in the creative sector in the Bucharest-Ilfov Development Region.

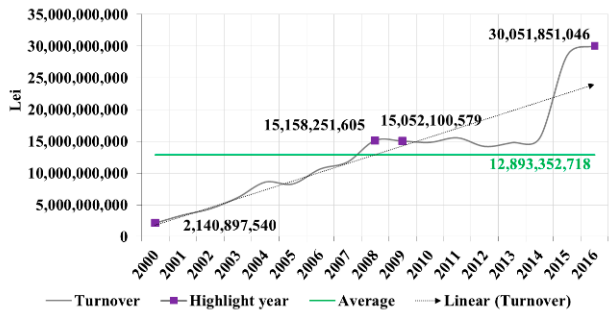

Figure 5. The evolution of the turnover in the creative sector in the Bucharest-Ilfov Development Region.

In Figure 6 are presented the evolution of the share of the turnover in the creative sector versus the total turnover in the region (A) and the share of the turnover in the creative sector in the same region versus the total turnover in Romania (B); the first indicator shows a constant evolution, with small fluctuations, falling between values of 4.49%, which represents the smallest share of the turnover in the creative sector registered in 2002, and 8.99%, the highest, in 2011.

The trend matrix for the NACE codes in the creative sector of the turnover shows an evolution of 20 creative activities (Table 2), where the top three positions are occupied by basic activities of the creative economies, advertising and architecture, and activities related to a field with a spectacular trajectory, IT (codes 7311—advertising agencies, with a value of 449,419,320 Ron in 2000 and reaching in 2016 a value of 5,041,850,886 Ron; code 7112—engineering activities and related technical consultancies, with a value of 244,020,034 Ron in 2000 and increasing to 4,458,934,256 Ron in 2016; IT is represented by the code 6202 (computer consultancy activities) and had values of RON 138,029,029 in 2000 and RON 3,244,752,653 in 2016).

Two time spans are highlighted: the pre-crisis period (2000–2008), when we observe increases in the various creative activities (for example, code 6202 moved from the sixth position to the first

position) but also decreases (for example, code 7311 dropped from first place to 24th in 2008), due to the growth dynamics of the activities of this sector both in Romania and at the European level. In the post-crisis period (2009–2016), creative activities present different development trajectories, so we have codes such as 7311 and 7112 in the first two positions, showing a clear evolution, but other codes that show stagnation (e.g., 7320 and 5811) or decreases (e.g., 5814 and 7111). The year 2016 epitomizes the dynamics of the 20 codes in the creative sector, representing the pole of productivity growth and economic innovation.

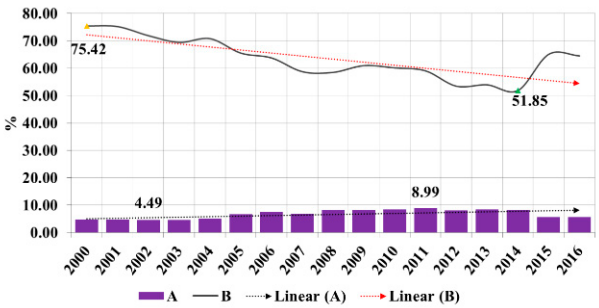

Figure 6. Evolution of the share turnover in the creative sector in terms of total economy (**A**) and total creative economy in Romania (**B**).

Table 2. Trend matrix of the first 20 NACE codes for turnover in the creative sector for 2000–2016.

NACE Codes	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
7311	1	1	1	1	1	28	27	24	24	26	24	23	22	22	23	2	**1**
7112	3	2	2	2	2	1	1	15	14	11	10	9	9	8	9	1	**2**
6202	6	6	3	3	3	2	2	1	1	1	1	1	50	47	44	3	**3**
8622	20	18	18	17	17	11	12	12	9	5	6	2	1	1	1	4	**4**
5829	16	15	15	15	15	14	13	13	11	7	4	3	5	3	2	5	**5**
7219	7	7	7	7	7	5	4	3	4	4	5	4	2	2	4	6	**6**
6311	4	4	4	4	4	3	3	2	6	9	7	7	3	4	6	8	**7**
6209	2	3	6	6	6	6	5	6	3	2	3	6	4	7	3	7	**8**
7120	11	13	12	13	14	16	15	14	15	16	12	12	8	6	7	9	**9**
7320	12	14	14	14	13	13	11	11	10	10	9	8	6	5	5	10	**10**
7312	14	11	10	11	11	7	6	4	2	3	2	5	7	9	10	11	**11**
8690	19	20	19	19	21	21	18	18	17	17	16	15	13	11	11	12	**12**
5911	5	5	5	5	5	4	7	7	7	8	8	10	10	10	8	13	**13**
7111	13	12	13	12	12	12	8	5	5	6	11	11	11	12	12	14	**14**
7490	15	16	16	16	16	15	16	16	16	18	17	16	14	15	14	15	**15**
5811	8	8	8	9	10	8	14	9	13	14	14	14	15	14	13	16	**16**
8623	23	25	25	27	27	22	20	20	22	22	23	21	20	20	18	18	**17**
6399	44	46	48	49	47	49	37	33	40	30	34	28	28	32	25	22	**18**
5914	17	19	50	24	23	24	25	31	33	23	21	22	21	21	20	20	**19**
5814	10	9	11	10	9	10	9	8	8	13	13	13	12	13	15	19	**20**

Notes: The numbers in the last column, which represents the year 2016 show the position of the NACE codes of that year.

3.1.2. The Economic Dynamics of the Number of Employees

The analysis of the spatial distribution of the number of employees from the creative economies of the Bucharest-Ilfov region (Figure 7) shows the dominant position of the Bucharest municipality, which totalled, in 2000, 39,618 employees in the creative sector, followed by cities in which this sector is growing: Măgurele (1,751 employees), Volunteers (becoming a private sector hub) with 286 employees, Buftea (known for its film industry) with 219 employees, and Pantelimon (210 employees). The values show a positive evolution until 2008, when the municipality of Bucharest had a total of 125,814 employees, followed by the cities Volunteers (2,133 employees), Măgurele (1,951 employees), Buftea (1,239 employees) and Otopeni (591 employees). After the economic crisis, the number of employees in the creative sector did not undergo a significant change because this sector is dynamic and some fields, such as IT, did not have to resort to redundancies in the post-economic crisis period;

however, there were decreases in the number of employees (especially in Bucharest, as it is the main area where most of the employees in this sector work).

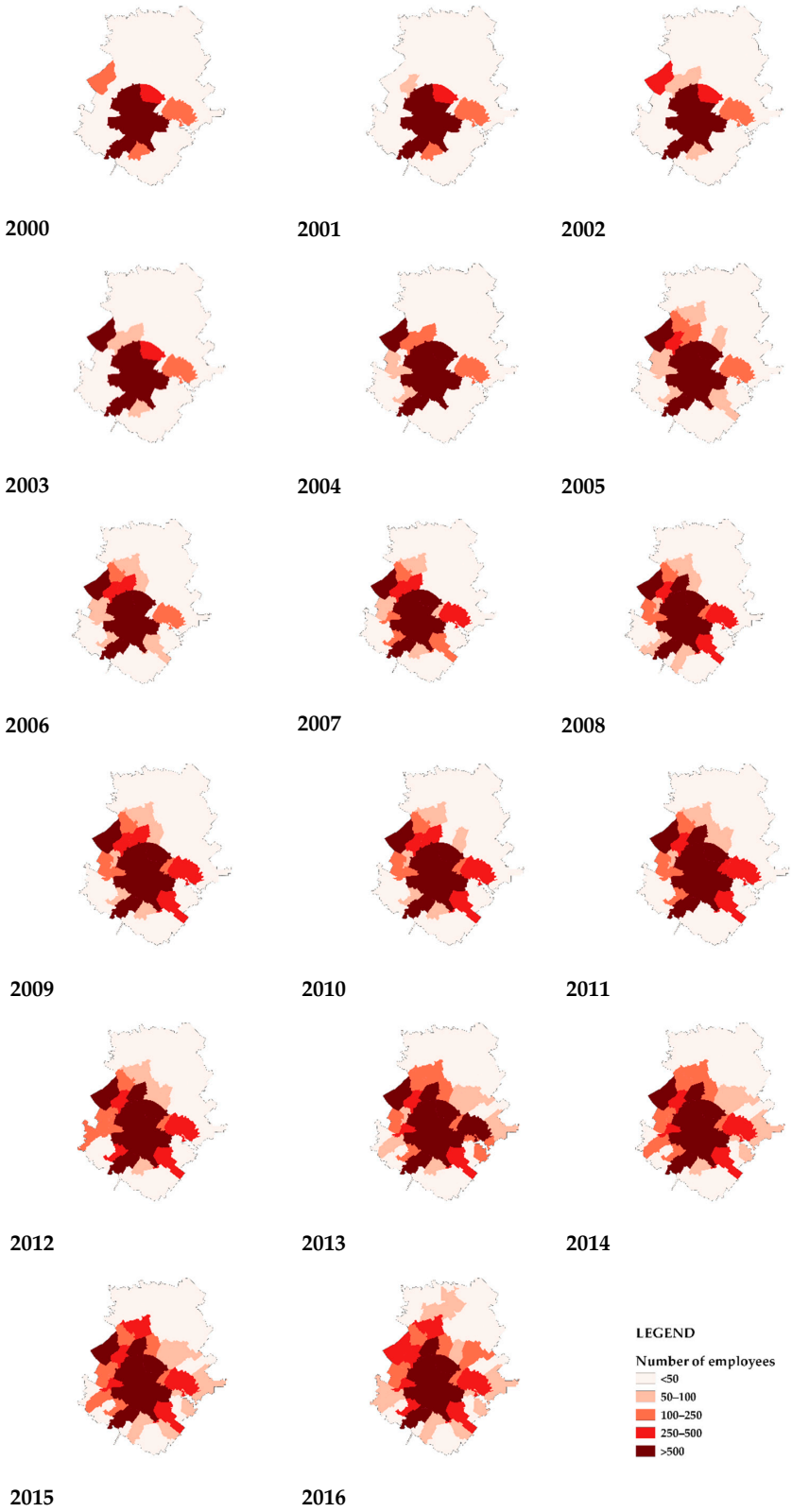

Figure 7. Distribution of the number of employees in the creative sector in the Bucharest-Ilfov Development Region.

The period 2015–2016 is characterized by a positive trend, with the number of employees in creative sector activities increasing—Bucharest reached 112,326 employees in 2015 and 115,945 in 2016, followed by Volunteers (4,464 employees in 2015 and 4,156 in 2016), Măgurele (1,986 employees in 2015 and 2,058 in 2016) and Otopeni (561 employees in 2015 and 943 in 2016); Buftea suffered a decrease in the number of employees, from 546 in 2015 to 321 in 2016.

The number of employees in the region showed an upward trend over the period analysed, starting from 42,366 employees in 2000 and reaching 127,406 in the final year of analysis (Figure 8). The NACE codes in which most of the employees were registered during this period were: 7112 (engineering activities and related technical consultancies), with 24,606 employees in 2008 and 20,546 employees in 2009; 7311 (advertising agencies), with 11,576 employees in 2008 and 11,518 in 2009; and 7219 (other research and experimental development in the natural sciences and engineering) with 9,494 employees in 2008 and 8,688 in 2009.

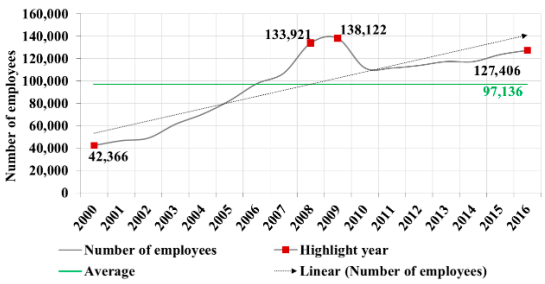

Figure 8. The evolution of employees in the creative sector in the Bucharest-Ilfov Development Region.

The share of employees in the creative sector in the region rose throughout the analysed period, so the global economic crisis did not significantly affect this economic indicator (except in 2010, when a decrease occurred, down to a value of 8.83%) (Figure 9). The maximum value of 9.89% was registered in 2016. As for the share of employees in the creative sector of this region versus the total number of creative employees in Romania (B), things were different: the evolution presented fluctuations, with significant decreases in 2007–2008 due to the increase in value of other economic activities, which also produced decreases in the number of employees in the creative sector.

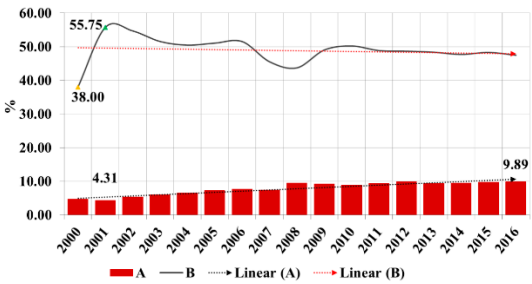

Figure 9. Evolution of the share of employees in the creative sector in terms of the total economy (**A**) and the total creative economy in Romania (**B**).

The analysis of the trend matrix for the number of employees of the creative sector at the region level offers an image on the growth potential and development of activities specific to this economic sector. The first three codes present activities in the subdomain of architecture (7112—engineering activities and related technical consultancies), with 16,869 employees in 2016; advertising (7311—advertising agencies), with 12,600 employees in 2016; and health (8622—specialist medical practice activities), with 12,577 employees in 2016; followed by IT (present in this classification under four codes: 6202—computer consultancy activities, 6311—data processing, hosting and related activities, 6209—Other information technology and computer service activities, and 6399—other information service activities n.e.c.) and a

total number, for the four codes, of 19,341 employees, representing 15% of the total employees in the creative sector in the region (Table 3).

Table 3. Trend matrix of the first 20 NACE codes for the number of employees in the creative sector for 2000–2016.

NACE Codes	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
7112	2	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	**1**
7311	3	3	3	3	3	3	3	2	3	3	2	2	2	2	2	2	**2**
8622	23	17	16	12	10	4	6	4	5	5	4	3	3	3	3	3	**3**
6202	10	9	9	7	6	5	5	6	7	7	5	5	5	5	5	4	**4**
7219	1	2	2	2	2	2	2	3	4	4	3	4	4	4	4	5	**5**
5829	17	19	15	17	17	16	15	11	11	12	10	9	8	7	7	6	**6**
7120	5	5	4	4	4	8	8	10	10	10	8	7	6	6	6	7	**7**
8690	21	23	17	20	19	21	19	18	18	15	13	10	9	9	9	8	**8**
7320	14	16	14	14	13	15	18	17	15	16	15	12	11	11	10	10	**9**
6311	13	14	13	16	15	13	11	9	2	8	6	6	7	8	8	9	**10**
7490	4	4	20	9	9	10	14	14	13	14	14	14	13	13	11	12	**11**
8623	16	15	12	13	14	14	16	13	13	13	12	11	12	10	12	11	**12**
7111	8	6	6	6	5	6	4	5	6	6	7	8	10	12	13	13	**13**
6209	12	11	10	10	12	9	9	8	9	11	11	15	14	15	14	14	**14**
8621	27	21	19	21	20	20	20	20	19	20	17	16	16	16	16	17	**15**
6399	47	48	54	49	51	52	52	43	52	39	37	33	28	31	22	19	**16**
5911	9	13	8	5	7	7	7	7	8	9	9	13	15	14	15	15	**17**
8559	20	18	18	19	21	19	21	21	21	22	21	18	17	17	17	16	**18**
5811	6	7	5	8	8	11	12	12	16	17	16	17	18	18	18	18	**19**
9329	31	30	28	26	27	25	25	25	24	25	23	22	23	22	24	21	**20**

Notes: The numbers in the last column, which represents the year 2016 show the position of the NACE codes of that year.

With the help of the matrix, two periods were highlighted: one between 2000 and 2008 (pre-crisis), where you can see increases (for example 8622, 8621 and 9329), decreases (for 7490) and stagnation in the positions that the creative activities occupies, it being a period in which the creative sector is characterized by an economic dynamism, affirming the development based on the increase of productivity and the degree of economic innovation; and 2008 to 2016 (post-crisis), which presents a unique situation based on the competence of the specialists in the creative field, the contribution to increasing the absorption of European sources, the subdomains that are based on the internationalization of their work and developing products and services for clients abroad (IT), as well as numerous successful start-ups.

3.2. The Sholl and Kolmogorov Complexity Analysis of Creative Economies

Sholl analysis for turnover in the creative sector (Figure 10) reveals a positive trend in the evolution of creative economies. One sees a growth stage in which the propagation directions extend spatially, between 2000 and 2008, due to the increasingly significant development of the creative economies and the public policies that come to their aid. The economic crisis that took hold in 2009 is associated with the compacting of the phenomenon, causing a circular development towards the centre. After 2012, a downward trend represented by the circular economic development around the city is observed.

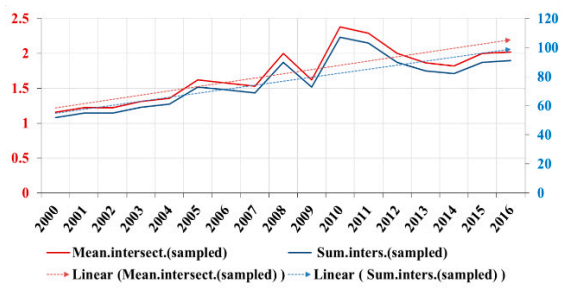

Figure 10. Sholl analysis of the turnover of the creative sector in the Bucharest-Ilfov Development Region.

Figure 11 captures the periods of maximum extension in the development of the creative economies. It highlights the period of 2000–2008 as having a positive evolution and a maximum in 2008, followed by a decrease due to the economic crisis, felt especially keenly in 2009. The second growth period is located in 2010, with a maximum of 10.07, an increase that can be explained by the developing creative economies around accessibility lanes, as well as by the development possibilities offered by the northern area of Bucharest.

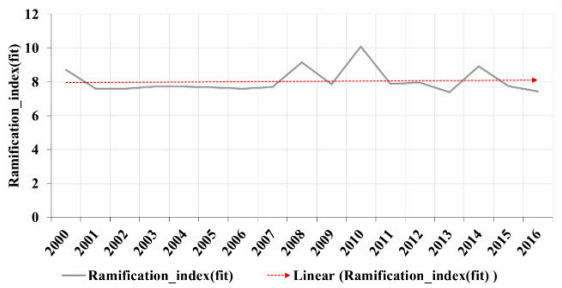

Figure 11. Branching index for turnover in the creative sector in the Bucharest-Ilfov Development Region.

Figure 12 offers a complex picture of the distribution of job offers and the number of employees involved in creative activities in the region. The total number of intersections and their average follow the same positive trend determined by the appearance of the propagation directions—from 2005, a development towards the north; and from 2008, an increase towards the southeast, towards Popești-Leordeni.

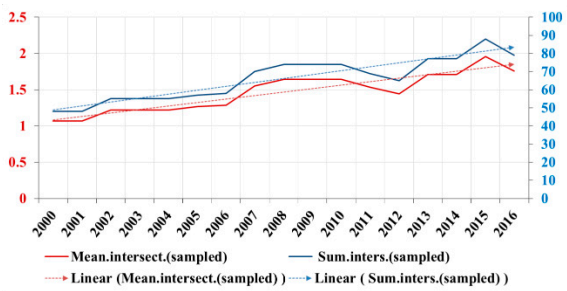

Figure 12. Sholl analysis for the number of employees in the creative sector in the Bucharest-Ilfov Development Region.

The number of employees showed a negative evolution in 2012, in which the development phenomenon was declining and creative activities were restricted in the area near the city (Figure 13).

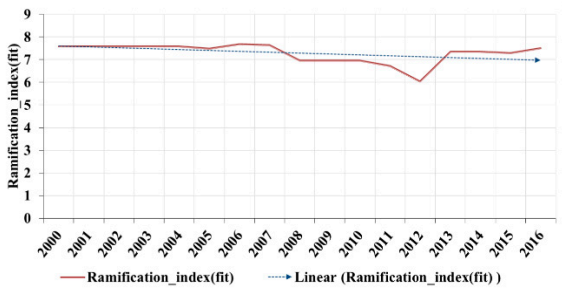

Figure 13. The branch indicator for the number of employees in the creative sector in the Bucharest-Ilfov Development Region.

In the chart showing the evolution of Kolmogorov complexity for turnover (Figure 14), the development of the creative economies is emphasized, showing the complexity of the process. Thus,

for 2000 to 2008, there is a positive trend in terms of the growth of creative economies, which leads to an area with uneven distributions around the main communication axes and to the high value of Kolmogorov complexity. In 2010 there was a maximum of complexity due to the increasingly evident growth in the northern part of Bucharest, which offers more and more development opportunities, especially along the DN1 and the Bucharest-Ploiești Highway, and due to the existence and growth of a large number of projects in that area. The period 2012–2016 presents a compaction of the turnover and a downward evolution of the Kolmogorov complexity, with a minimum in 2014, as a result of the uniform polarization around Bucharest of the creative activities.

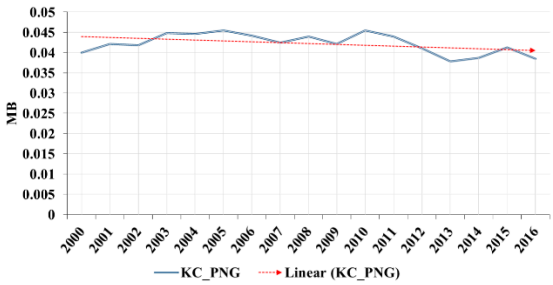

Figure 14. Kolmogorov complexity of the turnover of the creative sector in the Bucharest-Ilfov Development Region.

As to the evolution of Kolmogorov complexity in the number of employees in the creative sector (Figure 15), there is an upward trend, with an increase in complexity each year analysed based on an uneven development in the areas where employees are concentrated in the creative sector. This complexity is accentuated due to the spreading along accessibility corridors, especially in the north (Voluntari), southeast with the Popești-Leordeni area and towards the east, which has the A2 motorway.

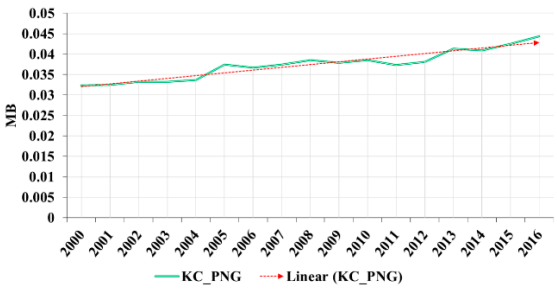

Figure 15. Kolmogorov complexity of the number of employees in the creative sector in the Bucharest-Ilfov Development Region.

4. Discussion and Conclusions

In this paper, we introduced Sholl analysis and Kolmogorov complexity to calculate the dynamics of the spatial distribution of turnover and the number of employees in creative economies in the Bucharest-Ilfov Development Region.

Sholl analysis is a key measure of dendritic complexity and has applications from assessing pathology-induced structure changes to estimating the expected number of synaptic anatomical contacts. Based on these considerations, we applied the Sholl analysis to the GIS-generated image set and found that Sholl intersection profiles can be reproduced using similar logic.

In previous studies of brain cell morphology [53,54], Sholl was used as a tool of discrimination of morphological features; in this paper we have followed the dynamics of the same phenomenon in 17 successive years. As far as we know, this is the first time that an analysis of the Kolmogorov complexity has been made for the dynamics of spatialization of some economic phenomena; fractal

implementation was recently done by Helmut Ahammer from the Medical University of Graz, Austria through the IQM operator Logical Depth.

There are also a number of limitations to the analysis. The Sholl analysis, to be comparable, must be performed at the same resolution, and binarization must be done based on the same algorithm, and the centre from which the concentric circles will be drawn will be central to the mass of the object to be analysed. KC analysis also implies a limitation, as its result is dependent on the image size. Therefore, in order to be valid and comparable, the images analysed must have the same resolution.

The results obtained highlight the increase in knowledge brought about by Sholl and fractal analysis in terms of understanding the complex of factors that determine the sustainable development of the regional economy, as well as the role of the creative economies in the balanced development of the local economies. Instead of classical GIS, spatial analysis or fractal analyses, we opted for Sholl analysis due to the ability of this indicator to quantify the dynamics of the spatial distribution of turnover and the number of employees, depending on the increases and decreases of these parameters at the level of the territorial administrative unit. To identify the complexity of this dynamic at the level of the territorial administrative unit, we applied Kolmogorov complexity, which for this type of analysis is more versatile than Higuchi 1D, Higuchi 2D, or Pyramid Dimension. Detailed research into the creative economies has shown the important role of these economic activities in the evolution of each local economy, with the creative economies supporting the economic crisis very well and fostering an adaptive capacity to cope with structural crises. The applied methodology can help to model the adaptive capacity of the territorial systems, the limitations being highlighted in numerous specialized works [55–57].

Sholl analysis allowed the morphological characteristics of the spatial model of the distribution of creative economies to be identified, identifying the development directions and, indirectly, the determined factors. With the aid of the results obtained, the study contributes to the development of the established methodologies for qualitative and quantitative analysis of the spatial distribution of geographical processes and phenomena [38,40,49,51]. This algorithm is relevant for analysing the ways in which certain types of infrastructures determine groups of creative economies.

Using Kolmogorov complexity for the analysis of the distribution of creative economies at a regional level has demonstrated the usefulness of this method for exceeding the current methodological limits in knowing the dynamics of the territorial reality, limits recorded in numerous specialized studies [58–60].

The obtained results showed the relevance of Sholl and fractal analysis in the advanced modelling of the structural dynamics of the local economies, with the fractal algorithms, together with the statistical and GIS models, offering a significant increase in knowledge.

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