



## ON A DEMONSTRATIVE MODEL OF A SMART CITY

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**Abstract** This paper offers an application of the Fibonacci sequence in developing a demonstrative model for a 3-levels smart city. The model is thought to gather data from the world through a sensor network, to store and process the data into a kernel (brain of the city) and to expose through services the processed data. In the idea of an existing city with a given architecture (streets and buildings), the paper intends to develop a model of intelligent infrastructure based on the Fibonacci sequence. The Fibonacci sequence is defined as a homogeneous linear recurrence relation with constant coefficients. Some theorems and identities in the field of number theory regarding the properties of Fibonacci numbers are introduced and discussed. These features in the design of a smart city demonstrate not only the universal nature of the Fibonacci sequence, but also the aesthetic nature of God.

*Key words:* Fibonacci sequence, smart city, kernel, ICT infrastructure.

### 1. INTRODUCTION

The mathematical concepts have applications in different fields of applications. Without these important concepts, each area of mathematics would apparently be disjoint and unrelated to topics in other mathematical or engineering fields. One of these concepts was discovered by Leonardo Pisano in the early period of the thirteenth century. This particular concept is known today as *the Fibonacci sequence*. The Fibonacci sequence is one of the most fascinating concepts in the whole field of mathematics by its remarkable characteristics. Its useful applications are found in different subject areas, such as number theory, discrete mathematics and geometry.

Nam and Pardo [1, 2] analyze the definitions of a smart city adopting the architectonic, social and infrastructural points of view. Different aspects regarding the design of the exterior and tangible part (architecture, ecology, etc.), the citizen interaction which can transform the citizen from a passive subject into a live actor in the city which in turn becomes a real, smart ecosystem [3-5], and the relational part (governance, policy and citizen interaction) with the infrastructures based on the technological and internet combinations, are analyzed in the context of new opportunities made available to each city actor (citizens, companies, authorities) in an intelligent city.

A smart city must be viewed as an optimized system where citizens are independent and interconnected to each-others and also to the brain of the city which can be defined as the *Information and Communication Technology* (ICT) infrastructure [6].

In a recent book [7] Komninos studies the drivers and architectures of a smart city by the managing the environments with the architecture of streets and buildings [8, 9].

In the idea of an existing city with a given architecture (streets and buildings), this paper intends to develop for this city a model of intelligent infrastructure based on the Fibonacci sequence. The smart city definition has a guiding thread of integration of existing and conventional infrastructure into a smart infrastructure that collects data generated throughout the city and provides a unified platform for accessing it.

## 2. FIBONACCI SEQUENCE AND THE GOLD SECTION

According to O'Connor and Robertson [10], Leonardo Pisano was born into a family of merchants in Pisa, Italy, in 1175 A.D. He is known by his nickname Fibonacci. Fibonacci was educated in North Africa and not in Italy; because his father, Guglielmo Bonacci, held a diplomatic post in the area. Fibonacci's father was a representative of the Pisan traders in the Mediterranean port city of Bugia, which was located in northeastern Algeria.

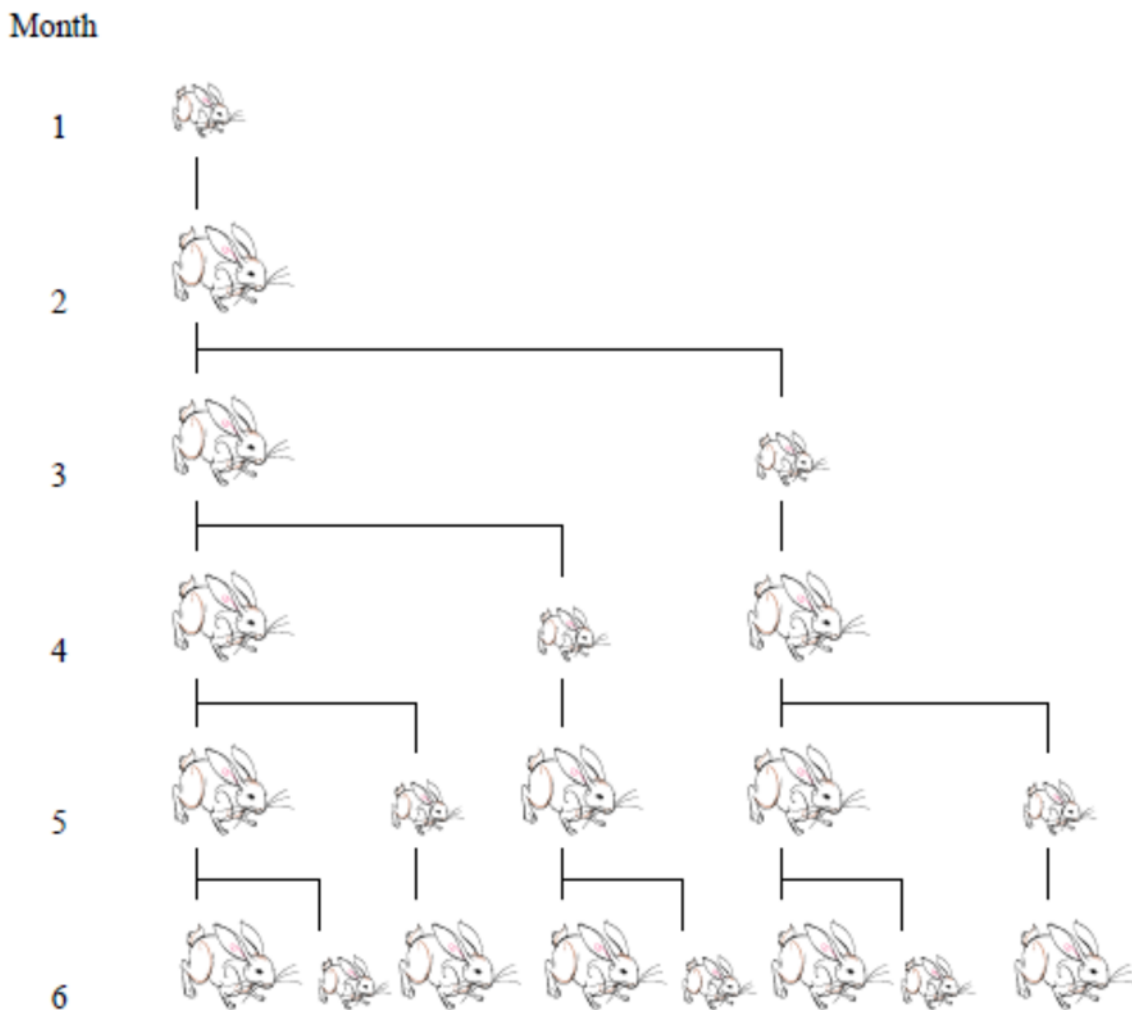


Fig.1. The Fibonacci hypothetical problem [18].

In 1200 A.D., Fibonacci returned to his birthplace and began working on a book that became a masterpiece of mathematics: *Liber Abaci*, which means the Book of Calculus [11-14]. The book contains interesting mathematical ideas that he encountered during his travels through the

Mediterranean. Fibonacci introduced numbers, the decimal system, numerous topics in the field of number theory and a particular sequence of numbers now known as the Fibonacci sequence [15-18]

The initial words of Fibonacci in *Liber Abaci* were: *These are the nine figures of the Indians: 9 8 7 6 5 4 3 2 1. With these nine figures and this sign 0 what is called in zephyrum in Arabic, you can write anything number* [9-14]. The introduction of this sequence has forever changed the face of mathematics in the Western world.

Although Fibonacci was credited with discovering the sequence, it was not officially named the Fibonacci sequence until after his death in 1250 A.D. [18]. In fact, this sequence was not labeled the Fibonacci Sequence until the 19th century, when a theorist Edouard Lucas examined a problem from Fibonacci's *Free Abacus* and linked Fibonacci's name to the sequence that the problem involves.

In his book, Fibonacci (1202) introduced the sequence as the following hypothetical situation: "A man put a pair of rabbits in a place surrounded by a wall. How many pairs of rabbits can be produced from that pair in a year, if each month each pair gives birth to a new pair that becomes productive from the second month?" [15, 16].

When Fibonacci examines this issue, he discovered a sequence of numbers which involves the number of pairs of rabbits. The problem starts with a pair of rabbits. After one month, this initial pair of rabbits reaches adulthood and is capable of reproduction [18]. Assuming that the average gestation period for a rabbit is one month, the initial pair of rabbits will give birth to a second pair of rabbits at the beginning of the third month. At this point in the problem, there is a pair of adult rabbits and a pair of baby rabbits. Fibonacci assumes in its problem that once a pair of rabbits has reached adulthood, it reproduces another pair of rabbits each time.

To maintain uniformity, Fibonacci assumes that none of the rabbits die [15]. After each month, Fibonacci counted the pairs of rabbits, and its conclusions led to a succession of numbers. The problem of rabbits is illustrated in Fig. 1 [18]. The images with smaller rabbits represent rabbits that were recently born, and larger rabbits represent adult rabbits that are at least one month old.

The sequence terms in the Fibonacci problem are 1, 1, 2, 3, 5, 8, 13, 21, 34, 55, 89, 144. Based on the Fibonacci's findings, it is clear that each term is a sum of two preceding sequence term [18]. In fact, the sequence can be recursively defined in the form

$$f_n = f_{n-1} + f_{n-2} , f_0 = 0, f_1 = 1 . \quad (1)$$

With this recursive definition, the terms in the Fibonacci sequence have interesting features. One of these characteristics is *the limit of the ratio of two consecutive terms in the Fibonacci string*.

In this limit, the convergence of the Fibonacci string can be demonstrated. We show below that the limit of the ratio of two consecutive terms in the Fibonacci string tends to the number

$$\varphi = \frac{1 + \sqrt{5}}{2}$$

$$\lim_{n \rightarrow \infty} \frac{f_{n+1}}{f_n} = \lim_{n \rightarrow \infty} a_n = \varphi , \quad (2)$$

where  $n \in N$ , and

$$a_1 = \frac{1}{1} = 1, \quad a_2 = \frac{2}{1} = 2, \quad a_3 = \frac{3}{2} = 1,5, \quad a_4 = \frac{5}{3} = 1,66 \dots\dots \quad (3)$$

The number  $\varphi = \frac{1 + \sqrt{5}}{2}$  it has been known for many centuries as *the golden ratio* or the golden section [19]. Kepler referred to it as the divine proportion.

To prove the convergence of the string  $a_n, n \in N$ , we start from

$$a_n = \frac{f_{n+1}}{f_n} = \frac{f_n + f_{n-1}}{f_n} = \frac{f_n}{f_n} + \frac{f_{n-1}}{f_n} = 1 + \frac{f_{n-1}}{f_n} = 1 + \frac{1}{a_{n-1}}, \quad (4)$$

to obtain

$$a_n = 1 + \frac{1}{a_{n-1}}. \quad (5)$$

We need to show the edge of each term in the string. It results from (5) [20]

$$a_n \leq 2, \forall n \in N. \quad (6)$$

Therefore, it follows that the Fibonacci string is convergent. We note this limit with  $\alpha$

$$\lim_{n \rightarrow \infty} \frac{f_{n+1}}{f_n} = \lim_{n \rightarrow \infty} a_n = \alpha. \quad (7)$$

From (4) we can write

$$a_{n+2} = 1 + \frac{1}{a_{n+1}} = 1 + \frac{1}{1 + \frac{1}{a_n}} = 1 + \frac{a_n}{1 + a_n}. \quad (8)$$

For  $n \rightarrow \infty$ , we have

$$\lim_{n \rightarrow \infty} a_{n+2} = \lim_{n \rightarrow \infty} \left( 1 + \frac{a_n}{1 + a_n} \right). \quad (9)$$

or

$$\alpha = 1 + \frac{\alpha}{1 + \alpha}. \quad (10)$$

It results from (10)

$$\alpha^2 - \alpha - 1 = 0, \quad (11)$$

with solutions

$$\alpha = \frac{1 \pm \sqrt{5}}{2}. \quad (12)$$

Because all the terms in the string  $a_n, n \in N$  are positive, only the solution

$$\alpha = \frac{1 + \sqrt{5}}{2}, \quad (13)$$

has the physical sense. Then, (7) yields to

$$\lim_{n \rightarrow \infty} \frac{f_{n+1}}{f_n} = \lim_{n \rightarrow \infty} a_n = \varphi = \frac{1 + \sqrt{5}}{2}. \quad (14)$$

The first mention of the golden report or the golden section  $\varphi$  appeared in Euclid's elements in 300 BC. In him elements, Euclid proposed a problem that involves dividing a line into two segments by following a certain law [11-14]. The problem begins with a segment equal to the unit which is divided into two lines having lengths and respectively. Euclid found that the ratio of the lower part of the segment to the larger part of the segment is equal to.

Although Euclid was the first who studies the gold section, this number has been known for

thousands of years. The Greeks were fascinated by this report, because it appeared frequently in geometry. A geometrical application of the golden section can be found in proportion to the lines of a pentagram [19]. Throughout history, many artists have used the golden section because it was aesthetically pleasing. Many architectural structures around the world have evidence of the golden ratio in their proportion. One of the most fascinating features of the Fibonacci sequence as well as the golden section is their very frequent occurrence in nature. The Fibonacci sequence was highlighted in the arrangement of the flower petals. Many flowers contain a number of petals that match the numbers in the Fibonacci sequence. Fibonacci string can also be found in the spiral arrangement of pine cones and pineapple, in flower petals and seeds [19].

When you look at a pine cone, a pineapple or a sunflower, a leaf or a plant stalk sees numerous springs sprouting from their center. According to Knott [11-14], the number of spirals is a number in the Fibonacci sequence. Starting from a leaf with a given shape, color and position, the number of rotations required to find another leaf with the same characteristics and position is a Fibonacci number. Moreover, the number of leaves in a tree is also a Fibonacci number [11-14].

According to Nickel [19], the Fibonacci sequence is also found in the music. For example, the keys on a piano are divided into Fibonacci numbers. Numerous classical compositions implement the golden section. According to Beer [16], such an example can be found in the Alleluia Choir in Handel's Messiah. The whole composition consists of ninety-four measures, and one of the most important events in the song takes place during the measures fifty-seven and fifty-eight.

In many of Chopin's preludes, the highlight of the music is located very closely to golden section which is dividing the length of the piece. This is especially true for his Prelude no. 1 of the C major, which has 34 measures. The highlight of this piece appears in measure 21 and the ratio between the measures is the golden section [17]. God has clearly shown that the aesthetic nature of mankind comes from the golden section.

### 3. DEFINITION OF A SMART CITY

As we said, a smart city must be viewed as a high-performance system where citizens are independent and interconnected to each-others and also to the city itself through the Information and Communication Technology (ICT) infrastructure [6]. The ICT infrastructure is the brain of the city which governs and control the natural resources and energy, transport and mobility, buildings, living, government, and economy and people.

A smart city uses new ideas to control, improves and develop all aspects of the city such as the economy, industry, politics, governance and mobility. Fig. 2 shows a 3-levels system which gathers data from the world (sensor networks, world wide web and user contribution), stores and processes these data into a kernel (the city brain), and exposes through several services the processed data.

The service layer is used by citizens and other relevant city actors such as businesses, industries and local government. The access layer contains the sources of information composed by sensor networks, the Internet and the citizens themselves through user contribution.



Fig.2. A schematic representation of a smart city.

All information provided by the access later is processed at the kernel layer. Here, the raw data is collected and analyzed by brain of the city through the computing infrastructure (kernel) of the city. Then the citizens and other city players such as the local governments, research institutions, grassroots movements, technology vendors, property developers, etc., have access to this data through service layer with dedicated services and interfaces and request them.

The European Union has paid a close attention in the last years to the development of medium-sized cities. The EU have proposed in [21, 22] a model to contribute to optimization of internal organization, allocation of resources and improvement of living standards in 70 European cities among which there are Amsterdam, Vienna and Geneva.

This study provides general information on smart cities in the EU and explains how the brain mechanism of these cities works. In this study, a custom definition for a smart city is proposed and the map of those cities that fit this definition in all member states.

In this paper, the smart city model is strictly related to the ICT infrastructure which may include for example video control and urban surveillance, security, energy saving, control of industrial facilities, hydrological networks and gas supply, logistics, safety at work, community healthcare, waste management, public transport networks and parking, monitoring air and noise pollution, social interaction etc.

The model of a smart city is related in this paper only to the intelligent infrastructure with a sensor network which connect the control with the entire city.

In the daily life of the city, the information infrastructure will be accessed repeatedly by people and institutions in the real time. It will have to collect and store data provided by both sensors and citizens. It is important for the system to be available, to remain in operation, even if it is overloaded. In the event of a failure of one of its components, the repairing will have to be carried out as soon as possible. Continuously, the addition of new sensors and new features is an essential requirement to enhance performance.

The Fibonacci sequence is applied in this paper to design a scenario for smart ICT infrastructure for a given city. The optimization criterion introduces an objective function which depends on some indicators to evaluate the performance of the city kernel.

The key components of the city kernel are:

1. The traffic monitoring. The intelligent transportation system is composed by optical over-roadway sensors equipped with ethernet or wi-fi interfaces. These sensors are based on reflection of transmitted energy (like infrared laser radar, ultrasonic sensors, and microwave radar sensors), radar sensors aligned with lanes to prevent the breakage of the road surface. The smart infrastructure may develop the subway's intelligent stations and efficient bike-sharing systems.

The intelligent transportation system is based on the electrical network both for power supply and for communication.

2. Smart services. The smart services enable the storage of the raw data gathered in the urban area and their subsequent processing in order to expose smart-services and value-added services. The smart services are:

- 2.1. Mobile traffic control. This service avoids queues and traffic jams during a trip on their own transport, choosing the more owing path.

- 2.2. Visual traffic control. This controller consists of a smart camera equipped with embedded software responsible of traffic data capturing, and a communication module enables to provide the power line communication.

- 2.3. Extreme weather sensing. This service improves efficiency in emergency responses to extreme weather events.

For a particular city, the economy, industry and the urban structure influence the activity of the city kernel. The geographical location, density of population associated to the congestion problems of the city affects the kernel strategy.

#### 4. RECONSTRUCTION OF ICT URBAN INFRASTRUCTURE

The reconstruction of ICT urban infrastructure presented in this Section for a given city focuses on the city kernel design. Specifically, the optimal solution rationalizes the deployment of urban ICT infrastructures and connect them to smart services concerning the urban traffic and mobility.

The reconstruction of ICT urban infrastructure is described as a multi-objective optimization problem with 8 objective functions  $F_1(s,t), F_2(s,t), \dots, F_8(s,t)$  depending on the space  $s = (x, y, z)$  and the time  $t$ .

The objective functions are defined as:

$F_1(s,t)$  - omni-directional traffic for all types of vehicles

$F_2(s,t)$  - omni-directional traffic for each single type of vehicle

$F_3(s,t)$  - traffic for each single direction for all types of vehicles

$F_4(s,t)$  - traffic for each direction and each type of vehicle

$F_5(s,t)$  - traffic for each virtual-loop for all types of vehicles

$F_6(s,t)$  - traffic for each virtual-loop for a single type of vehicle

$F_7(s,t)$  - the average cruising speed

$F_8(s,t)$  - the average cruising speed for each single direction

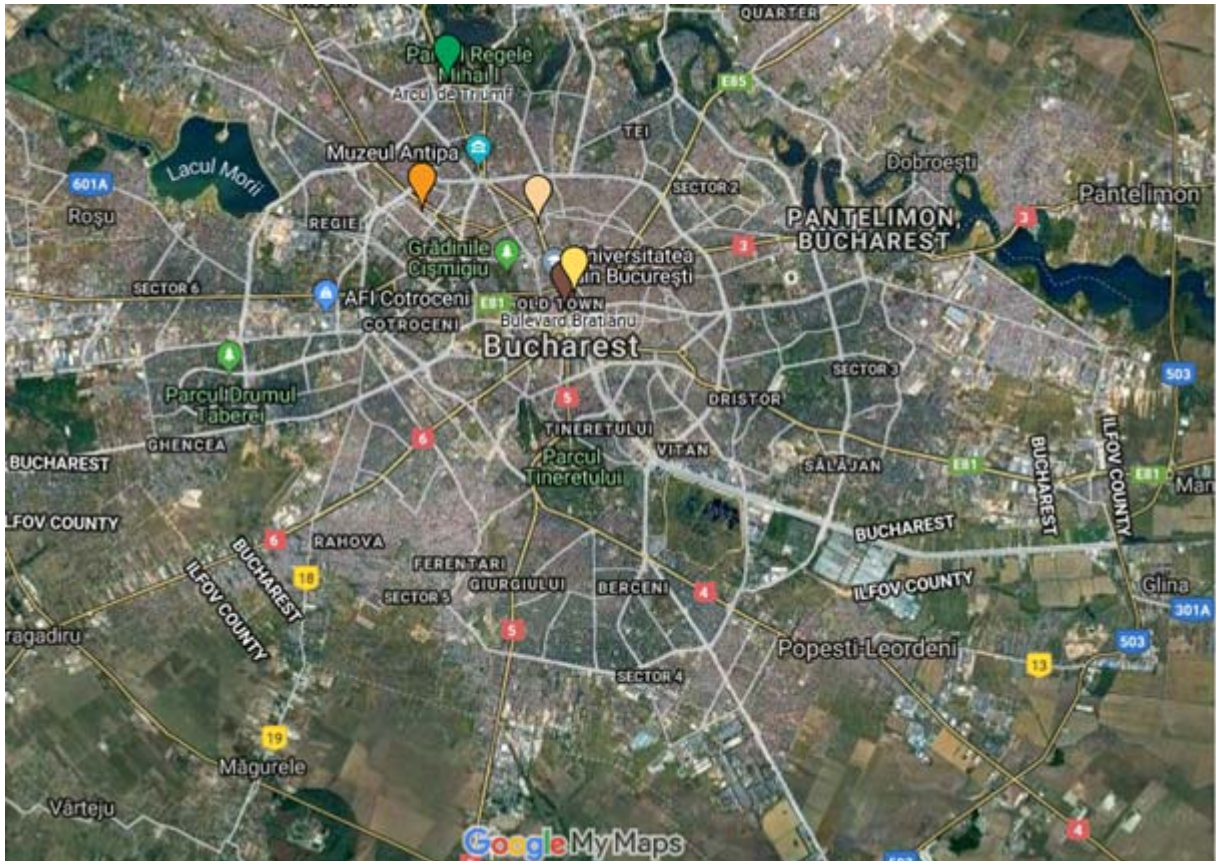


Fig. 3. The domain  $S$  designed for the city of Bucharest.



Fig.4. The Fibonacci sequence scaled on the domain  $S$ .

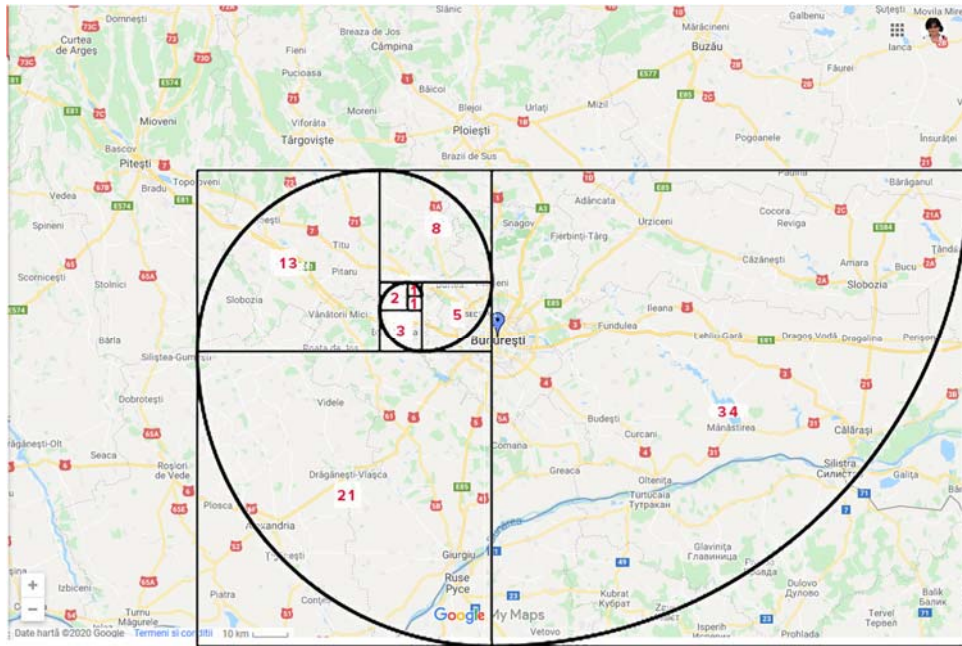


Fig.5. The Fibonacci sequence scaled on the neighborhoods of the domain  $S$ .

The optimization problem is to

$$\text{Maximise } y = F(s, t) = (F_1(s, t), F_2(s, t), \dots, F_8(s, t))^T, \quad s \in S, \quad t \in T, \quad (15)$$

where  $S$  and  $T$  are known domains. The domain  $S$  is referred to Bucharest city shown in Fig.3, and  $T$  extends over 24 hours. The Fibonacci sequence scaled on the domain  $S$  is presented in Fig.4.

The Fibonacci sequence scaled on the neighborhoods of the domain  $S$  is presented in Fig.5.

The Fibonacci sequence is used next to find the maximum values of the objective functions by searching the minimum values in each iteration of the algorithm.

Given the domain  $s \times t$ , the optimal values for the objective functions are obtained by using the Fibonacci sequence.

The use of the Fibonacci sequence to obtain the maximum of a unimodal function  $f(x)$  over an interval  $a \leq x \leq b$  is known [23]. The algorithm computes the number of iterations required to ensure the final interval is within a given tolerance  $\varepsilon$ , by computing the smallest value of  $n$  that makes this inequality  $f_n > (b - a) / \varepsilon$  true, where  $n$  is the Fibonacci number from the sequence  $\{f_0, f_1, f_2, \dots\}$ . The role of the Fibonacci string in our problem is to select from possible solutions of the objective functions those values that are leading to the optimum. The optimal values of the functions  $F_1(s, t), F_2(s, t), \dots, F_8(s, t)$  are found in the vicinity of each element in the Fibonacci sequence.

The density of all traffic associated to each objective function is very high. Fig.6 presents for example, the density of the traffic in the neighborhood of Băneasa, Bucharest with respect to the function  $F_1$  [24].

The algorithm generates the first  $k$  terms of the sequence

1	1	-	-	-	-	-	-	-	-	-	-	-	-	
1	1	2	-	2	-	-	-	-	-	-	-	-	-	
1	1	2	3	2	3	-	-	-	-	-	-	-	-	
1	1	2	3	2	4	3	-	4	-	-	-	-	-	
1	1	2	3	2	4	3	5	4	-	-	5	-	-	
1	1	2	3	2	4	3	5	6	4	-	5	-	6	
1	1	2	3	2	4	3	5	6	4	7	5	-	6	
1	1	2	3	2	4	3	5	6	4	7	8	5	6	
1	1	2	3	2	4	3	5	6	4	7	8	5	9	6

and the result is the folding of the 2D arrays  $x \times t, y \times t, z \times t$  into tori, as shown in Fig. 7. A torus is a surface of revolution generated by revolving a circle in 3D space about an axis that is coplanar with the circle.

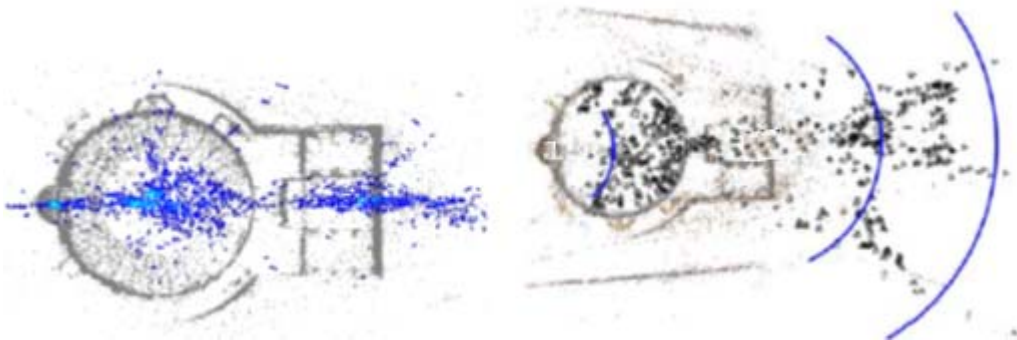


Fig.64. The density of the traffic associated to the function  $F_1$ .

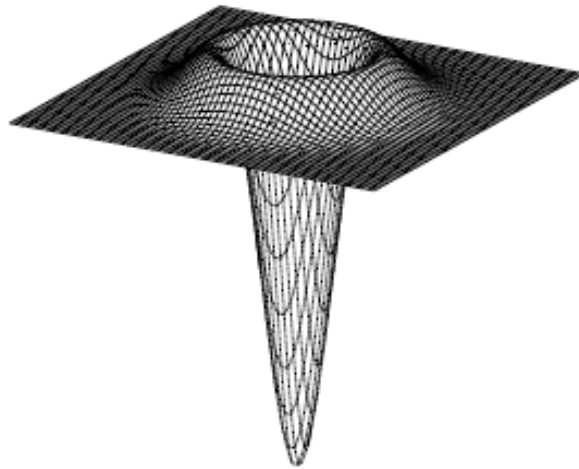


Fig. 7. A Fibonacci torus.

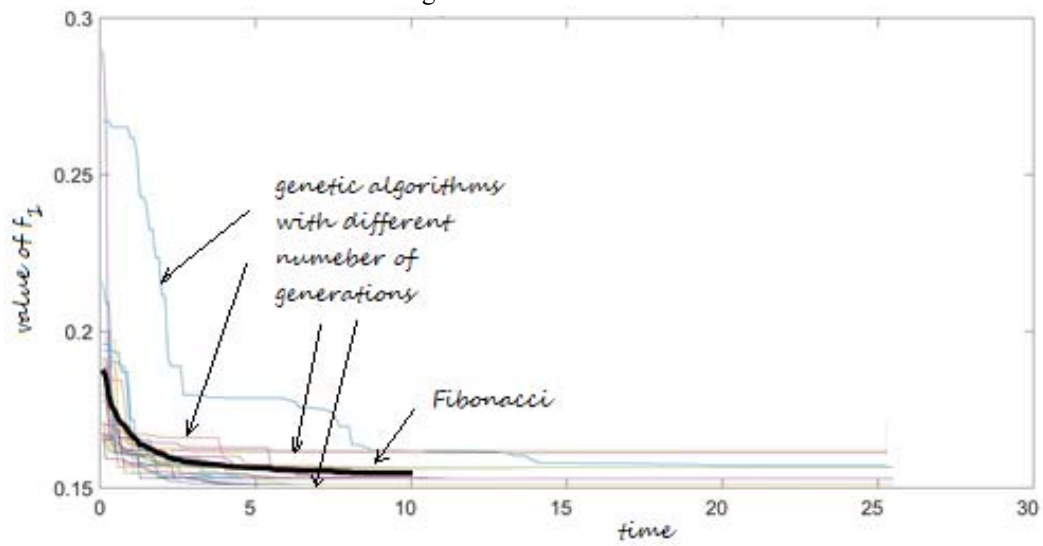


Fig.8. Convergence of the optimization problem for  $F_1$  - Fibonacci and genetic methods.

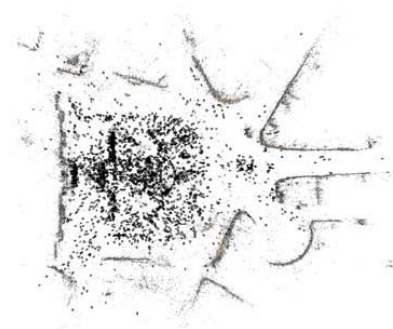
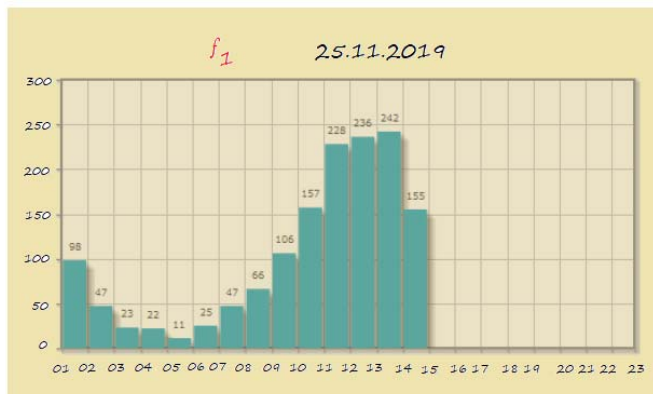


Fig.9. The result of the optimization problem for  $F_1$ .

Fig. 8 displays the convergence rate for  $F_1$  based on the Fibonacci method and the genetic algorithm with different number of generations. Genetic algorithm is a usual optimization technique which can be applied to such optimization problems. Both the Fibonacci and genetic algorithm have attained a very good value of the objective function  $F_1$  in the first 25 sec., with the difference that the Fibonacci method attains the optimal only in 10 sec. Despite this fact, the Fibonacci method has proven to be more reliable compared to generic algorithms in terms of the mean value of the objective function. Fig.9 presents the result of the optimization problem for the objective function  $F_1$ .

## 5. CONCLUSIONS

This paper applies the Fibonacci method for reconstruction of ICT urban infrastructure for Bucharest focused on the city kernel design. The optimal solution rationalizes the deployment of urban ICT infrastructures and connect them to smart services concerning the urban traffic and mobility. The Fibonacci method is based on the Fibonacci sequence.

The role of the Fibonacci sequence is to select from possible solutions of the optimization problem those values that are leading to the optimum. The optimal values of the objective functions are found in the vicinity of each element in the Fibonacci sequence.

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Received November 02, 2019