Article

Circle in Space—Space in Circle: A Study of Ratio between Open Space and Built-Up Area in Historical Circular Objects

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Abstract: Many cities nowadays explore different circular designs as new sustainable city concepts in different urban aspects. The new trend, as part of the adaptation for climate change, is a strategy of increasing the number of urban open spaces, and circular plan design could be a sustainable approach to urban development. This paper provides a historical overview of various examples of circular objects containing built structures and open spaces from the Neolithic to the present. The Built-Up Area (BUA) and Open Space (OS) relationships are shown histographically for 36 objects arranged chronologically. The morphospace analysis was performed to determine any possible regularity in the relationships of parts of circular objects. For the purpose of this research, three variables were chosen. First, all selected historical examples of circular objects were divided into two main categories: objects with a total diameter smaller than 300 m and objects with a total diameter bigger than 300 m. Additionally, the selected circular objects were divided by their type of open space to better understand their spatial position. The largest number of analyzed objects belongs to the Parks–Gardens category, followed by settlements, and then earth works, sacral objects and circular buildings, with the smallest number of circular objects being in the category of allotments and plazas. The second variable was Jam area and % of Jam. The buildings are of different sizes up to several hundred m², and the areas range up to several hundred ha. The total area to OS ratio ranges from 0% (for Large Serdab) to 100% (for multiple objects). There is a similar situation with the diameter ratios (total and “jam”). Additionally, the final variable was the historical position of the selected circular objects. Circular objects belong to all historical periods from the Neolithic to the present. The aim of this research was to explore the relationship between OS and BUA in various circular objects with different diameters of open spaces and find out if there was any regularity in this relationship. The morphospace analysis of this research indicates that there is no clear regularity in the relationship between the built-up area and the open space, but the aspects and research results shown here contribute to sustainability since the circular design approach could play a key role in future circular design processes.

Keywords: circular objects; open space; built-up area; morphospace analysis; doughnut objects

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1. Introduction

Many cities around the world explore different sustainable strategies (implementing circular economy, circular product design, circular urban systems, ideas of circular cities as a destination of the future) to improve city environment, and circular designs could be a sustainable approach for improving urban ecosystems and a solution for climate change adaptations.

The ratio between porous and non-porous surface areas in cities represents just one of the problems in urban environments. For sustainable urban development, it is important to find a proper ratio between these two urban structures. Different types of open spaces

have important roles in the urban environment (social, economic and also environmental role)—reducing negative effects of urban development, such as surface runoff and the urban heat island effect, and many others [1]. There are many definitions of open spaces. One definition defines open spaces as area with its surface open to the sky, regulated to serve conservation and urban shaping function in addition to providing recreational opportunities and many others [2]. In many definitions, open spaces are in unbreakable connection with green areas and natural spaces, so they often represent a porous area in a city (but not conditionally—there are many other types of open spaces too).

The concept of circular city and the circular approach in urban planning started at the end of the 20th century, as a contrast to linear planning practice [3]. Today, the circular concept includes more aspects, not only urban planning. The main focus is on circular city design, circular processes and circular management as a way to improve urban functions and protect natural resources. All these goals take place in some urban space. The circularity approach in urban landscape design could have an impact on various sustainable strategies, such as improving waste management and improving traffic paths and communities [4], and have an important role in the adaptation of cities for climate change.

The base of any circular process, circular city or circular object is a circle. Together with the quadrilateral and the cross, the circle belongs to the most basic and oldest symbols. The source of the circle is the point and together they are symbols of perfection: the point because of the nucleus and the source of everything created from it, the circle because it has neither beginning nor end, and speaks of infinite circular motion. In Euclidean geometry, a circle is the geometric location of points in a plane that are at an equal distance from one constant point in the same plane. If perfect is simple, then the circle is indeed the most perfect of all lines, precisely because it is the simplest. The circle is also the basic line in geometry because all other curved lines can be obtained starting from the circle. The circle has been and remains a symbol of perfection in all civilizations [5–8].

From the earliest epochs, the circle was an easily discernible sign that the visual world is obvious. First, the circular forms of the celestial vault, the sun and the full moon, were the most evident sources for their transfer and application into various beliefs. The ancient peoples knew of four key events in the annual cycle of the sun: the winter solstice, the summer solstice, and the spring and autumn equinox. The belief in the protective power of the circle in defense against evil forces, the magic circle, was widespread in many civilizations.

A circle is the only basic geometric shape that a curved line makes. This feature allows the circle to be an element of all artistic styles and trends in architecture and landscape architecture. It fits equally well with the geometric, formal style created primarily from straight lines and polygonal shapes, but also into landscapes or natural gardens.

2. Materials and Methods

The objectives of this study are circular objects containing a Built-Up Area (BUA) and an Open Space (OS) from the Neolithic to the present and the exploration of circular doughnut design. In this paper, a Built-Up Area (BUA) represents any land on which buildings and/or other built structures are present—man-made (non-porous) surfaces, and an Open Space (OS) is any piece of land that has no buildings or other built structures, usually a space that is partly or completely covered with grass, trees, shrubs, or other vegetation, with a porous surface—a green space. Circular objects were analyzed using the morphospace method to determine the relationship between an OS and a BUA and ascertain possible regularities in these relationships.

2.1. The Categories of the Selected Circular Objects and Geometrical Data in Morphospace Analysis

The morphospace method represents mathematical/graphical representations and is used for studying the evolution of morphological diversity and for the evaluation of evolved shapes among theoretically possible ones. It is a method in theoretical biology for the definition of natural forms of animals and plants [9,10], and in earlier research with the

application of this method in architecture [11], the relationship between the OS and the BUA is analyzed within circular based objects or, according to Steadman’s terminology, the “jam” and the “doughnut”.

For morphospace analysis, three variables were chosen. Each axis of the morphospace corresponds to a variable which describes some character of a selected circular object [12]. In this morphospace analysis, there were three selected axes/variables: the first variable is measurements of the area of selected circular spaces (also diameter and inner D), Jam area and % of the Jam, and the second variable is represented through two main categories with types of circular objects. The third variable represents a historical overview of selected circular objects. All selected objects with their variables are represented in Table 1.

Table 1. The basic data of morphospace analysis of selected circular objects.

	Site Name	Dating	Type	Coordinates	Diameter	Inner D	Area	Jam Area	% of Jam
1.	GöbekliTepe	10,000 BC	Sacral Objects	37°13'23" N 38°55'21" E	20 m	14 m	312 m ²	146 m ²	46.79
2.	Stonehenge	3000–2000 BC	Earthworks	51°10'44" N 01°49'34" W	110 m	109 m	9500 m ²	9354 m ²	98.46
3.	Mari	2900–1759 BC	Settlements	34°55'04" N 40°88'91" E	2000 m	1416 m	3,140,000 m ²	1,574,289 m ²	50.14
4.	Arkaim	2000–1600 BC	Settlements	52°38'57" N 59°34'17" E	150 m	63 m	16,917 m ²	3100 m ²	18.32
5.	Mycenean Grave Circle B	1700 BC	Sacral Objects	37°43'51" N 22°45'23" E	33 m	28 m	855 m ²	627 m ²	73.33
6.	Varro’s Aviary at Casinum (Tholos)	64 BC	Parks–Gardens	41°29'24" N 13°48'50" E	14 m	9 m	223 m ²	69 m ²	30.94
7.	Mausoleum of Augustus in Rome	31–28 BC	Sacral Objects	41°54'22" N 12°28'35" E	84.5 m	71 m	5600 m ²	4010 m ²	71.61
8.	Teatro marittimo-Villa Hadriana	118–138	Circular Buildings	41°94'24" N 12°77'58" E	45 m	35 m	1590 m ²	972 m ²	61.131
9.	Round city of Baghdad	766–7	Settlements	33°34'88" N 44°33'53" E	2400 m	1717 m	3,492,672 m ²	2,316,375 m ²	66.32
10.	Large serdab Dar al-Khalifa, Samarra	836	Plazas	34°23'05" N 43°87'40" E	50 m	0 m	1962 m ²	0 m ²	0
11.	Tell al-Banat	859–892	Earthworks	34°44'76" N 43°80'48" E	170 m	170 m	23,584 m ²	23,584 m ²	100
12.	The Early Slavic pagan shrine in Peryn	980–989	Sacral Objects	58°47'28" N 31°27'36" E	35 m	35 m	962 m ²	962 m ²	100
13.	Studena Monastery, Serbia	1183–1186	Sacral Objects	43°29'11" N 20°32'13" E	128 m	93 m	10,920 m ²	6851 m ²	62.74
14.	Harman Fortified Church	1240	Sacral Objects	45°42'56" N 25°41'06" E	100 m	63 m	6677 m ²	3115 m ²	46.65
15.	Hypnerotomachia Poliphili Island garden of Cythera	1499	Parks–Gardens	imagination	1482 m	1482 m	1,724,114 m ²	1,724,114 m ²	100
16.	Orto Botanico di Padova	1545	Parks–Gardens	45°39'12" N 11°88'08" E	84 m	64 m	5242 m ²	3205 m ²	61.14
17.	Palmanova	1593	Settlements	45°90'56" N 13°31'00" E	1530 m	1115 m	1,835,170 m ²	976,962 m ²	53.24
18.	Parc d’Enghien	1630–1665	Parks–Gardens	50°68'76" N 04°04'73" E	235 m	163 m	41,823 m ²	20,919 m ²	50.042
19.	The Palace Garden Karlsruhe	1731–1746	Parks–Gardens	49°01'38" N 08°40'44" E	865 m	589 m	575,069 m ²	272,250 m ²	47.34
20.	Clemenswerth Palace, Sögel	1737–1747	Parks–Gardens	52°83'83" N 07°53'71" E	100 m	84 m	7850 m ²	5550 m ²	70.71
21.	Schwetzingen Palace, Schwetzingen	1753–1770	Parks–Gardens	49°38'37" N 08°56'80" E	330 m	206 m	85,476 m ²	33,299 m ²	38.96
22.	ErylouHua’an tuloi, Hua’an, Zhangzhou, Fujian, China	1770	Settlements	25°01'25" N 117°41'12" E	73 m	27 m	4231 m ²	572 m ²	13.52
23.	Şarlota (Charlottenburg)	1771	Settlements	45°97'86" N 21°51'91" E	417 m	326 m	136,639 m ²	83,321 m ²	60.98
24.	Circleville, Ohio	1836	Earthworks	39°35'58" N 82°56'40" W	327 m	184 m	81,513 m ²	26,770 m ²	32.84

Table 1. Cont.

	Site Name	Dating	Type	Coordinates	Diameter	Inner D	Area	Jam Area	% of Jam
25.	Queen Mary's Gardens Regent's Park, London	1930s	Parks–Gardens	51°52'77" N 00°15'36" W	333 m	287 m	87,516 m ²	64,868 m ²	74.12
26.	Brøndby Garden City, Copenhagen	1964	Allotments	55°38'13" N 12°23'58" E	120 m	99 m	11,200 m ²	7720 m ²	68.93
27.	Kikar Hamedina, Tel Aviv	1970	Plazas	32°05'12" N 34°47'23" E	330 m	255 m	86,484 m ²	51,250 m ²	59.26
28.	Bublik Circular House, Moscow	1972	Circular Buildings	55°42'26" N 37°28'16" E	180 m	155 m	25,447 m ²	18,869 m ²	74.15
29.	Maheshwari Udyan, Mumbai	contemporary	Parks–Gardens	19°02'67" N 72°85'54" E	150 m	104 m	20,100 m ²	8414 m ²	41.86
30.	Gartenverein zur Sonnenblume Kamp-Lintfort	contemporary	Allotments	51°49'15" N 06°56'54" E	190 m	144 m	28,398 m ²	16,376 m ²	57.67
31.	Gasholder Park, London	2013	Parks–Gardens	51°32'13" N 0°07'41" W	45 m	34 m	1590 m ²	927 m ²	58.30
32.	Navy Yard Central Green, Philadelphia	2015	Parks–Gardens	39°89'38" N 75°17'12" W	113 m	81 m	10,020 m ²	5192 m ²	51.82
33.	Apple Campus 2, Cupertino	2017	Circular Buildings	37°33'50" N 122°00'90" W	461 m	348 m	167,000 m ²	95,000 m ²	56.89
34.	Bird enclosure earthwork at Kickapoo river, Wisconsin	Pre-Columbian era	Earthworks	43°28'32" N 90°41'38" W	118 m	118 m	10,936 m ²	10,936 m ²	100
35.	Portsmouth Earthworks Group C, Kentucky	Pre-Columbian era	Earthworks	38°44'09" N 82°54'12" W	424 m	424 m	141,196 m ²	141,196 m ²	100
36.	Upper Midwest Circle City	contemporary	Parks–Gardens	43°04'00" N 89°24'00" W	500 km		187,753 km ²	km ²	

The prototype is the space in which the elements are concentrically arranged, with the BUA on the outside and the OS inside, or vice versa, to further include those objects where the space is broken into more or less parts (Figure 1), either concentric, radially or irregularly spaced. In such a case, the inner diameter is obtained by summing the surfaces of the individual OS (jam) and calculating the diameter as if the OS were a single circle. At the same time, the percentage of OS in relation to the total area is given. For each of the 36 objects, the surface is shown histogrammically in a logarithmic division table.

Figure 1. Reduction of complex Open Space (OS) shapes to a single surface to obtain inner diameter for morphospace analysis.

The OS and BUA surfaces are calculated via satellite images from Google Maps using the Photoshop analysis tool. Thirty-six doughnut objects containing a BUA and an OS were analyzed. In addition, other doughnut objects will be mentioned that were not considered because their dimensions could not be obtained, but were significant in the development of some ideas. These are usually descriptions or ideas, often philosophical ones, such as Daedalus' labyrinth, St. Anne's Garden, Civitas veri sive morvm, or the contemporary Circle Cities concept [13]. Within the individual categories, there were a large number of objects, so only the most representative ones were taken (Earthworks, for example). Objects from the Neolithic to the present day, with dimensions ranging from several hundred m² to

several hundred ha, have been analyzed. The relative ratios of the bases of the 35 circular objects, as well as the ratios of BUA and OS diameters, or morphospace diagrams, are shown in Figures 2 and 3. One circular object, Upper Midwest Circle City, was excluded as this was a good example of a Circle City idea. Histograms of the BUA and OS surface area relationships arranged chronologically are presented in Figure 4.

Figure 2. A “morphospace” of diagrammatic plans for circular objects studied (objects with a total diameter smaller than 300 m—23 objects): (a) Varro’s Aviary at Casinum, (b) GöbekliTepe, (c) Mycenaean Grave Circle B, (d) The Early Slavic pagan shrine in Peryn, (e) Teatro marittimo-Villa Hadriana, (f) Gasholder Park, London, (g) Large serdab Dar al-Khalifa, Samarra, (h) ErylouHua’an tuloi, Hua’an, Zhangzhou, Fujian, China, (i) Orto Botanico di Padova, (j) Mausoleum of Augustus in Rome, (k) Harman Fortified Church, (l) Clemenswerth Palace, Sögel, (m) Stonehenge, (n) Navy Yard Central Green, Philadelphia, (o) Earthwork at Kickapoo river, Wisconsin, (p) Brøndby Garden City, Copenhagen, (q) Studenica Monastery, Serbia, (r) Arkaim, (s) Maheshwari Udyan, Mumbai, (t) Tell al-Banat, (u) Bublik Circular House, Moscow, (v) Gartenverein zur Sonnenblume Kamp-Lintfort, (x) Parc d’Enghien.

Figure 3. A “morphospace” of diagrammatic plans for circular objects studied (objects with a total diameter bigger than 300 m—12 objects): **A**—Circleville, Ohio, **B**—Schwetzingen Palace, Schwetzingen, **C**—Kikar Hamedina, Tel Aviv, **D**—Queen Mary’s Gardens Regent’s Park, London, **E**—Şarlota (Charlottenburg), **F**—Portsmouth Earthworks Group C, Kentucky, **G**—Apple Campus 2, Cupertino, **H**—The Palace Garden Karlsruhe, **I**—Island garden of Cythera, **J**—Palmanova, **K**—Mari, **L**—Round city of Baghdad.

In Figure 4, which represents a historical timeline logarithmic histogram of OS and BUAs of selected circular objects analyzing two variables, historical timeline and Jam area, it could be concluded that there are many circular objects where open spaces have larger surface areas than BUAs.

All selected historical examples of circular objects (except Upper Midwest Circle City) were divided into two main categories: objects with a total diameter smaller than 300 m and objects with a total diameter larger than 300 m. Additionally, the selected circular objects were divided by their type of open space to better understand their spatial position. All the categories are presented in Table 2.

Figure 4. Historical timeline logarithmic histogram of OS and Built-Up Areas (BUAs) of objects analyzed.

Table 2 presents all selected circular objects for this research. For this research, 7 types of circular objects were analyzed: Parks–Gardens (12), Settlements (6), Earthworks (5), Sacral Objects (6), Circular Buildings (3), Allotments (2) and Plazas (2).

Parks–Gardens: Of the 36 circular objects analyzed, 12 belong to the category of green spaces, namely parks or gardens, which occur from ancient times to the present. The oldest object analyzed is Varro's Aviary at Casinum, which was built in 64 BC [14].

During the Renaissance, the idea of circular gardens generally remained unrealized and had a utopian character, such as The Cythera Island garden from the work of Hypnerotomachia Poliphili. One of the few realized gardens is the Orto Botanico di Padova [15].

2.2. Historical Analysis of the Circular Spaces

Historical analysis, as a method of the examination of different historical epochs, helps us to better understand the past of these circular objects and the timeline. The timeline is presented in Table 3.

2.2.1. Neolithic

According to some opinions, the oldest form of human land-use planning was the garden, a piece of ground fenced off from cattle [16], even preceding the construction of a hut, the beginning of architecture.

In the Americas, there are many traces of circular earthworks, e.g., medicine wheels; Portsmouth Earthworks in Kentucky; the enclosure near the Kickapoo River in Wisconsin [17]; sunken circular plazas from Peru, etc. These creations have been preserved much longer in the New World than in Europe and Asia because of the lifestyle of the indigenous Americans, which was much more tied to nature and did not change much until the arrival of Europeans. With the arrival of European colonizers and the successive urbanization, circular forms were gradually replaced by an orthogonal street layout and building blocks. A good example is the city of Circleville in Ohio. During the 19th century, the Circleville Squaring Company converted a circular earthwork of local native tribes at its center into a squared grid [18].

The Fujian tulou, traditional Fujian earthen buildings, are Chinese rural dwellings unique to south-eastern Fujian, China. One of them has been analyzed, namely the Erylou Hua'an tulou [19].

Table 2. The categories of circular objects studied.

Types of Circular Objects	Site Name	Dating
Objects with a Total Diameter Smaller than 300 m		
Parks–Gardens	Varro’s Aviary at Casinum (Tholos)	64 BC
	Maheshwari Udyan, Mumbai	contemporary
	Orto Botanico di Padova	1545
	Parc d’Enghien	1630–1665
	Clemenswerth Palace, Sögel	1737–1747
	Gasholder Park, London	2013
	Navy Yard Central Green, Philadelphia	2015
Settlements	Arkaim	2000–1600 BC
	ErylouHua’an tuloi, Hua’an, Zhangzhou, Fujian, China	1770
Earthworks	Stonehenge	3000–2000 BC
	Bird enclosure earthwork at Kickapoo river, Wisconsin	Pre-Columbian era
Sacral Objects	Tell al-Banat	859–892
	GöbekliTepe	10,000 BC
	Mycenean Grave Circle B	1700 BC
	Mausoleum of Augustus in Rome	31–28 BC
	The Early Slavic pagan shrine in Peryn	980–989
	Studenica Monastery, Serbia	1183–1186
	Harman Fortified Church	1240
Circular Buildings	Teatro marittimo-Villa Hadriana	118–138
	Bublik Circular House, Moscow	1972
Allotments	Brøndby Garden City, Copenhagen	1964
	Gartenverein zur Sonnenblume Kamp-Lintfort	contemporary
Plazas	Large serdab Dar al-Khalifa, Samarra	836
Objects with a Total Diameter Larger than 300 m		
Parks–Gardens	Schwetzingen Palace, Schwetzingen	1753–1770
	Queen Mary’s Gardens Regent’s Park, London	1930s
	The Palace Garden Karlsruhe	1731–1746
	Hypnerotomachia Poliphili, Island garden of Cythera	1499
Settlements	Şarlota (Charlottenburg)	1771
	Palmanova	1593
	Mari	2900–1759 BC
	Round city of Baghdad	766–7
Earthworks	Circleville, Ohio	1836
	Portsmouth Earthworks Group C, Kentucky	Pre-Columbian era
Sacral Objects	-	-
Circular Buildings	Apple Campus 2, Cupertino	2017
Allotments	-	-
Plazas	Kikar Hamedina, Tel Aviv	1970

Table 3. The timeline of selected circular objects studied.

	Dating	Site Name	Coordinates
1.	10,000 BC	GöbekliTepe	37°13'23" N 38°55'21" E
2.	3000–2000 BC	Stonehenge	51°10'44" N 01°49'34" W
3.	2900–1759 BC	Mari	34°55'04" N 40°88'91" E
4.	2000–1600 BC	Arkaim	52°38'57" N 59°34'17" E
5.	1700 BC	Mycenean Grave Circle B	37°43'51" N 22°45'23" E
6.	64 BC	Varro's Aviary at Casinum (Tholos)	41°29'24" N 13°48'50" E
7.	31–28 BC	Mausoleum of Augustus in Rome	41°54'22" N 12°28'35" E
8.	118–138	Teatro marittimo-Villa Hadriana	41°94'24" N 12°77'58" E
9.	766–7	Round city of Baghdad	33°34'88" N 44°33'53" E
10.	836	Large serdab Dar al-Khalifa, Samarra	34°23'05" N 43°87'40" E
11.	859–892	Tell al-Banat	34°44'76" N 43°80'48" E
12.	980–989	The Early Slavic pagan shrine in Peryn	58°47'28" N 31°27'36" E
13.	1183–1186	Studenica Monastery, Serbia	43°29'11" N 20°32'13" E
14.	1240	Harman Fortified Church	45°42'56" N 25°41'06" E
15.	1499	Hypnerotomachia PoliphiliIsland garden of Cythera	imagination
16.	1545	Orto Botanico di Padova	45°39'12" N 11°88'08" E
17.	1593	Palmanova	45°90'56" N 13°31'00" E
18.	1630–1665	Parc d'Enghien	50°68'76" N 04°04'73" E
19.	1731–1746	The Palace Garden Karlsruhe	49°01'38" N 08°40'44" E
20.	1737–1747	Clemenswerth Palace, Sögel	52°83'83" N 07°53'71" E
21.	1753–1770	Schwetzingen Palace, Schwetzingen	49°38'37" N 08°56'80" E
22.	1770	ErylouHua'an tuloi, Hua'an, Zhangzhou, Fujian, China	25°01'25" N 117°41'12" E
23.	1771	Šarlota (Charlottenburg)	45°97'86" N 21°51'91" E
24.	1836	Circleville, Ohio	39°35'58" N 82°56'40" W
25.	1930s	Queen Mary's Gardens Regent's Park, London	51°52'77" N 00°15'36" W
26.	1964	Brøndby Garden City, Copenhagen	55°38'13" N 12°23'58" E
27.	1970	Kikar Hamedina, Tel Aviv	32°05'12" N 34°47'23" E
28.	1972	Bublik Circular House, Moscow	55°42'26" N 37°28'16" E
29.	contemporary	Maheshwari Udyan, Mumbai	19°02'67" N 72°85'54" E
30.	contemporary	Gartenverein zur Sonnenblume Kamp-Lintfort	51°49'15" N 06°56'54" E
31.	contemporary	Upper Midwest Circle City	43°04'00" N 89°24'00" W
32.	2013	Gasholder Park, London	51°32'13" N 0°07'41" W
33.	2015	Navy Yard Central Green, Philadelphia	39°89'38" N 75°17'12" W
34.	2017	Apple Campus 2, Cupertino	37°33'50" N 122°00'90" W
35.	Pre-Columbian era	Bird enclosure earthwork at Kickapoo river, Wisconsin	43°28'32" N 90°41'38" W
36.	Pre-Columbian era	Portsmouth Earthworks Group C, Kentucky	38°44'09" N 82°54'12" W

2.2.2. Antiquity

The moment of transition from circle to polygonal shaped structures can be sought in the period when large settlements are formed—cities, and later states—through urban revolution [20]. The first cities were created in Mesopotamia in 3000 BC [21]. Edmund Burke notes that Man's dwellings are the most appropriate and solid when they are in a polygonal

form, and that the pieces fit together easily [22]. However, there are heterogeneous circular structures that can be found throughout the old ages.

In the southern Trans-Urals were a number of middle Bronze Age fortified settlements of the Sintashta-Arkaim culture. The sites are characterized by settlements with closed double fortification walls and two circles of houses, separated by a street and a central square free of buildings. The most significant remains of that kind include Sintashta, Arkaim, Bersuat, Isiney, Sarym-Sakly and Zhurumbay [23,24].

In ancient Greece, elements of a circle are encountered in the amphitheater. The orchestra's area measured about 25 m and was in a circular shape at the foot of a slope along which rows of seats were arranged in a semicircular manner [25].

This concept of the amphitheater has been altered, and traces of possible alterations can be found in the writings of Pliny the Elder. He describes the creation of C. Scribonius Curio from 53 or 52 BC. It consisted of two semicircular theatres that could rotate and form an arena. This amphitheater is the harbinger of later circuses, stadiums, arenas and hippodromes. It indicates the possible evolution of the Greek semicircular into the Roman circular amphitheater (Figure 5).

Figure 5. Hypothetical scheme of evolution of Old Greek amphitheater to Roman one and some exemplars of ancient and contemporary amphitheatres.

Varro's Aviary, built at Casinum by Marcus Terentius Varro, consists of two main parts, one square and one round. The round domed structure, the tholos, was surrounded with a colonnade. Its outer pillars were made of stone, and the inner ones of living trees; these were used for cages. A narrow stone path divides the colonnade from the round canal inside that held a variety of birds [26].

The only exception is the Mausoleum of Augustus in Rome within which the planting of trees on the peripheral part, that is, on the lower annular part of the roof, was carried out. The description in Strabo Geography is very illustrative: "The most noteworthy is what is called the Mausoleum, a great mound near the river on a lofty foundation of white marble, thickly covered with evergreen trees to the very summit. Now on top is a bronze image of Augustus Caesar; beneath the mound are the tombs of himself and his kinsmen and intimates; the wall which round his crematorium is surrounded by a circular iron fence and the space within the wall is planted with black poplars" [27–29].

At Hadrian's villa in Tivoli is the Teatro Marittimo circular island, accessed by two drawbridges. A circular wall of tuff and brick outside the canal forms, along with 40 ionic white marble columns, an internal portico, concentric with a wide and deep marble tiled channel [30].

2.2.3. Middle Ages

Since the collapse of the Roman Empire in 476, Roman style buildings and gardens in Europe became more decentralized, deurbanized and agrarian. Circular structures are rare because of the cramped space in cities, monasteries and castles. If they exist, they are simple and with plenty of BUA.

The Early Slavic pagan shrine in Peryn, south of Novgorod, an example of a primitive structure with a circular floor plan, belongs to the Early Medieval period. The sanctuary was surrounded by a ditch 1 m deep. The trench had 8 semicircular flower petals with a radius of 7 m. The petals were used for ritual fires (eternal flames), which is inferred from the findings of coal. In the center of the shrine was a statue of the god Perun [31].

The medieval Serbian Orthodox monastery of Studenica is surrounded by a circular stone wall with a temple in the center. The main entrance to the monastery is placed on the main east–west axis. The elliptical shape of the base occurs due to the slope along the north–south axis, making it a smaller axis of an ellipse, and proof of the incredibly accurate measurement of distance in the field [32].

In the absence of any archaeological remains of the Byzantine gardens, we cite the work of Theodore Hirtaken, a 14th century literatus, describing the garden of St Anna, the mother of the Virgin Mary, as a typical Byzantine garden, displaying his plan in a circle [33]. Hirtaken's description evokes a ring-shaped stone wall and several concentric circles of trees–choruses. The outer chorus was composed of cypresses, and several inner choruses of all kinds of fruit trees. In the center of the garden was a fountain with a pine cone in the middle.

Cvetković Tomašević (1973) describes a mosaic on the floor of the narthex of the Great Basilicain Heraclea Lyncestis (North Macedonia) from the early Byzantine period [34]. If the arrangement shown is seen as a radial cross-section of a circular garden, it does not fully fit with the earlier descriptions by which the “protective” trees are on the outer rings and edible fruits in the middle. What is common is the central decorative element, which here is a vessel with vines instead of a fountain, but surrounded by cypress trees. The next concentric circle, or chorus, consists of olive trees. The next chorus is apples and pears, and the periphery consists of cherries and figs, rather than cypresses as in the garden of St Anna. An outer circle then represents a “second periphery”, consisting of cedar and pomegranate (Figure 6).

Figure 6. Possible appearance of 3D Byzantine Garden reconstructed from mosaic in Heraclea Lyncestis.

2.2.4. Islamic Style

One of these circular projects was the Round City of Baghdad, similar to the much older city of Mara. The Circular City had four main gates, at equal distances from each other. The walls were made of adobe brick with a girder, while the domes and vaults were of baked brick [35]. The space between the outer and inner wall was occupied by houses and shops and divided into quadrants [36,37]. The space from the inner wall to the central buildings (palace, a mosque, residences for princes and offices) was a garden. Unlike Mari,

the zones of Baghdad are reversed, with green spaces separating the peripheral residential area from the palace and mosque in the center.

In Samarra, the city that was the capital of the Abbasid Caliphate from 836 to 892, Dar al-Khilafa, a palace complex, was erected. In the complex is an easily recognizable circular structure named the Large Serdab (or Birka Da'iriyya), a sunken basin without an OS and with subterranean chambers around it [38].

Two kilometers southeast of al-Dur there is a circular artificial mound, Tell al-Banat, standing 18.2 m above the surrounding plain. The canal of al-Mutawakkil circles the base of the mound. On the mound, a pavilion may have existed. Susa (1948–9) mentions the remains of bricks [39].

2.2.5. Renaissance

Leon Battista Alberti, one of the greatest contributors to Renaissance ideas on architecture, in his classic treatise *De re aedificatoria* (On the Art of Building), begins with the ideal form of the circle, which is expressed in numerous examples of nature. In Alberti's work *De Architectura*, he desires to see circles and semicircles, considered beautiful in villas, in the garden as well, and these he would have made with laurel, citron, and yew, with interwoven branches [40].

In Cortile del Belvedere, at the Vatican Palace in Rome finished by Pirro Ligorio in 1562–65, designer Bramante continued with Alberti's concept of the application of circles or, more precisely, semicircles as building and garden details. The exedra on the facade of the Villa Belvedere and the nicchione on the top are semicircular elements of the upper end of the court. On the opposite, southern, end was an amphitheater attached to the main palace and corresponding to the exedra and nicchione. With seats for spectators in the amphitheater, this lower part of the courtyard could be used for entertainment and performances (Figure 7).

Figure 7. Spherical and circular elements in Cortile del Belvedere (Belvedere Courtyard) at the Vatican Palace.

2.2.6. Baroque

Baroque style and compositional features are expressed through absolute symmetry, geometry, monumentality and central perspective. The geometry is dominated by a circle, a trapezoid or an ellipse, and the internal and external organization of the space interconnect one another [41].

2.2.7. Contemporary Era and Circle City Idea

Gartenverein Zur Sonnenblume, Kamp-Lintfort's garden society is composed of about 70 plots of land made available for individual, non-commercial gardening or for growing food in a community garden. The society advocates an ecological approach and propagates a natural kind of life through gardening and beekeeping. The space is divided into radially concentric parcels [42].

The designers of the Navy Yard Central Green Park are James Corner Field Operations. The circular segments, from the designers' vision, are original designs of nature. Central Green provides spaces for relaxation and escape and for exercise and recreation for 11,000 employees of companies of the 1200 acre Navy Yard community. The circular park division appears to have separate outdoor rooms that create a multi-purpose space. The uses include a fitness station, an amphitheater/"sun lawn", a hammock grove, bocce courts, ping-pong tables, a communal table, and a "bio-basin" for storm water. The vision is similar to Garden Cities [43]; to build a sense of a cohesive mixed-used village integrating jobs and residents. Here exists a transition from the dull cubicle working lifestyle to an urban oasis within a commercial zone that boasts a great quality of life.

Apple Campus 2, Cupertino was erected from an idea of Steve Jobs, the co-founder of Apple Inc., to consolidate his employees. He wanted to create a new campus in the suburb of Cupertino, California, where the border between nature and the circular building would be blurred. The total area of the complex is 71 ha, but for our investigations we have taken into account only the area of the circular building and the space inside it. There are 9000 trees on the Apple Park campus, with 309 varieties of indigenous species. Due to its circular shape and size, the Apple Campus has been nicknamed "the spaceship" [44].

Circle Cities is an idea by Philip H. Lewis Jr, the founder and director of the Madison Environmental Awareness Center (EAC), based on North America Night-time Satellite Imagery and Urban Partial Illumination (BUA) versus Dark Conserved Nature (OS). To connect the illuminated parts, Lewis used ring megalopolises that surround natural landscapes. One of the circular cities is the Upper Midwest Circle City ($43^{\circ}04'00''$ N, $89^{\circ}24'00''$ W), which is 500 km in diameter and covers an area of 187,753 km². The center of the circle is the Kickapoo Valley, WI within which the biodiversity is at its greatest, with the cities of Chicago, Milwaukee and Minneapolis located peripherally (Lewis, 1996). This trend should be maintained and urbanization within the "ring" of cities should not allowed. It connects US cities in a similar way with a methodology for guiding development in a manner that preserves and enhances natural diversity and quality of life for present and future generations (Figure 8) [45].

Figure 8. Circle Cities and Upper Midwest Circle City as idea of Philip H. Lewis.

3. Results and Discussion

The results of morphospace analysis are presented in Table 4. Analyzing all three chosen variables, categories and types of circular objects, Jam area and % of Jam and comparing these data with the historical timeline, we tried to explore if there is a ratio between OS and BUA and its historical interpretation. The morphospace analysis of this research indicates that there is no clear regularity in the relationship between the built-up area and the open space.

As we could see in Table 4, all circular objects are divided into two main categories: Objects with a Total Diameter Smaller than 300 m and Objects with a Total Diameter Larger than 300 m. These categories are made so all selected circular objects could be studied as potential examples for circular building designs for different ratios of urban environments (smaller cities and areas, and larger urban spaces—circular cities studies) [46].

All circular objects are also split according to the type of open space (seven types): Parks–Gardens, Settlements, Earthworks, Sacral Objects, Circular Buildings, Allotments and Plazas. It is important to represent the types of selected circular objects as there is a difference between parks, settlements and, for example, large circular buildings, which will be explained further in the text.

Table 4. The representation of three variables of morphospace analysis of selected circular objects. Gray color represents value of % of Jam below 50%, and green color—above 50%. All images are from free Wikimedia Commons media repository.

Types of Circular Objects	Site Name	Dating	% of Jam	
Objects with a Total Diameter Smaller than 300 m				
Parks–Gardens	Varro's Aviary at Casinum (Tholos)	64 BC	30.94	
	Maheshwari Udyan, Mumbai	contemporary	41.86
	Orto Botanico di Padova	1545	61.14
	Parc d'Enghien	1630–1665	50.042	
	Clemenswerth Palace, Sögel	1737–1747	70.71	
	Gasholder Park, London	2013	58.30
Settlements	Navy Yard Central Green, Philadelphia	2015	51.82	
	Arkaim	2000–1600 BC	18.32	
	ErylouHua'an tuloi, Hua'an, Zhangzhou, Fujian, China	1770	13.52	
Earthworks	Stonehenge	3000–2000 BC	98.46	
	Bird enclosure earthwork at Kickapoo river, Wisconsin	Pre-Columbian era	100	
	Tell al-Banat	859–892	100	

Table 4. Cont.

Types of Circular Objects	Site Name	Dating	% of Jam	
Sacral Objects	Göbekli Tepe	10,000 BC	46.79	
	Mycenean Grave Circle B	1700 BC	73.33	
	Mausoleum of Augustus in Rome	31–28 BC	71.61
	The Early Slavic pagan shrine in Peryn	980–989	100	
	Studenica Monastery, Serbia	1183–1186	62.74
	Harman Fortified Church	1240	46.65
Circular Buildings	Teatro marittimo-Villa Hadriana	118–138	61.131	
	Publik Circular House, Moscow	1972	74.15	
Allotments	Brøndby Garden City, Copenhagen	1964	68.93	
	Gartenverein zur Sonnenblume Kamp-Lintfort	contemporary	57.67	
Plazas	Large serdab Dar al-Khalifa, Samarra	836	0	
Objects with a Total Diameter Larger than 300 m				
Parks–Gardens	Schwetzingen Palace, Schwetzingen	1753–1770	38.96
	Queen Mary's Gardens Regent's Park, London	1930s	74.12
	The Palace Garden Karlsruhe	1731–1746	47.34	
	Hypnerotomachia Poliphili, Island garden of Cythera	1499	100	
	Şarlota (Charlottenburg)	1771	60.98	
	Palmanova	1593	53.24	
Settlements	Mari	2900–1759 BC	50.14	
	Round city of Baghdad	766–7	66.32

Table 4. Cont.

Types of Circular Objects	Site Name	Dating	% of Jam	
	Circleville, Ohio	1836	32.84	
Earthworks	Portsmouth Earthworks Group C, Kentucky	Pre-Columbian era	100
Sacral Objects	-	-	-	
Circular Buildings	Apple Campus 2, Cupertino	2017	56.89	
Allotments	-	-	-	
Plazas	Kikar Hamedina, Tel Aviv	1970	59.26	
Circle City				
Parks–Gardens	Upper Midwest Circle City	contemporary	/	

In the category of Parks and Gardens, the dimensions of these green spaces range from 223 m² for Varro's Aviary at Casinum to 1,724,114 m², the size of the imaginary island Garden of Cythera. The total area to OS ratio ranged from 31% for Varro's Aviary to 100% for the Garden of Cythera. In other gardens, the OS ranged from 39 to 74% (Table 1). The ratio of the total diameter to the inner diameter (morphospace) is smallest at Schwetzingen Palace with 62.42%, followed by Varro's Aviary with 64.28% and Karlsruhe with 68%; the inner diameters of Parc d'Enghien and Maheshwari Udyan represent 69% of the total diameter. For Navy Yard Central Green, Orto Botanico di Padova, and Gasholder Park, the ratio is 71 to 78%. The highest percentages were recorded at Clemenswerth Palace (84%), Queen Mary's Gardens (86%) and the Garden of Cythera, where the entire area is OS, so the overall diameter and inner diameter are the same.

In the category of Settlements, the total area to OS ratio ranges from 50% at Mari to 66% at the Round City of Baghdad, while the OS at Palmanova was 54%. The ratio of the total and inner diameters is 71% for Mari, 72% for Baghdad and 73% for Palmanova. Smaller settlements are included in the same category. This work covers three such spaces built from 2000–1600 BC to 1771. The first is Arkaim, the second is Şarlota, and the third fortified settlement is the ErylouHua'an tuloi. Settlement areas are significantly smaller than fortified cities, being 16,917 m² for Arkaim and 4231 m² for ErylouHua'an tulou, while Şarlota is much larger (136,639 m²).

The OS is significantly smaller in the fortified settlements of Arkaim and ErylouHua'an tuloi, at 18% and 14%, respectively, while in Şarlota the OS is 61%. Morphospace analysis indicates that the inner diameter is less with a fortified settlement (37% with ErylouHua'an tuloi and 42% with Arkaim) than with Şarlota (78%).

In the category of Earthworks, as a rule, the earthwork's OS is the only surface confirmed by Tell al-Banat, the Bird enclosure earthwork and Portsmouth Earthworks. With Stonehenge's OS, the 98% ratio is smaller for the surface on which stone monoliths lie. Circleville had a 100% OS before the settlement was established, and with urbanization in the 19th century the OS fell to 33%, and today it is certainly even smaller.

The morphospace analysis in this group indicates a specific diameter ratio, with total and inner diameter coinciding (100%) with pure earthworks, and varying from 56% in Circleville to 99% in Stonehenge.

In the category of Sacral Objects, the OS is relatively the largest in Peryn (100%), followed by the Mycenaean Grave Circle B (73%), the Mausoleum of Augustus (71%), Studenica (63%), and it is the lowest in Göbekli Tepe and Harman (47%).

The ratio of the total diameter to the metaphorical “jam diameter” is at Peryn (100%) followed by the Mycenaean Grave Circle B (85%), the Mausoleum of Augustus (84%), Studenica (73%), and Göbekli Tepe (70%), while the smallest OS is at Harman.

In the category of Circular Buildings, the OS is largest at Bublik with 74%, followed by the Teatro Marittimo (61%), with Apple Campus 2 having the smallest OS in the circular buildings category (57%).

In the category of Allotments, it is logical that in this type most of the space is occupied by the OS, but the part leading to the OS is not significantly different from the OS in other groups. The OS of Gartenverein zur Sonnenblume is 58% and it is 69% at Brøndby Garden City. The metaphorical “jam” diameters are 76% and 82%, respectively.

In the category of Plazas, two plazas were taken into consideration—Large Serdab in Samarra and Kikar Hamedina in Tel Aviv. Kikar Hamedina is a contemporary (1970) object with an area of 86,484 m² and an area to OS ratio of 59%, with 77% of the diameters belonging to the “jam”. Large Serdab is part of Dar al-Khalifa, erected in 836, in the time of Abbasid Samarra. Its area is 1962 m², without an OS.

In Table 4, for the purpose to represent some potentially good examples which have more than 50% of Jam area—open space of circular objects, we selected two colors: green color (for the % values higher than 50%) and gray color (for the % values lower than 50%).

Evaluating this value in Table 4, from 35 selected circular objects for this research (Circle City excluded), 25 circular objects have more than 50% of open space in both categories. The 10 circular objects have lower than 50% of open space in both categories, and in this analysis Upper Midwest Circle City was excluded because it was an example of the Circle City idea—large space area. This could show the potential of using circular objects as a city form in future urban development, as more than 50% of selected circular objects had more than 50% of open space.

Evaluation by chosen categories has shown a ratio in the category Objects with a Total Diameter Smaller than 300 m of 16:7, and in the category Objects with a Total Diameter Larger than 300 m of 9:3. In first category, we could also see that more than 50% of selected circular objects had values above 50% of open space and that seven objects had below values. In the second category, the ratio 9:3 shows the same conclusion.

The analysis according to type of open spaces was best presented in graphical representations below.

This research represents a study of the relationship of open spaces (OSs) and built-up areas (BUAs) through history. One thing that could be concluded is that the larger % of open space area could be achieved by using circular shapes—based on Figure 4, many selected circular objects have a ratio in favor of open spaces, and especially in “green” types of open spaces such as parks, gardens, earthworks and others. Other types of open spaces such as settlements, circular objects and plazas have around 50–65% of Jam area.

In the context of sustainable design, the main value in this research was the % of Jam. The reason for that is that this chosen value represents the % of open space in selected circular objects. The % of Jam of all circular objects divided into two main categories is presented in Figures 9 and 10. In these graphical representations, we could see that two types of open spaces in both categories had high values of % of Jam: Parks and Gardens and Earthworks. The lower values had types of spaces such as Settlements, Allotments and Plazas. In these graphical presentations, high values of % of Jam had selected circular objects in the type Sacral Objects, which could be an interesting observation, and which could confirm the possibility of using circular building forms as new urban forms for sustainable urban development.

The high % of open spaces in urban environments represents one of the sustainable strategies towards sustainable urban living, as the increase in this value has many positive outcomes to especially environmental aspects of urban environment [47–49]. There are many sustainable performances that different buildings in urban environments have to ensure, such as sustainable energy sources, water management, waste management and sustainable materials used, and for other aspects: health and safety, circular economy

and other performances [50–53]. For the purpose of this research and in the aspect of exploring circular designs as possible sustainable urban forms which could possible ensure the increase in porous spaces in urban environments, the value % of Jam explored in this research was important. The increase in porous spaces in cities has, for example, big significance for urban ventilation, air quality, soil quality and others. Additionally, social benefits are also important, in the form of recreational spaces, parks, urban gardening and many others. The increased % of porous spaces in cities is one of the most important sustainable strategies in the climate change adaptation of cities [54–57].

Proof of using circular design through history could be clearer if these three objects, Bramante's tempietto, The Radcliff Camera and Sanaa's 21st Century Museum of Contemporary Art, currently not included in this research, are subjects of our future interest since they are obvious examples of using circular design in different periods and places.

Figure 9. The graphical representation of selected circular objects with a total diameter smaller than 300 m.

Figure 10. The graphical representation of selected circular objects with a total diameter larger than 300 m.

The future circular design process could bring more stability, and the ratio between OS and BUA could be more balanced [58].

The new role of the architects as well as landscape architects could be the main actor for driving circular design by linking innovative production to circular economy principles [59].

Sustainability indicators such as environmental, socio-cultural, economic, and institutional indicators for urban development should include more parameters related to green open spaces, not only historical ones [60] but also circular design.

This study analyzes a number of historical circular objects with the aim of creating sustainable urban environments as a key ingredient for cities living sustainability.

4. Conclusions

The morphospace method makes it possible to strategically look at the range of possibilities for realizing circular space plans and the share of the built-up area (BUA) and open space (OS) within it. Of the 36 existing circular spaces analyzed, variants occur from those for which the entire space goes to BUA to those for which only an OS exists. This covers the full range of possible variants of the OS/BUA ratio, that is, the limit of analysis. From the perspective of certain categories of circular objects, no regularity can be observed in these relationships, with the exception of earthworks, where the proportion of OS is above 90%. The largest variations in the relationship are in parks and gardens, where the OS ranges from 30–100%. There are no regularities in the OS/BUA relationships over a long period of time from the Neolithic to the modern era, and it cannot be said that the percentage of OS increases or decreases. The same can be said about the size of circular objects.

As circular design and processes continue to have a main role in many sustainable strategies, the idea of circular cities as a future urban model will be more popular. An important part of every urban environment is open spaces in all their types, especially green spaces. The need for increasing the number of urban greenery and spaces is present in all cities around the world.

As there is a trend of increasing open spaces in city plans around the world and providing more spaces and ways of integrating urban greenery is one of the sustainable goals, this research could be used as a base for further research on circular forms and shapes. Many selected circular objects have a ratio in favor of open spaces through the history timeline, which is shown by this research, so the circular/doughnut shape could be a future reinvented pattern for urban development. Additionally, the observed occurrence of the disappearance of circular forms with urbanization, which is evident as a result of the space deficit and the difficulty in fitting circular forms together with one another or with other forms, cannot be fully accepted. The circular form will move to different levels, such as the mega spaces of Circle Cities. In addition, exploration beyond planet Earth and the conquering of outer space again gives room for circular shapes, and they are also inevitable as the only possibility for producing artificial gravity by their rotation and the influence.

Little is known about the benefits of circular designed spaces despite our understanding of the benefits of urban green spaces. The research results shown here highlighted the importance of circle design use with regard to citizens' well-being by environmental sustainability. A key component of sustainability is urban circular spaces providing optimal psychological and social benefits by raising citizens' quality of life.

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Abbreviations

BUA	Built-Up Area
OS	Open Space

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