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RESILIENCE STRENGTHENING OF CULTURAL HERITAGE OBJECTS TO CLIMATE CHANGES IN MODERN CITY CENTERS BY MEANS OF LANDSCAPE ARCHITECTURE

The article is focused on the issue of climate change mitigation and strin Englishthening the sustainability of cultural heritage objects, taking into account the specifics of the landscape organization of buffer zones, which perform not only the function of their protection in the middle of modern cities, but also function as public spaces. The purpose of the article is to identify threats to climate change for cultural heritage objects and to justify the effectiveness of methods of landscape organization of their buffer zones in order to strin Englishthen the stability of these objects. The article uses a systematic approach, methods of generalization and analogies, empirical and comparative analysis. The research revealed the specifics of the functioning of the "active surface" of the city and its non-urban territories, which is caused by the "two-phase mechanism" of the formation of "urban heat islands" (the direction of heat flows depends on the location of underlying surfaces in space with the contrast of temperatures and time of day - morning/afternoon or evening/night). The results of research on remote sensing of the Earth's surface and satellite monitoring of the thermal environment of cities have been systematized and summarized; factors and conditions for the emergence of "urban heat islands" over cities in temperate zones (Birmingham, Brno, Budapest, Bucharest, Warsaw, Kyiv, Prague) and "urban cool islands" over cities in zones with hot and arid climates (Abu Dhabi, Acre, El Kuwait, Cairo, Casablanca, Singapore, Shanghai). The results of studies of the "thermal behavior" of urban surfaces indicate that the formation of "cool oases" in the summer is caused by the prolonged shading of "urban canyons" in the desert and the cooling effect of the urban (due to shading, landscaping and watering of the territory) and natural breeze in the coastal zone. By analogy with the formation of oases of coolness in the desert, landscape means of strin Englishthening the climate change resistance of cultural heritage sites (as well as public spaces) during the summer overheating of modern cities, there may be additional "mobile" and "stationary" landscaping and watering of urban surfaces, such as "Flower

carpets of Brussels," sometimes even with fountains; "blue-green" roofs of Amsterdam, "The Vertical Garden" of Paris and Madrid, "green facades" of Kyiv. The practical value of the study is the ability to take into account its results when developing scientifically sound adaptive-regulatory programs to mitigate the effects of climate change and enhance the sustainability of cultural heritage sites.

Keywords: global warming; objects of cultural heritage; urban heat islands; public spaces; gardening; watering; landscape architecture; sustainable development.

Problem statement. Climate Action is one of the greatest threats to humanity for the next century. All cities suffer tremendously because of the increase in the surface temperature of the Planet. Extreme global warming events, in particular, heat waves with an increase in the number of hot days and nights during the summer overheating of cities, will increase heat stress [1, 2].

This stress has been caused by the peculiarities of interaction of urbanized areas with the Earth's climate system. All this is detected by the observed tendency to increase the temperature of the urban surface, which forms the so-called "urban heat islands" in the city areas, as well as an increase in the average and extreme rainfall over the city, especially in the afternoon and early evening [1].

Climate change negatively affects the physical and mental health of people, most of whom today live in cities [3, 4, 5]. In particular, this was discussed at the World Climate Summit 2023, the Declaration of which focuses on the relationship between climate change, health and human well-being; on the need to prioritize sustainability, mitigation and adaptation of humanity to climate change; on the maintenance of mental health and psychosocial well-being of a person, which is associated with the traditional and cultural environment of his being [6].

Global warming is one of the greatest threats both to the world heritage [7] and to the extraction of armed conflicts and wars [8]. Understanding the consequences of climate change and the associated risks of loss of authenticity and integrity of world heritage sites (cultural and natural), which are part of the social and environmental processes of development of communities and territories, actualizes the need to protect the universal values of mankind with the support of society [7].

This actualizes the urgent need to integrate interdisciplinary approaches that take into account the direct, indirect and cumulative impacts of climate change on the lives of human communities and world heritage in order to develop scientifically sound adaptive-regulatory programs for the sustainable development of mankind and the preservation of the cultural heritage of civilization [9].

State of the art and conceptual framework. The achievement of conditions for sustainable development has acquired signs of the main reference point of the humanitarian activity of the international community after the UN "Stockholm Conference" (1972) [10, 11]. Sustainable development is today the organizational principle that guides the discourse on the achievement of Global Goals, including policy on "Strin Englishthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries" (Goal 13.1); "… awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning" (Goal 13.3) [9, 12].

As for World Heritage sites, the legal aspects of its protection are registered in the international "Convention Concerning the Protection of the World Cultural and Natural Heritage," which was adopted in 1972, in the year which became fundamental for sustainable development of mankind [13]. In modern international law, the legal protection of World Heritage sites in city area should provide: "a buffer zone is an area surrounding the nominated property which has complementary legal and/or custom restrictions placed on its use and development to give an added layer of protection to the property" [14].

But legal laws are powerless before the action of the fundamental laws of the development of nature. As far as we know, there are no exceptions to these laws and any natural or artificial system that does not obey these laws is doomed [15, 16]. That is why the 2021 United Nations Climate Conference produced the Intergovernmental Panel on Climate Change Report: "Climate Change 2021: The Physical Science Basis" [17]. This report deals with the latest physical understanding of the climate system and the mechanisms of climate change, by combining the latest advances in climate science, abundant evidence of paleoclimate, modern observations and modeling of global climate. The report, as of 2021, assesses climate change and risks to humanity for the coming century. Particular attention was paid to cities, which are called "hot spots of global warming" [18].

All facts mentioned above encouraged scientists to conduct large-scale studies of this phenomenon all over the world [19 – 28]. Officially, these "hot spots," or the temperature effect of the city, have been investigated since the beginning of the 19th century: «The climate of London: Deduced from meteorological observations, made at different places in the neighborhood of the metropolis» (1818) [29, 30]. Today, the Urban Heat Island (UHI) is one of the most documented phenomena in urban climatology [22]. This effect refers to the modified thermal climate in urbanized areas, compared to nearby rural ones. He is an example of micro- and mesoscale anthropogenic climate change, which is usually caused by differences in the heat capacity of urban and non-urban surfaces [23].

As usual two types of "heat islands" are distinguished. The first one is the atmospheric type of urban heat island (UHI), which is investigated and evaluated using ground-based observations and meteorological network data (air temperature, humidity, wind speed and direction) [22, 23, 31]. The second type is the Surface Urban Heat Island (SUHI), which has been studied and evaluated since the emergence of remote sensing technology of Land Surface Temperature (LST) from space and air platforms [23, 24, 25, 27].

The Climate Change 2021 Report predicted an acceleration in the rate of warming. This will lead over the coming decades to the lin Englishthening of warm seasons and the intensification of heat waves, in which extreme indicators will often reach critical tolerance thresholds for human health, and in different regions of the world there will be changes in humidity and dry air; increased winds, hurricanes and rainfall, as well as associated drought and flooding [1, 17, 18].

The forecast for 2021 has already been confirmed by the Report of the World Meteorological Organization to the UNO Climate Conference in 2023, according to which on all continents "2023 shatters climate records, with major impacts". This is about unprecedented tropical cyclones, floods, heat and drought, as well as forest fires. For example, the summer heat of 2023 in Italy reached 48.2 ° C; and the Canadian wildfire season exceeded any of the previously recorded: the area of burned hectares of forest of 18.5 million hectares was six times higher than the corresponding average for the previous 10 years (2013-2022) [32].

Regarding the issue of heritage protection, “The Policy Document on Climate Action for World Heritage” (2023) [7]. stated that it requires the development of a wide range of mitigation and adaptation options for climate change, as well as a significant increase in investment. The guidelines of this "Strategic Document" indicate that risks depend on the magnitude and speed of warming, the location of the heritage site in space, the level of adaptive capabilities, as well as on "uncertainty (lack of full scientific certainty)," which "should not be used as a reason for delaying action to solve problems and minimize risks..." [7, p.21].

A significant number of objects of Cultural Heritage is located in cities, that is, in the zones of influence of "thermal islands." Therefore, the results of studies that focus on the factors and conditions of the emergence of the "urban heat island"; means for determining its location in space and the dynamics of change; the potential hazards of having and being associated with land use features in a city are crucially important for solving the problems of "uncertainty" and "risk minimization."

The purpose of the study. The purpose of this study is to identify the threats of climate change to cultural heritage sites in the center of modern cities and justify the effectiveness of methods of landscape organization of their buffer zones in order

to strin Englishthen the stability of these objects, as well as adaptation to climate change and mitigate the effects of the "urban heat island" on public spaces.

Summary of the main material. So far, there are no studies that are devoted to landscape methods of mitigation and strin Englishthening the stability of cultural heritage objects, taking into account the specifics of the organization of their buffer zones in the face of climate change. And this is despite the fact that buffer zones in the center of modern cities perform not only the function of protecting World Cultural Heritage sites, but also function as public spaces.

The article is based on a study by I. Ustinova & A. Matsokha (2024), which was held for the UNESCO cultural heritage site under No. 527 "Kyiv: Saint-Sophia Cathedral and Related Monastic Buildings, Kyiv-Pechersk Lavra" (was constructed in the 11th century, year listed in the 1990) (was constructed in the 11th century, year listed in the 1990) [33]. To understand the peculiarities and "isolate the mechanism" of interaction of urbanized areas with the Earth's climate system, the given research relied on a wide range of in English-language scientific literature [19 – 28]. The authors systematized and summarized the results of world scientific research to determine the factors and conditions for the formation of "urban heat islands" in temperate zones in the cities of Birmingham [22]; Brno and Prague [26]; Budapest, Bucharest and Warsaw [27]; as well as "urban cool islands" which are formed in areas with a hot and arid climate, according to the results of research for cities of Abu Dhabi [21]; Acre [20]; Kuwait and Cairo [25]; Casablanca [24]; Singapore [19] and Shanghai [28].

The means of "early warning of consequences" and visualization of climate change threats for our research were the results of satellite monitoring of urban heat islands of Kyiv, which was conducted by the "Scientific Center for Aerospace Research of the Earth of the Institute of Geological Sciences of the National Academy of Sciences of Ukraine" in the period from 1985 to 2016 [34, 35]. Initial data for observations for the “The scientific center” " have been the materials of space surveys in the thermal channel, which were obtained from satellites of the Landsat series during the period of maximum annual temperatures: late July – early August (Fig. 1), weather information for survey periods (Table 1).

The methodology for studying the surface temperature of the urban environment, the "Scientific Center for Aerospace Research" of the National Academy of Sciences of Ukraine, was based on their own technology for calculating the temperature of the underlying surface according to the thermal range (10.40-12.5 microns) of the Landsat TM, ETM, TIRS satellites with the assessment of the coefficient of thermal radiation according to the normalized vegetation index (NDVR I) and methods for analyzing multi-hour series of space data. Space images were

obtained from the open archive of the US Geological Survey (www.earthexplorer.usgs.gov) [34, 35].

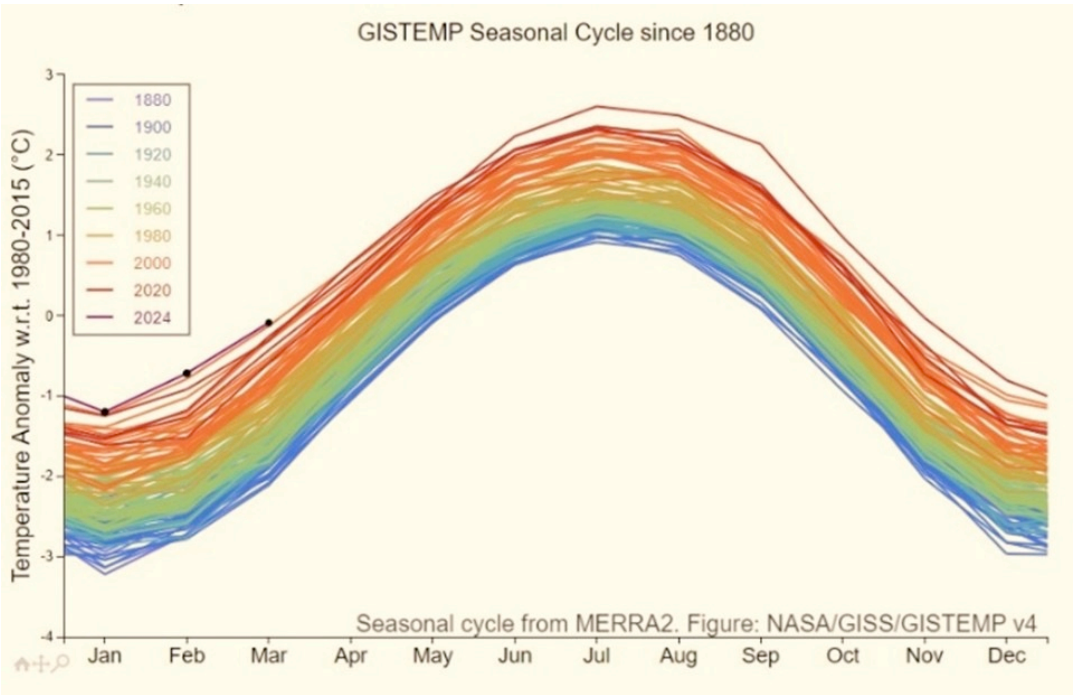


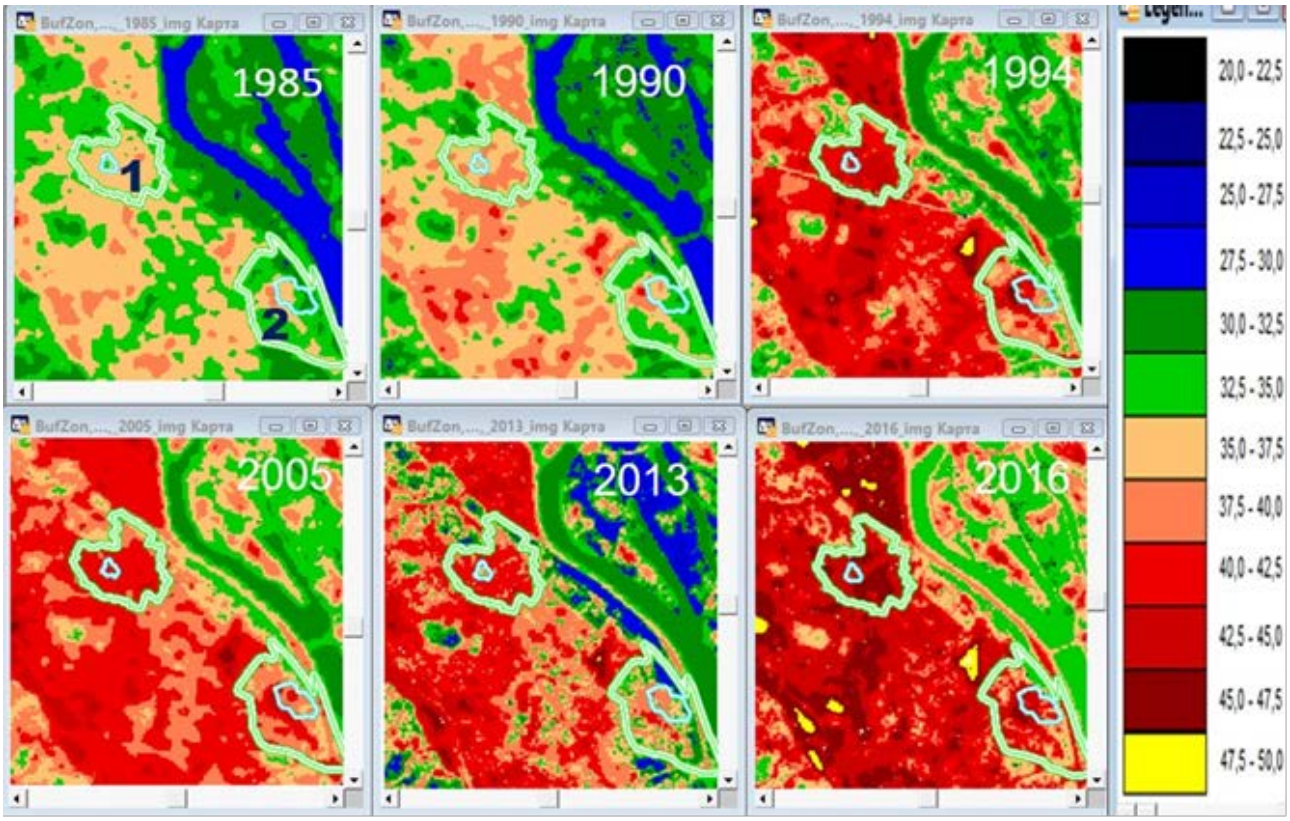
Figure 1. Seasonal cycles of change in average annual temperatures between 1880 and 2023 (data show how much warmer each month of GISTEMP data is for the annual global

Table 1. Land surface temperatures (LST) and air temperature (AirT) during the period of maximum annual temperatures from 1985 to 2016 [35].

Date	Temperature (T°C)		
	Land Surface Temperatures (LST)		Air Temperature (AirT)
	min.	max.	
25.08.1985	28,4	41,6	29,2
06.07.1990	26,4	42,5	29,9
17.07.1994	28,9	50,1	30,8
31.07.2005	29,6	46,6	30,7
06.08.2013	25,2	47,6	25,7
29.07.2016	30,5	50,5	31,2

The research is also based on full-scale and cameral investigations of the authors, the main methods of whom were field surveys and photographing. The research also took into account the generalization and systematization made by another scientists. As auxiliary materials, the authors used information from official Internet resources, in particular, sites: UN; UNESCO, RESILIO, Flowercarpet and others. The preliminary results of the study were tested by two at international

conferences [36, 37]. Analysis of heat maps of the city center of Kyiv for more than 30 years records a steady increase in the temperature of the underlying surface of the city in the areas of buffer zones and the location of cultural heritage objects: Saint-



Sophia Cathedral (1037), Kyiv Pechersk Lavra (1051) and the Church of the Savior on Berestov, next to the Lavra (1113) (Fig. 2) [35].

Figure 2. Dynamics of changes in the surface area of maximum heating in the buffer zones of the UNESCO cultural heritage object under No. 527 from 1985 to 2016: 1) Kyiv: Saint-Sophia Cathedral and Related Monastic Buildings; 2) Kyiv-Pechersk Lavra [35].

Statistical data on the dynamics of changes in the area of maximum heating in the buffer zones of Saint-Sophia Cathedral and Kyiv Pechersk Lavra from 1987 to 2014 (Table 2) [34] highlight the interaction between temperature and the earth's cover, as well as the inversion of the phenomenon of urban thermal islands, which is characteristic of cities in desert regions of the world [21, 24, 25].

Table 2.

Dynamics of changes in the surface area of maximum heating in the buffer zones of objects of cultural heritage of Kyiv in the period from 1987 to 2014 [34].

Dates	Area of maximum heating (Km^2)	
	Sofia of Kyiv	Kyiv Pechersk Lavra

1987	0,100	0,078
1992	0,125	0,057
2014	1,270	0,075

Table 2 data show that the area of maximum surface heating within the buffer zone of Sofia Kyivska has increased more than 10 times, and within the buffer zone of "Kyiv-Pechersk Lavra," on the contrary, has slightly decreased. The increase in the surface of maximum heating within the buffer zone " Sofia Kyivska" is due to the increase over the years in the number of multi-storey new buildings and the corresponding decrease in green areas, including the replacement of green lawns on Sofia and Mikhailovsky squares with artificial paving (clinker brick) (Fig. 3).

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Figure 3. Surfaces of maximum heating within the buffer zone " Sofia Kyivska": solid paving of Sofia Square (A); Mikhailivska Square (B) *(photos taken by A. Matsokha (2024))*

Reducing the surface area of maximum heating in the buffer zone of the Kyiv Pechersk Lavra (see Table 2), under conditions of general temperature increase (see Fig. 1, Table 1), can be explained by the relatively small number of new buildings and proximity to the river. Dnipro (the longest river in Ukraine and the fourth longest in Europe) with a large park area along it (see Fig. 2). Results of thermal field assessment "Kyiv: Saint-Sophia Cathedral and Related Monastic Buildings, Kyiv-Pechersk Lavra" and the dynamics of its changes over the period from 1985 to 2016, allow us to conclude that the presence and preservation of significant areas of flooded and green areas, the protection and increase of vegetation, including by means of "green roof" and "green wall," becomes not only an urgent task of forming a comfortable environment of public spaces of the modern city, but also a means of preserving cultural heritage [36, 37].

It should be noted that in our case, the means of preserving a significant area of green areas was the unification in 2020 of two territorially separated buffer zones into a single cultural heritage object with an increase in their joint buffer zone by more than 100 hectares for the sake of species disclosure of the object from the most significant points of visual perception of the panorama of Kyiv from the right bank of the Dnipro (Fig.4).

You can ask if the landscape organization of buffer zones an effective means of protecting cultural heritage in the face of climate change. In our case, the means of solving this "uncertainty" to minimize the risks of "action deposition" in the context of global climate change became the author's generalizations of the results of studies conducted using remote sensing methods of the Earth's surface in different countries of the world.

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Figure 4**.** The boundaries of the buffer zone of the UNESCO cultural heritage object under No. 527: spatially separated (A) *(processed by A. Matsokha for according to Management plan (2014)*; united in 2020 (B) [38];

Regarding factors whose synergy causes the emergence of an urban heat island. It can be noted that they are: human life (working household and industrial ventilation and air conditioning systems; vehicles; industry) [22, 26]; densification of buildings (proximity and height of buildings and structures), which leads to a decrease in the airing of urban space, as well as high heat-absorbing properties of building materials and underlying surfaces with low albedo (dark stone, brick or concrete buildings and structures; asphalt roads, squares, sidewalks; metal and bitumen roofs) [19, 28, 31]; features of land use, lack of vegetation and water bodies [24, 25, 27]. The joint action of these factors is also illustrated by the results of

studies of the surface of maximum heating in the center of Kyiv (see Fig. 2; Table 1, 2) [34, 35].

Regarding the "mechanism" of the formation of the thermal island. It can be noted that this effect is due to the "two-phase" functioning of the "active surface" of the city, which absorbs a large amount of short-wave solar radiation in the morning/afternoon, and slowly gives it to the urban space in the form of long-wave thermal radiation in the evening/night [25, 27, 28]. All mentioned above causes a slower decrease in night temperatures in modern cities than in non-urban territories, which leads to an almost round-the-clock heat load during the summer overheating of modern cities. Studies of the thermal field of Kyiv show that this happens against a background of more than 1.5 times higher maximum temperatures of daytime heating of the underlying surface than heating of air in cities (see Table 1) [35].

Thermal anisotropy (temperature contrast) in heterogeneous landscapes (see Fig. 2) also illustrate the results of studies of the effect of urban thermal islands of Budapest, Bucharest and Warsaw. So, on the graphs (Fig. 5) the "thermal radiation" of urban and arable surfaces differ markedly, while thermal measurements of water bodies are almost twice lower than them [27].

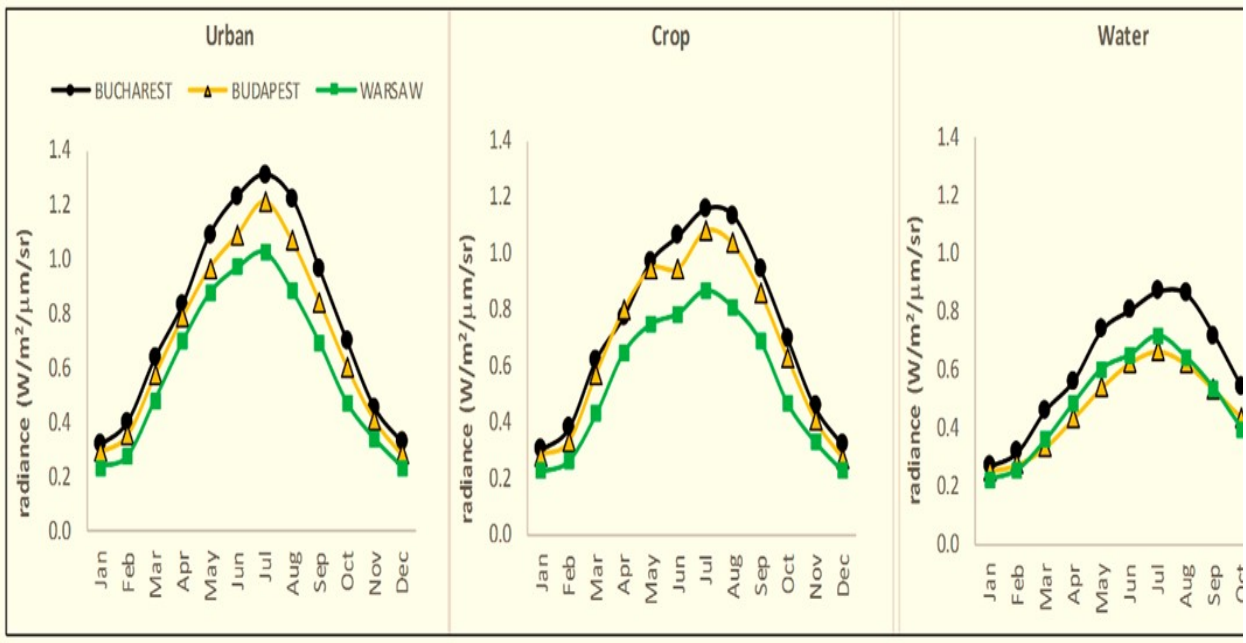

Figure 5. Average monthly radiation the Middle Infrared (MIR) of urban, arable and water surfaces in cities of Budapest, Warsaw [27].

All mentioned above is confirmed by satellite data on the "local climatic zones" of Brno and Prague. According to which, in almost 90% of the tests, the warmest were industrial zones and dense buildings, and the coldest were ponds and areas with densely planted trees [26]. The fact of the contrast of surface temperatures

with the formation of "cool islands" around woodlands and reservoirs has been found for Singapore [19] and Shanghai [28].

The cooling effect of vegetation and water surfaces on urban heat was found in almost all studies. But there is a specificity of the thermal behavior of urban surfaces in different climatic zones of the Earth. For example, in cities located in temperate climatic zones, the surface urban heat island (SUHI) is warmer during the day than outside the country (Birmingham [22], Brno, Prague [26], Budapest, Bucharest and Warsaw [27], Kyiv [34, 35]; and in cities located in areas with hot and arid climates, by contrast, SUHI is colder during the day than the non-urban territories (Abu Dhabi [21], Acre [20], Kuwait and Cairo [25], Casablanca [24], Singapore [19], Shanghai [28].

This specificity is due to the already mentioned mechanism for the formation of an urban heat island, according to which the direction of heat flows in space depends on the time of day: morning/afternoon or evening/night; and from the location of surfaces with the contrast of temperatures in space (thermal anisotropy). The space-temporal variations of SUHI, with the advent of the "urban cool island" in cities with hot and arid climates during the day, are due to the prolonged shading of the "urban canyons," landscaping, watering, and cooling effect of the sea breeze as established for Abu Dhabi [21]; Kuwait and Cairo 25; Casablanca [24]; Singapore [19].

All mentioned above due to oase effect (from French oasis "fertile spot in a desert, where there is a spring or well and more or less vegetation", but originally from Coptic oasis is properly "dwelling place"… [40]. So, by analogy with the emergence of an "oasis of coolness" among the desert, the experience of "mobile" and "stationary" gardening, watering and shading of urban surfaces can become a means of strin Englishthening the climate change resistance of cultural heritage objects.

Regarding the protection of "Kyiv: Saint-Sophia Cathedral and Related Monastic Buildings," within the buffer zone of which the area of maximum surface heating has significantly increased (see Fig. 2, Table 2), which can contribute to the intensification of the processes of physical weathering, corrosion of metals and the acceleration of the destruction of buildings and structures [35]. To cool the underlying surface of Sophia Square, which directly approaches the walls of Saint - Sophia Cathedral by continuous paving (Fig. 3. a), the experience of the "Flower Carpets of Brussels" (Fig. 6).

These carpets, sometimes even with fountains (2010), appear every two years on the central historical square of the capital of Belgium (UNESCO Cultural Heritage Site No. 857 "La Grand-Place, Brussels") [41].

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Figure 6. Floral carpet of Brussels, "temporary landscaping of the cultural heritage site" La Grand-Place, Brussels, "examples: 2008 (A); 2010 years (B) [41].

Effective means of landscape organization of multi-level urban space, in conditions of lack of greening of the city center, can be innovative methods of "blue-green" roofs of Amsterdam (Fig. 7) [42].

Figure 7. Smart Blue-Green Roofs (project RESILIO), Amsterdam, Netherlands [42].

The experience of "green" facades from the French botanist and designer Patrick Blanc, who invented and patented a modern vertical hydroponic garden, can also be useful. Examples of The Vertical Garden by Patrick Blanc are L'Oasis d'Aboukir on the wall of a residential building in Paris and CaixaForum, which is part of the UNESCO Cultural Heritage Site No. 1618bis "Paseo del Prado and Buen Retiro, a landscape of Arts and Sciences" (Fig. 8) [43, 44].

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Figure 8. The Vertical Garden from Patrick Blanc: L'Oasis d'Aboukir in Paris (A); 2) CaixaForum in Madrid (B) [42].

It should be noted that similar "green" facades exist today in Kyiv (Fig. 9).

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Figure 9. “Green” facade of Vichy grapes on Andriyivsky Uzvizin the historical part of Kyiv: autumn (A); spring (B) *(photos taken by A. Matsokha (2023, 2024))*

In summary, it is worth noting that in our time, world heritage sites suffer not only from global climate change, but also from the fact that they become "the main target in recent wars" [45]. Therefore, UNESCO, in cooperation with the international organization "Blue Shield," contribute to the protection of cultural property through the creation of the "World Heritage List under threat". In 2023, this list also included World Heritage sites of Ukraine, such as: " Kyiv: Saint-Sophia Cathedral and Related Monastic Buildings, Kyiv-Pechersk Lavra", " L'viv – the Ensemble of the Historic Centre" and " The Historic Centre of Odesa" [44]. And here, by analogy with the mission of the "Blue Shield," which was conceived as the "cultural equivalent of the Red Cross," in order to protect against air attacks on World

Heritage sites in the event of armed conflicts, methods of protecting cultural heritage objects by means of landscape architecture (landscaping, watering and shading the active surface of the city) in the face of global climate change, may be called the "Green Shield" methods [36, 37].

Conclusions and Prospects for the Study. Global warming, with the exception of armed conflicts and wars, is today and for the next century the greatest threat to humanity and the preservation of cultural heritage sites. This fact actualizes the need to integrate interdisciplinary approaches to the development of scientifically sound adaptive-regulatory programs to mitigate the effects of climate change and strin Englishthen the sustainability of cultural heritage sites. Of special attention here are cities, which in the UN Report "Climate Change 2021" have been called "hot spots of global warming" due to the fact that "urban heat islands" are formed above them, since more than half of the world's population lives in them and cultural heritage sites are located.

Understanding the "fluctuation physics" of the Earth's climate system, as well as the conditions, factors and mechanisms for the formation of urban heat islands, became possible due to the combination of achievements in the field of climate science, remote sensing technologies of the Earth's surface and satellite monitoring of urban heat islands. This is a means of early warning of the consequences and visualization of the threats of climate change to UNESCO cultural heritage sites, in our case, according to No. 527, "Kyiv: Saint-Sophia Cathedral and Related Monastic Buildings, Kyiv-Pechersk Lavra." In particular, the analysis of maps of satellite monitoring of urban heat islands in the middle of Kyiv for more than 30 years revealed a steady increase in the temperature of the underlying surface in the buffer zones of this cultural heritage object.

The author's generalization of the results of remote sensing of the Earth's surface identifies a characteristic inversion of the thermal behavior of urban surfaces in different climatic zones of the Earth. In particular, in temperate climatic zones over cities during the day, urban "heat islands" arise, since non-urban territories are usually greener (shaded) and watered. Conversely, in areas with hot and arid climates, urban "cool islands" appear over cities during the day, since non-urban territories are usually deserts, and shaded, green and watered (pools and fountains) are "oases of urban canyons."

Proving the fact of the cooling effect on the urban climate of green and water surfaces, even with the appearance of coolness in cities with a hot and arid climate of urban islands during the day, allows us to assert that the landscape organization of buffer zones of cultural heritage objects (as well as public spaces of cities) can be an effective means of protecting, strin Englishthening stability and mitigating the effects

of high temperatures in the conditions of summer overheating of modern cities. By analogy with the emergence of an oasis of coolness among the desert, a means of strin Englishthening the climate change resistance of cultural heritage objects can be the use of world experience in landscaping, watering and shading urban surfaces. The methods of protecting cultural heritage objects by means of landscape architecture in conditions of global climate change, by analogy with the mission of the "Blue Shield," should be called the "Green Shield" methods.

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ПОСИЛЕННЯ СТІЙКОСТІ ДО ЗМІН КЛІМАТУ ОБ'ЄКТІВ КУЛЬТУРНОЇ СПАДЩИНИ В СЕРЕДМІСТІ СУЧАСНИХ МІСТ ЗАСОБАМИ ЛАНДШАФТНОЇ АРХІТЕКТУРИ

Дослідження актуалізує питання пом'якшення наслідків змін клімату та посилення стійкості об'єктів культурної спадщини з урахуванням специфіки ландшафтної організації буферних зон, які виконують не лише функцію їх охорони в середмісті сучасних міст, а й функціонують як громадські простори. Метою дослідження є виявлення загроз змін клімату для об'єктів культурної спадщини та обґрунтування ефективності методів ландшафтної організації їх буферних зон заради посилення стійкості цих об'єктів. У дослідженні використано системний підхід, методи узагальнення та аналогій, емпіричного та порівняльного аналізу. В ході дослідження було виявлено специфіку функціонування «діяльної поверхні» міста та його позаміських територій, яку зумовлено «двофазним механізмом» формування «міських теплових островів» (напрям теплових потоків залежить від розташування в просторі підстилаючих поверхонь із контрастом температур та часу доби – вранці/вдень чи ввечері/вночі). Систематизовано та узагальнено результати досліджень щодо дистанційного зондування поверхні Землі та супутникового моніторингу теплового середовища міст; виокремлено фактори та умови виникнення «міських островів тепла» над містами в зонах із помірним кліматом (Бірмінгем, Брно, Будапешт, Бухарест, Варшава, Київ, Прага) та «міських островів прохолоди» над містами в зонах із жарким та посушливим кліматом (Абу-Дабі, Акра, Ель-Кувейт, Каїр, Касабланка, Сінгапур, Шанхай). Результати досліджень «теплової поведінки» міських поверхонь вказують на те, що формування «оаз прохолоди» влітку заподіяно тривалим затіненням «міських каньйонів» в

пустелі та охолоджуючим ефектом міського (за рахунок затінення, озеленення та обводнення території) та природнього бризу в прибережній зоні. За аналогією із формуванням оаз прохолоди в пустелі, ландшафтними засобами посилення стійкості до змін клімату об'єктів культурної спадщини (як і громадських просторів) в період літнього перегріву сучасних міст, може стати додаткове «мобільне» та «стаціонарне» озеленення та обводнення міських поверхонь, на кшталт, «Квіткових килимів Брюсселя», інколи навіть з фонтанами; «синьо-зелених» дахів Амстердаму, «The Vertical Garden» Парижу й Мадриду, «зелених фасадів» Києва. Практичною цінністю дослідження є можливість врахування його результатів при опрацюванні науково обґрунтованих адаптивно-регулюючих програм щодо пом'якшення наслідків змін клімату та посилення стійкості об'єктів культурної спадщини.

Ключові слова: глобальне потепління; міські острови тепла; об'єкти культурної спадщини; буферні зони; середмістя; громадські простори; ландшафтна архітектура; сталий розвиток.

REFERENCES

1. *Climate Change 2021. (2021): The Physical Science Basis.* IPCC Sixth Assessment Report. Retrieved from https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SummaryVolume.pdf. (data 15.09.2024). {in English}

2. *"GISS Surface Temperature Analysis (v4) / Temperature Change for Three Latitude Bands" (2023).* GISS Surface Temperature Analysis (v4). National Aeronautics and Space Administration Goddard Institute for Space Studies. Retrieved from https://data.giss.nasa.gov/gistemp/graphs_v4/. (data 15.09.2024). {in English}

3. Watts N., Amann M., Arnell N., Ayeb-Karlsson S., Beagley J., Belesova K., ... & Costello A. (2021). «The 2020 report of The Lancet Countdown on health and climate change: responding to converging crises». *The Lancet,* (397(10269)), p.129-170. https://doi.org/10.1016/S0140-6736(20)32290-X.{in English}

4. Charlson F., Ali S., Benmarhnia T., Pearl M., Massazza A., Augustinavicius J. et al. (2021). «Climate change and mental health: A scoping review». *Environ Res Public Health,* (18(9):4486). doi:10.3390/ijerph18094486. {in English}

5. Pleshkanovska A. & Savchenko O. (2019). *"Epochs and cities"*. Kyiv: Institute of Urban Studies. {in Ukrainian}

6. *COP28 Declaration on Climate and Health*. (2023). Retrieved from https://cdn.who.int/media/docs/default-source/climate-change/cop28/cop28-uae-

climate-and-health-declaration.pdf?sfvrsn=2c6eed5a_3&download=true. (data 15.09.2024). {in English}

7. *Policy Document on Climate Action for World Heritage.* Climate Change and World Heritage. (2023). UNESCO. Resolution 24 GA 8, p. 34, item 1, 8, 9. Retrieved from https://whc.unesco.org/en/climatechange/ (data 15.09.2024). {in English}

8. *World Heritage in Danger.* World Heritage Convention (2019). Retrieved from https://whc.unesco.org/en/158/. (data 15.09.2024). {in English}

9. *Goals and targets (from the 2030 Agenda for Sustainable Development).* (2017). Resolution adopted by the General Assembly on 6 July 2017 General Assembly 10 July 2017 Goal 13: Climate Action, p. 17-18. Retrieved from https://www.un.org/sustainabledevelopment/climate-change/ (data 15.09.2024). {in English}

10. Louis B. Sohn. (1973). The Stockholm Declaration on the Human Environment, UNEP. *The Harvard International Law Journal*, (V.14, No.3, p.94). Retrieved from https://wedocs.unep.org/20.500.11822/28247.{in English}

11. Mensah J. (2019). «Sustainable development: Meaning, history, principles, pillars, and implications for human action: Literature review». *Cogent Social Sciences,* (V. 5 (1)). https://doi.org/10.1080/23311886.2019.1653531. {in English}

12. Ferguson P., Wollersheim L. (2023). «From sustainable development to resilience? (Dis)continuities in climate and development policy governance discourse». *Sustainable Development*, (V. 31(1)), p. 67-77. https://doi.org/10.1002/sd.2374. (data 15.09.2024). {in English}

13. *Convention Concerning the Protection of the World Cultural and Natural Heritage* (1972). Retrieved from https://web.archive.org/web/20200705131631/https://whc.unesco.org/archive/convention-en.pdf. (data 15.09.2024). {in English}

14. *Operational Guidelines for the Implementation of the World Heritage Convention.* (2012). UNESCO, p.26. Retrieved from https://whc.unesco.org/archive/opguide12-en.pdf (data 15.09.2024). {in English}

15. Odum Yu. (1983). *"Ecology",* (V.2), USA: CBS College Publishing. {in English}

16. Ustinova I.I. (2023). *«Fundamental Laws and Space-Time Measurements of Ecological Urban-Planning Systems as the Basis of Advanced Analytics of Urbanized Territories Development».* IEEE International Conference on Smart Information Systems and Technologies (SIST), p.232–236. DOI:10.1109/SIST58284.2023.10223517. {in English}

17. IPCC. (2021): *Summary for Policymakers in Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, p. 3-32, 204. doi:10.1017/9781009157896.001. (data 15.09.2024). {in English}

18. Intergovernmental Panel on Climate Change (IPCC). (2021). *«Frequently Asked Questions»*. Climate Change 2021 – The Physical Science Basis: Working Group I Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press; 2023:3-32, p. 204-205. {in English}

19. Jung Y. (2024). «Urban heat islands and the transformation of Singapore». *Urban Studies,* (V.0). https://doi.org/10.1177/00420980231217391. {in English}

20. Cobbinah P.B. (2021). «Urban resilience in climate change hotspot». *Land Use Policy,* (V. 100, 104948). https://doi.org/10.1016/j.landusepol.2020.104948. {in English}

21. Lazzarini M., Marpu P.R., Ghedira H. (2013). «Temperature-land cover interactions: The inversion of urban heat island phenomenon in desert city areas». *Remote Sensing of Environment,* (V. 130), p. 136-152. https://doi.org/10.1016/j.rse.2012.11.007. {in English}

22. Azevedo J.A, Chapman L, Muller C.L. (2016). «Quantifying the Daytime and Night-Time Urban Heat Island in Birmingham, UK: A Comparison of Satellite Derived Land Surface Temperature and High Resolution Air Temperature Observations». *Remote Sensing*, (8(2):153). https://doi.org/10.3390/rs8020153. {in English}

23. Nguyen L.H, Henebry G.M. (2016). «Urban Heat Islands as Viewed by Microwave Radiometers and Thermal Time Indices». *Remote Sensing*, (8(10):831). https://doi.org/10.3390/rs8100831. {in English}

24. Bahi H., Rhinane H., Bensalmia A., Fehrenbach U., Scherer D. (2016). «Effects of Urbanization and Seasonal Cycle on the Surface Urban Heat Island Patterns in the Coastal Growing Cities: A Case Study of Casablanca, Morocco». *Remote Sensing*, (8(10):829). https://doi.org/10.3390/rs8100829. {in English}

25. Taheri Shahraiyni H., Sodoudi S., El-Zafarany A., Abou El Seoud T., Ashraf H., Krone K.A. (2016). «Comprehensive Statistical Study on Daytime Surface

Urban Heat Island during Summer in Urban Areas, Case Study: Cairo and Its New Towns». *Remote Sensing*, (8(8):643). https://doi.org/10.3390/rs8080643. {in English}

26. Geletič J., Lehnert M., Dobrovolný P. (2016). «Land Surface Temperature Differences within Local Climate Zones, Based on Two Central European Cities». *Remote Sensing,* 8(10):788). https://doi.org/10.3390/rs8100788. {in English}

27. Tomaszewska M., Henebry G.M. (2016). «Urban–Rural Contrasts in Central-Eastern European Cities Using a MODIS 4 Micron Time Series». *Remote Sensing*, (8(11):924). https://doi.org/10.3390/rs8110924. {in English}

28. Zhang H., Jing X-M, Chen J-Y, Li J-J, Schwegler B. (2016). «Characterizing Urban Fabric Properties and Their Thermal Effect Using QuickBird Image and Landsat 8 Thermal Infrared (TIR) Data: The Case of Downtown Shanghai, China». *Remote Sensing*, (8(7):541). https://doi.org/10.3390/rs8070541 . {in English}

29. Stewart I.D. (2019). Why should urban heat island researchers study history? *Urban Climate, (*30: 1004842019). Retrieved from https://doi.org/10.1016/j.uclim.2019.100484. {in English}

30. Howard L. (1818). The climate of London: Deduced from meteorological observations, made at different places in the neighbourhood of the metropolis (Vol.1). London: W. Phillips. Retrieved from https://www.tottenhamclouds.org.uk/uploads/5/6/9/4/56947305/lukehoward_climate-of-london-v1.pdf . (data 15.09.2024). {in English}

31. Ustinova I.I. & Koziatnyk I.P. (2020). *"Assessment and regulation of the microclimate thermal regime of residential areas by means of urban planning and landscape architecture".* Guidelines, Kyiv: KNUCA. {in Ukrainian}

32. *2023 shatters climate records, with major impacts*. (2023). Retrieved from https://wmo.int/news/media-centre/2023-shatters-climate-records-major-impacts (data 15.09.2024). {in English}

33. *«Kyiv: Saint-Sophia Cathedral and Related Monastic Buildings, Kyiv-Pechersk Lavra".* World Heritage Convention. UNESCO. Retrieved from https://whc.unesco.org/en/list/527. (data 15.09.2024). {in English}

34. Lyalko V.I., Filipovich V.E., Lischenko L.P., Pazynych N.V., Teremenko A.N. & Krylova A.B. *(2015).* «Remote Sensing Monitoring of Historical Centre of Kyiv for Reducing Risks from disasters at World heritages properties». *Journal Japanese Geotechnical Society Special Publication*, (V.2(78)), p. 2671-2675. DOI: 10.3208/jgssp. tc301-04. {in English}

35. Filipovych V.E. & Shevchuk R. (2018). *«Satellite technology for determining the heat load on the city in summer and ways to overcome it through green planning»*. Conference: Sustainable cities: implementing green planning,

design and construction ideas in Ukraine. Retrieved from https://www.researchgate.net, DOI:10.13140/RG.2.2.17113.08807. {in English}

36. Ustinova I.I. & Matsokha A.S. (2024*).* "Preservation of world heritage sites in the context of climate change by means of landscape architecture". *Collection of Scientific Papers «ΛΌГОΣ»,Oxford,* UK, p. 432–442. {in Ukrainian} https://doi.org/10.36074/logos-02.02.2024.090. {in English}

37. Ustinova I.I. & Matsokha I.I. (2024). "Reduction of the impact of climate change in the middle historical cities and buffer zones of cultural heritage objects by means of landscape architecture," *Collection of Scientific Papers «ΛΌГОΣ»,* Oxford, UK, p. 563-571. https://doi.org/10.36074/logos-29.03.2024.121 {in Ukrainian}.

38. *Management plan in the period from 2014 to 2030*. (2014). World Heritage Site No. 527: Kyiv: Saint-Sophia Cathedral and Related Monastic Buildings, Kyiv-Pechersk Lavra, p. 45. Retrieved from Microsoft PowerPoint - Management plan (kyiv-heritage.com). (data 15.09.2024). {in Ukrainian}

39. *In Kyiv, approved new buffer zones of world heritage sites.* Vechirniy Kyiv (2020). Retrieved from https://vechirniy.kyiv.ua/news/39127/ (data 15.09.2024). {in Ukrainian}

41. Harper D. (2024). *"Etymonline – Origin of 'Oasis".* Online Etymology Dictionary. Retrieved from https://www.etymonline.com/search?q=oasis. (data 15.09.2024). {in English}

42. *Flower Carpet | Le Tapis de Fleurs: un spectacle éphémère sur la plus belle place du monde!* Retrieved from https://www.flowercarpet.be/#carpets-overlay. (data 15.09.2024). {in English}

43. *RESILIO - Het slimme daken project in Amsterdam.* Retrieved from https://resilio.amsterdam/en/. (data 15.09.2024). {in English}

44. Blanc P. (2012). *"The Vertical Garden: From Nature to the City".* NY: W. W. Norton Company. (data 15.09.2024). {in English}

45. *Paseo del Prado and Buen Retiro, a landscape of Arts and Sciences.* (2021). UNESCO. Retrieved from https://whc.unesco.org/en/list/1618/. (data 15.09.2024). {in English}

46. *World Heritage in Danger.* (2019). World Heritage Convention. Retrieved from https://whc.unesco.org/en/158/. (data 15.09.2024). {in English}

47. *What is the Blue Shield?* (2021). Retrieved from https://theblueshield.org/about-us/whatis-the-blue-shield/. (data 15.09.2024). {in English}