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# POTENTIAL APPLICATIONS OF AI IN BIOPHILIC URBANISM AND NATURE-BASED SOLUTIONS IN CITIES

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**Abstract.** Applications of Artificial Intelligence (AI) in the fields of design and planning become increasingly common. At the same time fears related to the threats of technocentrism and disconnectedness from nature towards applications of AI in managing and shaping our living environments are rising. The concept of biophilic design holds the potential for bridging the gap between urban population and nature and avoiding technocentrism in urban life and planning. Thus, the need arises to connect biophilic design and planning and the applications of AI in urbanism. Consequently, this research presents the review, discussion and experiment of potential applications of AI (mainly focusing on generative AI) in biophilic urbanism and nature-based solutions in cities.

***Keywords:*** *Biophilia, biophilic design, biophilic urbanism, nature-based solutions, Artificial Intelligence (AI), generative AI.*

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## 1. Introduction

Nowadays applications of Artificial Intelligence (AI) including generative AI in the fields of architectural design and urban planning become increasingly common practice. The Royal Institute of British Architects states that currently 41 percent of UK architects are using some AI tools in their work (Crook, 2024). The definitions of AI by scholars (Dobrev, 2012; Galle & Nitoslawski, 2020) claim that computer program can be considered AI if it simulates human intelligence processes in order to perform tasks that normally requiring human intelligence (Galle & Nitoslawski, 2020) and will cope not worse than a human in an arbitrary world (Dobrev, 2012). Meanwhile generative AI is a technology that uses large amounts of data and machine learning techniques to generate content reflecting its training set (Chiancone, 2023; Stephens, 2023).

Cities on our Planet continue to grow, expand and become more and more complex. Thus proponents, enthusiasts and researchers in the fields of AI claim that this technology will shape the trajectories of cities management and development. It is already transforming the way cities are planned, operated and experienced (Stephens, 2023). However, at the same time fears and skepticism towards applications of AI in managing

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and shaping our living environments are rising. New technologies are leading towards technocentric approach to the city and its planning and threaten further distancing of contemporary urban residents from nature (Sonetti *et al*., 2018).

Sonetti et al. (2018) mention the concept of biophilic design as the way to avoid technocentrism and to bridge the gap between urban population and nature. Biophilic design draws inspiration from positive impacts of nature on humans and contact with it and aims to integrate natural elements, features and patterns into artificial environments constructed by humans. In general, "biophilic design aims to establish a profound and positive connection between people and nature and between people and the built environment designed according to biophilic principles" (Ramm *et al*., 2023, 2024). Researchers distinguish numerous human and societal benefits of biophilic design and urbanism: it contributes to human well-being and mental health and also has a range of other economic, environmental and social functions (Cabanek *et al*., 2020); for example, biophilic buildings have improved comfort levels and reduced related energy costs etc. (Sonetti *et al*., 2018). Biophilic approach towards design and planning brings new perspectives on how natural systems need to be integrated into urban fabric (Cabanek *et al*., 2020). This allows to connect the biophilic approach to cities with the movement of application of nature-based solutions in urbanism, generally defined as solutions to societal challenges that involve working with nature (Seddon *et al*., 2020).

Biophilic approach to designing environments includes not only integration of actual natural elements, like plants, water, natural materials, ecosystems, but also using the same generative processes that nature uses in order to create the built environment (Salingaros, 2015; Ramm *et al*., 2023; 2024). As the human body and mind perceive, recognize and positively react to artificial structures that embody the complex mathematics of nature (Salingaros, 2015). The possibility to generate artificial structures that have positive biophilic impact on humans identified by the researchers (Salingaros, 2015; Ramm *et al*., 2023; 2024) and growing complexity of contemporary cities that require new technological solutions justify *the aim of this research*: review and analysis of potential applications of AI (mainly focusing on generative AI) in biophilic urbanism and nature-based solutions in cities.

*The methods of research* include review, analysis and systematization of existing literature on the topic and relevant AI tools, SWOT analysis and the experiment of quantitative analysis of urban structures in order to describe them quantitatively, compare and understand their biophilic potential in this way obtaining relevant data for further generative AI applications. For accumulation of relevant literature Web of Science scientific literature database and Google Scholar search engine as well as currently available Large Language Models (LLMs) (Bard, 2024; ChatGPT, 2024) were used. The LLMs were used in SWOT analysis as well. For the quantitative experimental analysis, description and comparison of biophilic qualities of urban structures, the concept of isovist (Benedikt, 1979) and visual graph analysis functionalities of Depthmap software were applied.

The structure of the article is organized as follows: first of all, general review of features of biophilic urbanism and nature-based solutions in cities are presented, this section is followed by the overview and analysis of potential applications of AI in different stages of biophilic and nature-oriented urban planning, including the isovist experiment, the overview is followed by the discussion of challenges and SWOT analysis of AI applications in this field, which is followed by the conclusions.

## 2. Literature review: biophilic urbanism and nature-based solutions

When reviewing biophilic urbanism, at first it is necessary to understand the original concept of biophilia. And it is not just about the physical - the material object. The term originated in 1973 and its author was the philosopher and psychologist E. Fromm. He argued that biophilia is a feeling and that the very definition could be "a passionate love for life and for all that is alive" (Fromm, 1973). Among other things, Fromm (1973) diagnoses that industrial societies are systematically necrophilic, i.e. that our way of living, producing and consuming makes us see natural resources as something to be used and depleted.

Another equally important author on biophilia is the biologist Wilson (2002), who defines biophilia as "our innate tendency to focus on and in some cases emotionally connect with, life and life-like forms". Wilson (2022) argued that belonging to nature is an emotional connection to particular life forms that arises under certain circumstances. From an evolutionary perspective, the sense of belonging seems to arise from "our capacity to experience empathy for other beings and to respond to their concerns as our own" (Goodenough, 1998). For Wilson (2022), "biophilia is not a single instinct but a complex of learning rules that can be teased apart and analyzed individually. The feelings molded by the learning rules fall along several emotional spectra: from attraction to aversion, from awe to indifference, from peacefulness to fear-driven anxiety". The evolutionary dependence on nature was also expounded by social ecologist Kellert (1993) by identifying nine values of biophilia: utilitarian, naturalistic, scientific, aesthetic, symbolic, humanistic, moralistic, dominionistic and negativistic. The latter point might be a deliberate "softening" of "innate", which prevents biophilia from being restricted to the significance in evolutionary psychology (Joye & De Block, 2011).

The concept of biophilic design emerged at the start of the 21$^{st}$ century and found application in the field of architecture and urbanism, highlighting the emotional component of people's demand for interactions with nature within buildings. S. Kellert also categorized biophilic design into two: (1) vernacular or place-based design that create place attachment by connecting culture, history, ecology within geographic context and (2) organic design, directly, indirectly and symbolically interpreting nature. It was suggested that biophilic design could offer some design principles to satiate this desire for nature in architecture (Zhong *et al*., 2022).

The majority of world's cities have some natural elements and some of them can even boast abundant green areas and biodiversity. Urban environments contain a variety of natural features and areas, from parks to trees to rivers and riparian habitats. Currently, with rising ecological awareness, climate change threats and growing worldwide commitment to nature conservation and to preserve and enhance the quality of living environments, efforts are being made to further enhance the green elements and features of our living and work environments (Beatley & Newman, 2013). While there are numerous movements and approaches towards greening and re-naturing cities, the concept of the biophilic city and the principles of biophilic urbanism were introduced by T. Beatley (Milliken *et al*., 2023). Meanwhile the concept of nature-based solutions was first mentioned in 2008 by the World Bank (Sowińska-Świerkosz & García, 2022). Both concepts seem recent developments in urbanism, however, it is necessary to note that biophilic and nature-based features have appeared in environments designed by humans since antiquity.

Beatley (2020), the author and proponent of biophilic cities approach and global design and planning movement, defines biophilic cities as "those that are abundant in nature (trees, greenery, animals, gardens) and in opportunities to connect with and experience this nature". According to him, the recognition of the innate human affiliation with nature and the need to put contact with nature at the center are the basic premises of this approach (Beatley, 2020). Thus, it is possible to summarize that the abundant nature and natural elements in cities represent the component "bio". Meanwhile, the component "philic" is represented by direct and active engagement of urban residents in learning about, enjoying and caring for the nature around them and development of important emotional connections with this nature (Beatley & Newman, 2013). Citizens' engagement with nature may include hiking, bird watching, sky-gazing, gardening, restoring and caring for the nature around them (Beatley & Newman, 2013). Milliken et al. (2023) mention the ethical dimension of biophilic cities: the inherent moral worth of nature must be acknowledged in biophilic cities; they should exhibit a profound ethic of care for nature and other forms of life. Currently a worldwide official network of cities - Biophilic Cities Network - exists, uniting individuals, organizations and cities that agreed "to work on behalf of more natureful cities and urban environments" (Beatley, 2020).

Literature presents principles of biophilic urbanism from the points of view of:

- interactions (Tabb, 2020; Milliken *et al*., 2023);
- dimensions (Beatley & Newman, 2013; Tabb, 2020; Milliken *et al*., 2023);
- general principles (Beatley, 2016; Milliken *et al*., 2023);
- conditions (Beatley & Newman, 2013);
- scales (Beatley, 2010; Beatley & Newman, 2013).

*Interactions.* Three primary interactions are distinguished in biophilic urbanism: the impacts of nature on human beings and the built environment, the impacts of human beings and the built environment on nature and the impacts of the built environment on both nature and human beings (Tabb, 2020; Milliken *et al*., 2023).

*Dimensions*. Tabb (2020) and Milliken et al. (2023) distinguish social, environmental and transportation dimensions of biophilic urbanism.

*General principles*. General principles of biophilic urbanism include (Beatley, 2016; Milliken *et al*., 2023): cities of abundant nature and natural experiences; biodiverse cities; multisensory cities; cities of interconnected, integrated natural spaces and features; immersing in and surrounding inhabitants with nature; becoming outdoor cities; embracing the blue as well as the green - the marine and aquatic as well as the terrestrial; celebration of nature in small and the large scales; citizens caring and engaging with nature; fostering a profound curiosity; care about and nurture other forms of life; care about nature beyond the borders of cities; investment in nature; inspiration by and mimicking nature; exhibiting and celebration the forms of nature and equitable distribution of nature and natural experiences.

*Conditions*. Beatley and Newman (2013) identify four conditions for biophilic urbanism: biophilic conditions and infrastructure, biophilic behaviors, patterns, practices, lifestyles, biophilic attitudes and knowledge and biophilic institutions and governance.

*Scales*. According to Beatley (2010), Beatley and Newman (2013), biophilic design principles should be applied in multiple scales: 1) building, 2) block, 3) street, 4) neighborhood, 5) community, 6) region.

Biophilic Cities Network's website lists such human benefits of biophilic urbanism as deep and powerful connections with nature offering meaning in life, benefits for economic growth, positive impact on education, cognitive skills, academic performance, creativity, problem solving and intellectual capacity, health benefits related with stress reduction, healthier food and movement and exercise possibilities and general happiness (Biophilic Cities Network, 2024). Moreover, biophilic urbanism is closely related to urban biodiversity planning and management as it seeks to reframe nature as essential infrastructure for cities (Panlasigui *et al*., 2021).

Beatley and Newman (2013) provide examples of biophilic interventions and policies in cities, such as green rooftops and tree-planting programs, greenery and landscaping standards for new developments, greening of alleyways and gray spaces, establishing legal conditions for urban agriculture etc. Analysis of literature (Beatley & Newman, 2013; Cabanek *et al*., 2020; Rajaratnam, 2021; Cardno, 2022) has demonstrated that biophilic solutions in cities are implemented or envisioned in different scales from city/region to building and they all include integration of natural components - trees, vegetation, green areas, ecosystems.

The mere presence of green spaces in a city or the vertical planting of buildings does not guarantee that natural elements will contribute to solving challenges of society or that plants will be properly cared for. Mazzola (2019) observes that vertical greening of high-rise buildings is often more of a marketing and public relations tool than a real solution to ecological problems or an improvement in the quality of life and that vertical greening often fails to ensure that the right conditions are in place for plants to thrive and flourish. Moreover, as the theory of biophilic design underlines (Salingaros, 2019), biophilic qualities are determined not only by presence of nature, but also by certain shapes and order of forms and spaces. Even if presence of and contact with nature and nature-based solutions are crucial for biophilic urbanism, general principles of biophilic design (for example, sunlight; color; gravity; fractals; curves; detail; water; life; representations-of-nature and organized-complexity (Salingaros, 2019)) should become equally important feature of biophilic urban environments. The multi-scale and multi-dimensional character of biophilic urbanism, need to optimize the distribution of natural features in cities and to create biophilic geometries as well as the need to avoid superficial greening and greenwashing currently observed in “sustainable” urbanism (Mazzola, 2019), justify the relevance of integration of qualitative and quantitative approaches and application of AI solutions in this complex field.

## 3. Results: Application of AI in different stages of urban planning for biophilic qualities and nature-based solutions for cities

Biophilic urbanism and generative AI are both rapidly evolving fields and their potential intersections offer interesting possibilities. In an increasingly digital society, intersections between urban nature and technology will become more prominent (Galle & Nitoslawski, 2020). This section analyzes different stages of urban design and planning where generative AI and other quantitative solutions, biophilic design and nature-based solutions can be interconnected and potentially help to integrate nature and biophilic qualities of built environment into data-driven smart cities of the future:

- analysis;
- pre-design and design;
- post-design stage including monitoring, operation, maintenance and user experience.

### *3.1. Analysis*

AI can be used to analyze the effects of nature and biophilic features on humans, the results of such analysis can be further applied in optimizing design and planning solutions. Several interesting applications of advanced technologies, such as AI and virtual realities, in analysis of urban environments and biophilic design were identified in literature.

Virtual reality applications are interesting both as the possibility to pre-test the human response to design solutions as well as from the point of future perspective of generated virtual biophilic environments aimed at distant communication and entertainment (Viliunas & Grazuleviciute-Vileniske, 2022). The research by Mollazadeh and Zhu (2021) has revealed that virtual realities can be applied for "representing combinations of biophilic patterns, providing multi-modal sensory inputs, <…> supporting required exposure time to observe biophilic patterns and measuring human's biological responses to natural environments". Virtual reality can become a valuable medium for experimenting with biophilic forms in buildings and urban environments (Viliunas & Grazuleviciute-Vileniske, 2022). The advances of generative AI currently allow rapidly generating realistic images and videos, which can be combined with virtual reality technologies to explore effects of biophilic design and urbanism on humans.

Another interesting study measured the impact of biophilic design on positive emotions and productivity in two separate but conceptually related pilot studies that apply two novel approaches: (a) facial emotion recognition (FER) with residual masking networks and (b) sentiment detection using Large Language Models. The first study measures the emotions of people when confronted with images of different kinds of architecture, via FER and via a user survey. The study has found clear trends for emotions detected by FER and significant evidence for self-stated emotions that architecture implementing biophilic design evokes more positive emotions. The second study measured the influence of natural elements on productivity and team engagement. The findings show that natural elements in the surroundings do influence productivity and sentiment positively (Ramm *et al*., 2023, 2024).

Hung and Chang (2021) carried out the study of identifying biophilic elements and qualities in the photographs of urban green spaces using Google Vision AI. This study explored the possibility of utilizing the AI-based image recognition system for classification of landscape related label content in the images of urban green areas and predicting the impact of the features of the environment on people's psychological state. The research of Chang et al. (2020) involved social media and AI in providing the evidence of biophilic hypothesis linking the content of nature in 31 534 analyzed photographs with positive memories and life satisfaction. These two studies demonstrate that AI-based tools can be applied for identifying the biophilic features and elements in the images including the images of biophilic architectural design (Viliunas & Grazuleviciute-Vileniske, 2022).

### *3.2. Pre-design and Design*

Urban planning is a multifaceted field demanding the integration and scrutiny of a vast array of data - from population demographics and traffic flow to environmental factors and infrastructure requirements (Chiancone, 2023). Historically, urban planning relied heavily on manual processes and intuitive decision-making (Babin, 2024). Generative AI, with its advances in analyzing large datasets and crafting realistic urban blueprints (Chiancone, 2023) can be applied in data analysis, simulation, idea generation, elaboration and visualization of design solutions in the field of biophilic urbanism (Table 1).

*Data analysis and simulation*. For example, generative AI algorithms can be trained on vast datasets of natural patterns and urban design principles and can generate and optimize urban layouts to maximize green spaces and integrate natural elements and patterns. AI can be employed to design a green network throughout cities, offering multiple options for environmental enhancement and urban planning (Stephens, 2023). AI helps in identifying the most efficient use of resources (Babin, 2024), for example, AI can assist in optimizing plant selection and placement for biodiversity, aesthetics and functionality. AI algorithms can recommend optimal locations for green spaces, parks and vegetation, enhancing the overall green infrastructure of urban areas and suggest ways to incorporate diverse plant and animal species into urban ecosystems (Shaamala *et al*., 2024).

AI can analyze existing urban landscapes and propose optimal layouts for green infrastructure networks, considering factors like connectivity, biodiversity and accessibility. This can involve designing connected green corridors, strategically placing parks and gardens and optimizing street tree planting for maximum ecological and social benefits, considering their potential role as community centers and in disasters management (Stephens, 2023). Generative AI can integrate data on users and preferences, environmental conditions and local ecology to create personalized and adaptable urban spaces. AI algorithms can analyze vast amounts of data from various sources, including demographic statistics, traffic patterns, environmental data like local climate data, such as temperature, rainfall and sunlight patterns, to design spaces that are resilient and responsive to their environment (Babin, 2024).

Urban landscapes are complex ecosystems, bustling with diverse variables that interplay in complex manners. These variables encompass tangible elements like buildings, roads and parks, as well as dynamic factors such as population density, traffic flow and socio-economic activities. Each of these components generates a vast amount of data, which can be daunting to analyze manually (Chiancone, 2023). Thus, AI allows planners to make informed decisions based on comprehensive, real-time data (Babin, 2024). AI algorithms can be trained on data related to local cultural preferences and traditional design elements, enabling the creation of urban spaces that are both biophilic and culturally sensitive. This can foster a sense of place and ownership among residents, fostering a deeper connection with their surroundings. AI can simulate natural processes, helping urban planners understand how different design elements may impact ecosystems and biodiversity. AI can simulate numerous urban development scenarios in a fraction of the time it would take manually.

AI brings a data-driven, predictive approach to this field, enabling planners to visualize the impact of their decisions before they are made (Babin, 2024). AI can forecast the future needs of a city’s infrastructure (Babin, 2024) and generate a model of how the city might evolve under various scenarios. This could involve creating a city layout that prioritizes green space or one that reduces traffic congestion or one that enhances accessibility to public amenities like schools and hospitals. Singapore's urban planners have used generative AI to simulate various urban scenarios and predict the impact of different planning strategies (Chiancone, 2023).

**Table 1.** The areas of application of AI in the stage of pre-design and design process in biophilic urbanism

| **Data analysis** | **Simulation** | **Idea generation, participatory sessions, co-design** | **Idea elaboration, generation of designs** | **Visualization** |
|---|---|---|---|---|
| Analysis of natural patterns, urban design principles, plant species and habitats<br>Analysis of existing landscapes<br>Analysis of data on users and preferences, environmental conditions, local climate, and local ecology<br>Analysis of participants and users feedback | Simulation of natural and social processes | Generation of planning and design solutions using AI algorithms trained on datasets of natural patterns and urban design principles<br>Generation of multiple design solutions and iterations<br>Generation of images from texts (discussions, ideation sessions material) | Generation of planning and design solutions using AI algorithms trained on datasets of natural patterns and urban design principles<br>Generation of images from texts (detailed descriptions of desirable parameters) | Generation of planning and design solutions using AI algorithms trained on datasets of natural patterns and urban design principles<br>Generation of images from texts (detailed descriptions of desirable parameters) |
| Examples of available tools | | | | |
| TensorFlow (https://www.tensorflw.org/) and PyTorch (https://pytorch.org/) (can be employed for data analysis and pattern recognition, assisting in the extraction of insights from urban and environmental datasets to inform biophilic design) | Unity3D with ML-Agents (https://unity.com/products/machine-learning-agents) (can be used to simulate and model urban environments, allowing for the study of interactions between nature and urban structures)<br><br>OpenAI Gym (https://openai.com/research/openai-gym-beta) (while traditionally associated with reinforcement learning, OpenAI Gym can also be adapted for simulating and optimizing various aspects of urban planning, such as resource allocation and environmental impact) | UrbanistAI (https://toretei.com/work_urbanistai.html) (allows users to express design preferences through visualizations and translates them into actionable information for urban planners: can be used to explore design options that incorporate user preferences for nature connection and access to green spaces) | SpaceMaker AI (Landes, 2022) (offers functionalities for generating and optimizing urban layouts, including building placement, street networks and public spaces: can be used to explore layouts that prioritize green infrastructure integration, pedestrian connectivity and potential for incorporating biophilic elements)<br>Procedural Urban Design Tools (for example,- https://www.thebrief.space/) (in case these tools offer customizability, biophilic principles can be incorporated into the generation process)<br>Bentley Generative Components (https://communities.bentley.com/products/products_generativecomponents/w/generative_components_community_wiki) (with creative application, could potentially be used to explore biophilic design options, such as optimizing building forms for natural light or designing nature-inspired building facades)<br>Autodesk Generative Design (https://www.autodesk.com/solutions/generative-design) | Bentley Generative Components (https://communities.bentley.com/products/products_generativecomponents/w/generative_components_community_wiki ) (with creative application, could potentially be used to explore biophilic design options, such as optimizing building forms for natural light or designing nature-inspired building facades)<br><br>Autodesk Generative Design (https://www.autodesk.com/solutions/generative-design) (leverages algorithms and AI to explore numerous design possibilities based on specified parameters. It has applications in architectural design and urban planning, including considerations for biophilic elements)<br><br>Midjourney (https://www.midjourney.com/home ) and other text-to-image generation platforms |

| | | | | |
|---|---|---|---|---|
| | | | (leverages algorithms and AI to explore numerous design possibilities based on specified parameters. It has applications in architectural design and urban planning, including considerations for biophilic elements)<br>CityEngine by Esri (https://www.esri.com/en-us/arcgis/products/arcgis-cityengine/overview) (uses procedural modeling techniques to create detailed 3D city models. It can be employed to simulate urban environments and test different design scenarios, including those focused on biophilic elements)<br>Rhino and Grasshopper (https://www.rhino3d.com/) (enable parametric and generative design, supporting architects and planners in creating complex, nature-inspired structures) | |

*Idea generation, elaboration and visualization*. Generative AI can be applied for architectural biophilic designs, which are inseparable from urban environments as well. AI algorithms can be used to design building facades that integrate nature-inspired shapes, patterns, textures and living walls, softening the visual impact of urban structures and fostering a connection with the natural world. Algorithms can analyze building orientation, window placement and vegetation patterns to ensure optimal natural light distribution and airflow, promoting occupant well-being. Stephens (2023) recommends using AI algorithms to create nature-inspired art and patterns: these designs could be integrated into interactive and dynamic interior and exterior spaces, enhancing the connection between nature and urban environments.

AI can accelerate the design and planning process for biophilic urban spaces by generating multiple design options and design iterations. Generative design is a growing paradigm at the intersection of artificial intelligence and architecture, which defines a mechanism through which machines produce a large number of realistic designs (Landes, 2022). Generative AI techniques like those that synthesize images from text (text-to-image models) offer new possibilities for creatively imagining new ideas (Epstein *et al.*, 2022). AI can quickly generate a vast range of design possibilities, allowing stakeholders to explore different scenarios and find solutions that meet diverse needs (Landes, 2022).

Idea generation and participatory processes can be facilitated by the use of generative AI as well. For example, Epstein et al. (2022) analyzed the possibilities to use text-to-image generative AI algorithms that can help communities engage in conversations about their collective future and environments. They have conducted the experiment where participants collaboratively speculated on utopias they want to see and then produced AI-generated imagery from those speculations. In a series of in-depth user interviews they invited participants to reflect on the generated images and refine their visions for the future. Epstein et al. (2022) observed that participants often generated ideas for implementing their vision and drew new lateral considerations as a result of viewing the generated images. They found out that the unexpected difference between the participant's imagined output and the generated image is what facilitated new insight for the participant. Epstein et al. (2022) believe that their experimental model for co-creation, computational creativity and community reflection inspires the use of generative models to help communities and organizations envision better futures. They found that occasionally the image did meaningfully crystallize a vision for the future in a literal way and many participants noted the image gave them ideas for ways to implement their vision (Epstein *et al*., 2022). AI can help visualize proposed biophilic designs, making it easier for the public to understand and engage in the urban planning process.

AI can translate complex data sets (e.g., environmental impact assessments, traffic flow simulations) into easily understandable visualizations, aiding communication and decision-making. Generative models can analyze feedback from residents to refine and improve urban plans, ensuring they align with community needs. This helps ensure that urban development aligns with the needs and desires of the community (Babin, 2024).

### *3.3. Post-design: monitoring, operation, maintenance, user experience*

AI can analyze data from sensor networks to monitor environmental factors and ensure the health and sustainability of biophilic features within urban areas. AI systems, including drones with AI algorithms, can be used to survey green spaces (Stephens, 2023). This technology can identify plant species and assess their condition, aiding conservation efforts and ensuring biodiversity in urban areas, it can also help in tracking and protecting urban wildlife (Babin, 2024). For example, Singapore uses AI for environmental monitoring among other purposes (Babin, 2024). Galle and Nitoslawski (2020) present the concept of the Internet of Nature, where urban ecosystem components and their interrelation dynamics are described and represented through digital technologies and applications. These may include, but are not limited to, information and communications technology (ICT), remote sensing, machine learning, sensors and data loggers, 5G communications and advanced computing. In this representation, the benefits of urban nature are enhanced and self-organization, self-regulation and automation can be achieved (Galle & Nitoslawski, 2020). AI can predict when urban infrastructures including green infrastructures will need maintenance. This helps cities avoid costly emergencies and plan their budgets more effectively (Babin, 2024).

AI solutions can be applied in the stage of building and public space usage and maintenance, for example AI-controlled dynamic architectural elements, such as responsive facades, movable walls and retractable roofs can be implemented in order to adapt to changing weather conditions and enhance natural elements in public spaces (Stephens, 2023).

AI can be used to create dynamic and adaptive green spaces that respond to real-time environmental conditions and user interactions. AI can be used to create natural soundscapes in urban areas thus enhancing user experience: smart speakers and sound systems can be implemented to mimic natural environments, stimulating the senses and enhancing well-being (Stephens, 2023). AI can be used to personalize urban green spaces based on individual preferences and needs in real time: AI-powered apps that recommend parks or gardens best suited for user's mood or desired activity or that adjust features like lighting or soundscapes to create a more immersive and biophilic experience for each user can be developed. It is possible to envision walls that transform with changing seasons or interactive gardens that respond to touch and movement, fostering deeper connections with nature.

AI can be used to create engaging and interactive experiences that educate people about the benefits of biophilic design and encourage them to connect with nature in urban environments. This could include virtual tours of green spaces, educational games or even AI-powered chatbots that answer questions about local flora and fauna. Interactive displays or projections showing real-time air quality, natural light levels or plant health can engagingly educate the public, emphasizing the connection between urban living and nature (Stephens, 2023).

## 4. Experiment: Quantitative comparative analysis of urban structures in order to understand their biophilic potential

In order to train generative AI algorithms on datasets of urban design principles, traditional design elements and features of biophilic environments and thus generate and optimize biophilic and culturally sensitive urban layouts, it is important to obtain adequate quantitative data. In order to address this question, a quantitative comparative experiment aimed at biophilic qualities of urban structures was carried out. As it was stated above, biophilic approach, based on inspiration by and mimicking nature or biomimicry, can make various positive impacts on the built environment by making it more preferable, interesting to experience, etc. Moreover, it could be expected that at pre-design and design stages, analysis and comparison of both more and less biophilic environments could be used in order to obtain information, which later could be used in AI supported generative or parametric design. It is important to note that such comparative analysis could not only give some quantitative objective criteria which support inclusion of natural elements into urban structures, but offer clues for transformation of urban shape itself even if natural elements are absent there.

In order to test such a possibility a small research experiment related to urban planning and design, as the less attention receiving aspects in the biophilic context if compared to building design, was carried out. During the experiment four urban plans of historical and modernist cities were analyzed and compared with the plan of the park as a benchmark example of a biophilic environment created by a man and corresponding to human visual perception needs and scale well. Trakų Vokė manor park design by famous landscape architect Eduard Andre was chosen as an example of the 19$^{th}$ century English style park with some elements of neoclassicist spatial structures. Four plans of urban areas of a size of walkable spatial structure were analyzed based on the historical available maps: Edinburgh Old Town (EOT) as an example of organic medieval urbanism of Western Europe; Damascus medieval city as an example of Islamic organic urban planning; Edinburgh New Town (ENT) as an example of the ideas of Classicism implement at urban scale; Elektrėnai city in Lithuania as an example of modernistic 20$^{th}$ century city build from scratch without any consideration of historical context during the period of Soviet occupation.

The analysis was initially based on the idea of Hillier (1999) that space is a container for various functions, as it points out the importance of spatial configuration for the functioning of architectural and urban structures and interaction with them. The interaction with urban and natural environments functions and could be analyzed at various scales starting from the region and continuing to the whole city, neighborhood, block and visually perceived spaces. The last level should be seen as the fundamental relation formed based on visual interaction at the human scale, which, in a bottom-up way, affects higher scales of interaction through movement and memory. The experiment was focused on the analysis and comparison of visually perceived natural and urban structures. The experiment was grounded on the fundamental work of Gibson (1968), where he defines the visual environment as a system of objects, which structures the light as a source of stimuli for human perception: "Ambient light is structured as an array at a point of view in accordance with laws of ecological optics... The array at a stationary point consists of the perspective projections of things in the world - the surfaces, corners, curvatures and edges of the permanent layout - and the changing perspectives of moving or changing things … The most obvious cause of the structuring of light is the geometrical structure, the layout, of the environment" (Gibson, 1968). Based on the work of Gibson, the concept of the isovist, as the visual field perceived from the exact point of observation, introduced by Benedikt (1979) was applied while developing the methodology further. In simple words, the isovist could be described as the volume of space visible from a single point. Features of such form could be analyzed either in 3D volume or 2D planes either horizontal or vertical. Each point within the spatial structure has its isovist. As Benedikt (1979) notes: "...various perceptual and cognitive factors are well presented by certain numerical measures of shape and size attached to the isovist".

Based on Wiener and Franz (2004), isovists could be seen "...as objectively determinable basic elements of visual environment", which "...capture environmental properties of space that are relevant for spatial behavior and experience". Based on the conducted research experiments, it was concluded that "for experiential qualities and navigation behavior, already single isovist measurements were sufficient to widely explain the variance in the behavioral data" (Wiener & Franz, 2004). Consequently, the isovist model was chosen as an appropriate quantitative tool that allows to see the spatial environment through the human user's eyes and thus could be useful at all stages of biophilic urban planning and design:

- at the analysis stage for identification of visually perceived key features and comparison of biophilic and urban environments;
- at the design stage as a multivariate modeling tool that allows the prediction of human reaction to the planned changes or to compare them with a benchmark biophilic environment;
- at the post-design stage as a model offering a set of indicators for monitoring further changes or allowing to describe limits of changes in the environment in terms of visually perceived characteristics.

Modeling of the isovists was conducted while employing the mathematical graph model which allows to see the investigated structure as a network of the interconnected nodes and links with a possibility to apply mathematical calculations for modeling of the features of each node or isovist generation point. Depthmap software was used for this purpose (Turner, 2004; Varoudis, 2012) using its visual graph analysis functionalities. Modeling was performed in the following steps using the Depthmap: the modeled accessible public spaces of the structures were tessellated using the same step of 2-3 meters as a social distance at an urban scale, thus ensuring human scale of the created model; all tessellated cells were treated as nodes of the visual graph which were connected by the edges or links of the graph with the other cells if visible from each other; various graph centralities which represent properties of the isovists visible from each node were calculated based on the formulas used in Depthmap (Koutsolampros *et al.*, 2019). It would be important to note that such visual graph based isovist analysis was already successfully applied in Trakų Vokė park analysis and correspondence of the modeling results to the real human experience of the spatial structure was confirmed (Zaleckis *et al*., 2023).

The following isovist indicators were calculated and compared:

- Isovist Area which is calculated based on the following formula (Koutsolampros *et al*., 2019):

$$IsovistArea = A = \frac{1}{2}\sum_{i=0}^{n-1}(x_i y_{i+1} - x_{i+1} y_i)$$

where $x_i$ and $y_i$ are coordinates of a calculated node. The bigger area shows more public spaces, while smaller – more social and intimate places. In order to be able to compare this indicator between all investigated objects, it was normalized by dividing all values by the biggest Isovist Area of the park.

- Isovist Compactness shows which isovists have a shape closer to a circle as the most compact form. In terms of human - space interaction, higher compactness could be related to simplicity for perception, convexity as an attractiveness for functions to stay inside a space, etc. It is calculated based on the following formula (Koutsolampros *et al*., 2019):

$$Isovist\ Compactness = 4\pi A/\Pi^2$$

where A means Isovist Area. Normalization for the indicator is not needed. Value 1 would mean an ideal circular space, value closer to 0 – more prolonged space.

- Isovist Drift is calculated as the distance between the isovist generation point and its geometrical center. It shows direction and distance towards the largest parts of an isovist and could be seen as a catalyzer of a movement of observers (Koutsolampros *et al*., 2019; Conroy, 2001) or a kind of dynamic character of space. The following formula is used (Koutsolampros *et al*., 2019):

$$Isovist\ Drift\ Magnitude = \sqrt{(c_x - g_x)^2 + \left(c_y - g_y\right)^2}$$

where $c_x$ and $c_y$ are coordinates of the geometrical center of an isovists and $g_x$, $g_y$ – coordinates of a generation point of an isovist.

- The Isovist Perimeter is simply the length of boundaries of visual space and it is calculated by the following formula (Koutsolampros *et al*., 2019):

$$Isovist\ Perimeter = \Pi = \sum_{i=0}^{n-1}\sqrt{(x_{i+1} - x_i)^2 + (y_{i+1} - y_i)^2}$$

where $x_i$ and $y_i$ are coordinates of a calculated node. Longer boundary of an isovist could be related to more information about neighboring spatial structure, etc. For the purpose of comparison, the perimeter was normalized while dividing it by the maximal value of the park.

- Ration between Isovist Occlusivity and Perimeter was calculated simply by dividing part of the boundary which is invisible or perpendicular to the observation line from the generation point of the isovist by the whole perimeter. Bigger number means that there are more potential spaces to see and discover something unexpected from a precise isovist. Occlusive perimeter is calculated in the same way as perimeter. Normalization for the ratio is not needed.

- Point First Moment (PFM) within a distance of 100 meters as a max social distance which allows to see another person as one angular degree size object which is still distinguishable as a separate object, thus addressing human scale besides the earlier mentioned size of the nodes of the graph. It is calculated by the formula (Koutsolampros *et al*., 2019):

$$Point\ First\ Moment = \sum_{v_j \in N(v_i)} d(v_i, v_j)$$

where d is a distance for the isovist generation point $v_i$ to every other visible cell within it $v_j$. PFM sometimes is called skewness as bigger values demonstrate a more prolonged, axially shaped visual field. It could be considered as an opposition to compactness and as a stronger expression of an archetype of route in human perception. Dominance of high PFM values should be expected in a regular urban grid. The indicator was normalized while comparing it to the max value in the park.

- Point Second Moment (PSM) or variation is calculated by the following formula (Koutsolampros *et al*., 2019):

$$Point\ Second\ Moment = \sum_{v_j \in N(v_i)} d(v_i, v_j)^2$$

where d is a distance for the isovist generation point $v_i$ to every other visible cell within it $v_{j.}$ Raised by square values make the final result more dependent on high values in the Depthmap calculation. The indicator was normalized while comparing it to the max value in the park.

- The final proposed indicator was the ratio between Isovist Drift and Maximum Radius of an isovist. It can show a kind of dynamic character which does not depend on the size of an isovist but just from its configuration. Normalization was not needed.

Mean values of the calculated isovists were compared between the five objects, but in addition the idea to compare a whole structure with its functionally the most important part was developed. For this purpose, the idea of Cognitive Frame (CF) as the most important for perception of spatial structure by Peponis (2012) was employed. CF is made by the 10% of the spaces which are visible from the biggest number of the other spatial points. In the investigated case it would mean 10% of the visual graph nodes with the biggest Isovist Area. Because in urban structure the functional core which attracts the largest amount of people, objects, densities and functions does not necessarily coincide with the biggest visual spaces and even contrary, then CF was identified as 10% of nodes of the visual graphs which are the most reachable within the investigated structures or in space syntax terms, have the highest integration values. Comparison of changes of the mean values of the isovists within CF and a whole area allowed to see some inner differentiation and variety within perceived spatial structures. The example of isovist modeling is presented in Figure 1.

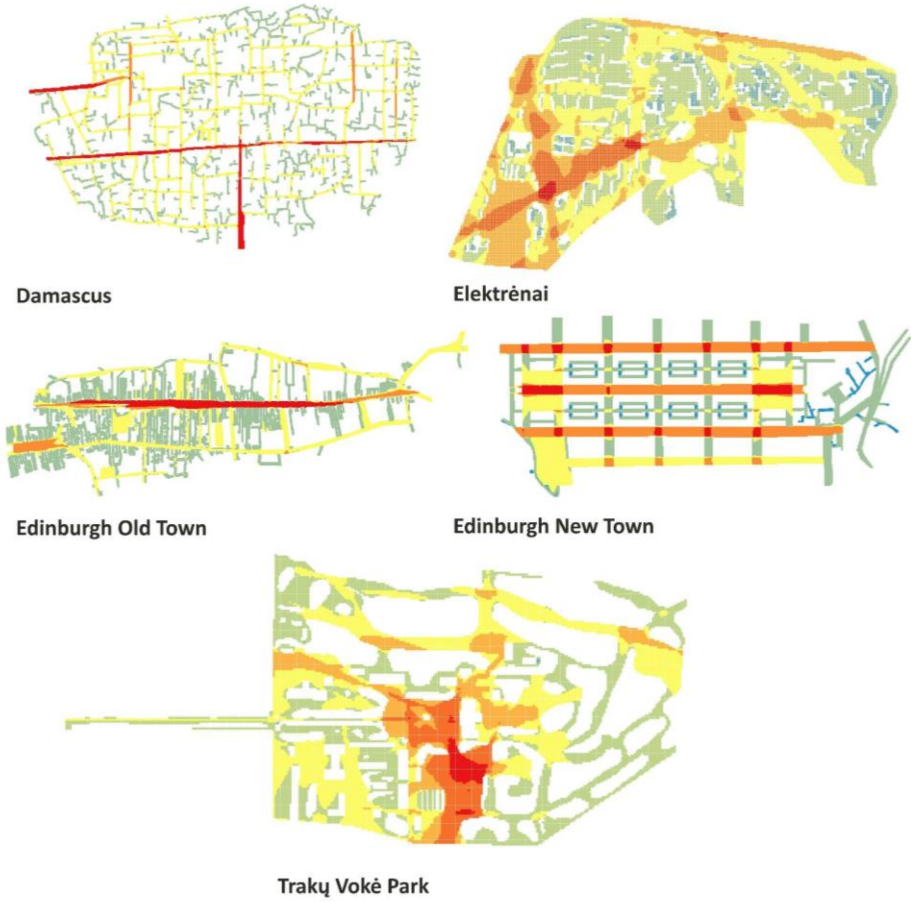


**Figure 1.** Isovist Area. Red color shows high numerical values, blue color - low values

The comparison results of the calculated and normalized indicators are presented in Figure 2. Similarity of the analyzed spatial structures should not be interpreted directly as similarity of form, but more as similarity of genotype in terms of similar visual experience of spaces.

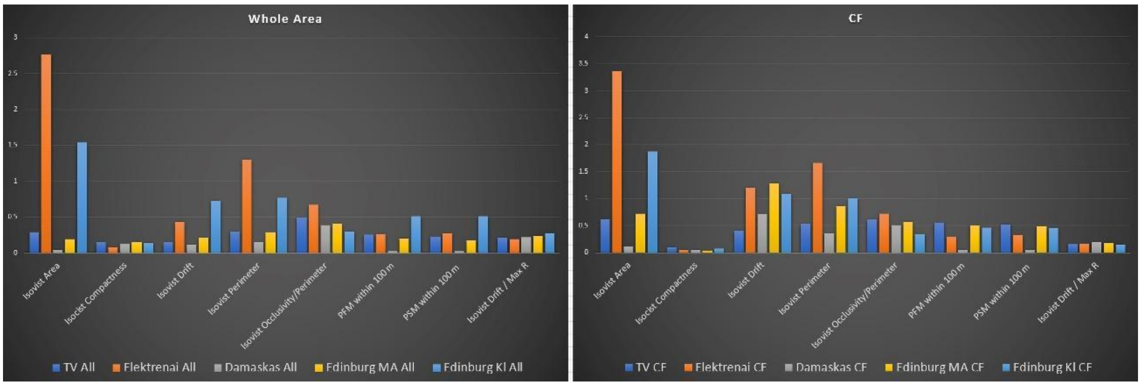


**Figure 2.** Comparison of the calculated mean values of the isovists while calculated within a whole structure (left) and Cognitive Frame (CF) (right)

While comparing mean values of the *Isovist Area*, the results could be grouped into three clusters: high values demonstrated in Elektrėnai and Edinburgh New Town (ENT). In Elektrėnai it reaches 2.75, in ENT – 2.5; medium values are demonstrated by the Trakų Vokė (TV) park (0.29) and Edinburgh Old Town (EOT) – 0,19; the Islamic city of Damascus demonstrates the smallest values (0.045) as it could be expected because of its very compact and dense form. The comparison of the mean values within each investigated area with CF in all cases demonstrates an increase in the indicator, but with notable differences. In Elektrėnai and ENT the isovist area mean values increase just around 21% of the mean value thus showing that in both cases hierarchy of spaces in terms of sizes is not very clearly expressed and perceivable. In the analyzed park and Damascus the increase is much more significant and reaches 100% and 135% correspondingly, thus pointing out structures with higher variety and clear hierarchy of spaces in terms of sizes. In EOT the increase is even bigger and reaches 268 %, thus pointing out even higher diversity of spaces. From the point of view of the Isovist Area it could be stated that EOT is the most similar to the park in terms of sizes of spaces while both EOT and Damascus are similar to it in terms of clearly perceived/expressed hierarchy.

*Isovist Compactness* in four cases demonstrates values close to ~0.14, meaning that in all structures compact spaces are rarely found. Elektrėnai demonstrates the exception with double less values of 0.07. If CF is analyzed, then in all cases it demonstrates decreased values of even less mean compact isovist with a kind of medium decrease in the park (37 %), Elektrėnai (32 %), ENT (44 %). The biggest decrease is observed in Damascus (60 %) and EMT (74 %). It could mean that in the first group of the cities, hierarchy of space in terms of compactness do not differ as much as in medieval cities, where it is expressed much stronger. Based on mean compactness and its change in the CF, ENT is the most similar to the park.

*Isovist Drift*, which stands for kind of dynamic composition of spaces demonstrates the following results. If a whole territory of every object is analyzed then two cases demonstrate the high mean drift: Elektrėnai with 0.43 and ENT with 0.72. In the case of modernist urban planning, it could be reflecting the exact case with asymmetrical forms of spaces but in the case of classicist urban structure it expresses its directive nature focused on regulation of movement with a help of dominant visual axes. The medium values within the presented context could be seen in EOT (0.21). The “calmest” spatial structures are presented by the park (0.15) and Damascus (0.12). If CF is analyzed then Isovist Drift in the cases of Damascus and EOT increases more than 5 times. Medium change in the presented context is demonstrated by the park (179%) and Elektrėnai (178%). The smallest change is observed in ENT – just 51 %. In this case it is showing the high “dynamic character” of all spaces based on the same urban planning principles focused on visual and functional axes and applied more or less evenly in a whole area of a classicism city. In terms of dynamic composition of spaces, Damascus is the most similar to the park; in terms of difference between CF and the rest of the structure – Elektrėnai demonstrates the biggest similarity.

Comparison of the *Isovist Perimeter* demonstrates three groups of results as well: Elektrėnai (1.3) and ENT (0.77) with the highest normalized mean values; medium or moderate values are seen in EOT (0.29) and the park (0.30); Damascus presents the lowest values as expected – 0.15. If CF is analyzed then changes are following: significant changes in Damascus (130%) and EOT (196%) thus reflecting potentially clearly perceived hierarchy of spaces within those structures; medium changes in the park

– 74 %; small changes in Elektrenai and ENT – 28% and 31%. In this case medieval Edinburg demonstrates the bigger closeness to the park.

In terms of *Isovist Occlusivity / Perimeter ratio* the results could be classified into three groups as well: biggest proportion of occlusivity is demonstrated in Elektrėnai (0.67); medium values could be seen in Damascus (0.39) and EOT (0.41); the lowest values were found in ENT – 0.30. These results could be related again to the directive nature of classicist urban planning when attention of the observer is drawn towards some predefined representative spaces and objects in contradiction to the more "democratic" spatial structure of medieval cities. The analyzed park in this case could be seen as having medium values between the max and medium groups with 0.50. CF in terms of occlusivity changes demonstrates the following: the biggest increase in EOT (40%) and Damascus (30%), the smallest increase in Elektrėnai (8%) and medium increase in the park (23%) and ENT (15%). If the mean values of the whole structure are considered then Elektrėnai and both medieval cities are the most similar to the park, while ENT demonstrates similarities in terms of CF differentiation from the rest of the structure.

*PFM* within 100 m or skewness demonstrates the following results: the biggest values are found in ENT (0.51) thus reflecting the axial structure of a classicism city; medium values are found in the park (0.26), Elektrėnai (0.27) and EOT (0.20); Damascus with its labyrinth-like structure demonstrates very low values (0.03). CF in the case of PFM differentiation demonstrates the following: biggest differentiation of CF in the park (118%),  ED ME (152%) and Damasus (99%); medium differentiation in Elektrėnai (14%); low differentiation – even decrease of CF values in ENT (-11%). The result demonstrates an interesting peculiarity of the classicist city model if compared to medieval towns: decreased skewness of the main functional spaces which could be probably treated as a specific feature of the genotype of such cities. EOT demonstrates the biggest similarity to the park.

*PSM* within 100 m or variation demonstrates in essence identical values as PFM: the biggest values in ENT (0.51); medium values in the park (0.23), Elektrėnai (0.28) and EnT (0.18); very low values in Damascus (0.02). Situations for CF is identical to PFM as well: biggest differentiation of CF in the park (128%),  EOT (169%), Damasus (116%); medium differentiation in Elektrėnai (14%); low differentiation ENT (-13%); EOT demonstrates the biggest similarity to the park.

For the *ratio between Drift and Max Radius* the whole structure demonstrates very similar indicators in all cases: the park – 0.21, Elektrėnai – 0.20, Damascus – 0.22, EOT – 0.23, ENT – 0.27. Situation changes if CF is analyzed: the biggest decrease of the indicator in CF is found in ENT – minus 49%; the medium results are seen in the park (-26%) and EOT (-26%); the smallest decrease is in Elektrėnai (-14%) and Damascus (-11%). The medieval Edinburg is the most similar to the park in this case.

The results of comparison are summarized in the matrix in Figure 3. The matrix clearly demonstrates the biggest genotypic similarity between the form of a medieval European city and the park. As it was mentioned above, the term "similarity" should not be interpreted in straightforward form as two types of in essence different spatial structures were compared: park and urban form. In this case "similarity" means a kind of genotypic closeness of spatial structures, which could be expressed in different types of forms and could be used as a technical tool for inspiration, biomimicry of natural structures in urban spaces, analysis and even parametric design. These preliminary analysis results justify the biophilic value of historic urban form, which, with reference to Mazzola (2019) can be identified as inheritable biophilic urbanism. Of course, the presented small investigation should be seen just as a test of the idea and possibilities of mathematical graph based mathematical modeling for the above-mentioned purposes.

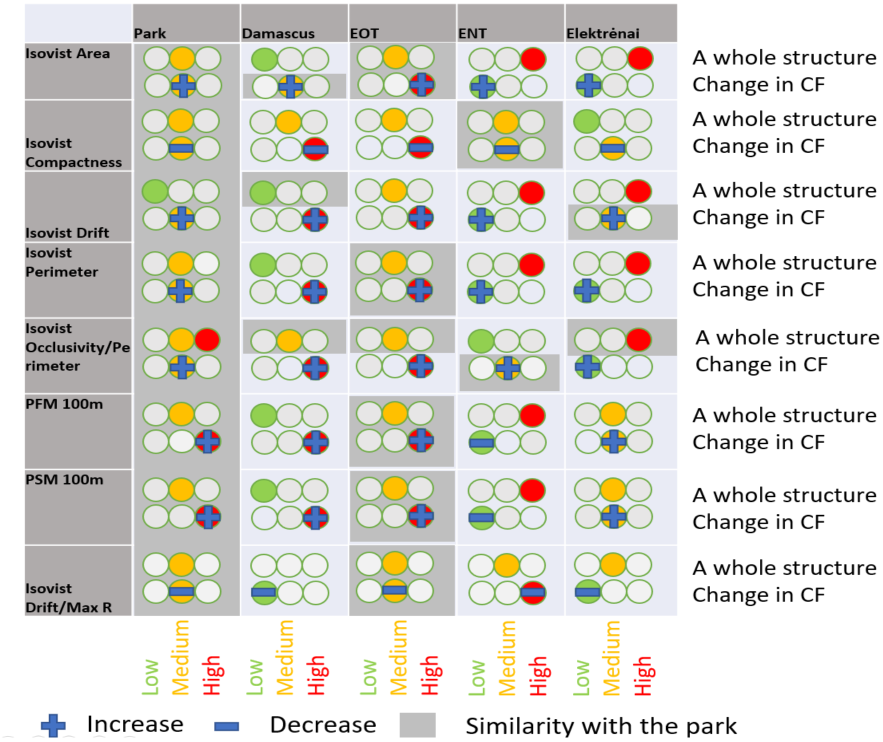


**Figure 3.** Matrix of the comparison of the analyzed spatial structures. The top line of circles represents the mean values of a structure while the bottom line – changes in CF. High values are marked on the right circle, medium – on the middle, low – on the left

## 5. Challenges of application of AI in biophilic urbanism

While AI tools have potentially beneficial, their impacts and risks are not yet fully understood. One of the risks, identified by Robu-Movilă (2025), is that design problems tend to be reduced to merely data manipulation and effective computing. This approach means simplification related to numerous and diverse incomputable dimensions that define the complexity of urban life and planning. Table 2 presents the SWOT analysis of applications of AI in biophilic urbanism, the analysis was carried out using LLMs (Bard, 2024; ChatGPT, 2024).

**Table 2.** SWOT analysis of applications of AI in biophilic urban design

| Strengths | Weaknesses |
|---|---|
| - AI can analyze vast amounts of data and generate numerous design iterations, optimizing for various biophilic elements and achieving efficient planning processes<br>- Generative AI can rapidly explore and generate a multitude of design possibilities, significantly reducing the time required for urban planning and design processes | - The effectiveness of AI models relies heavily on the quality and comprehensiveness of training and input data, which can be limited or biased, leading to inaccurate design outcomes and recommendations<br>- The inner workings of complex AI models can be opaque, making it difficult to understand how they arrive at design decisions, hindering transparency and accountability |

| | |
|---|---|
| - AI can consider diverse user needs and environmental factors, leading to personalized and adaptable urban spaces suitable to specific contexts and communities<br>- AI can translate complex data into understandable visualizations, facilitating communication and collaboration among stakeholders during the planning process<br>- AI can assist in designing optimal layouts for green infrastructure networks and public transit systems, promoting ecological benefits and sustainable mobility<br>- AI Algorithms can optimize urban layouts and designs for factors like green space distribution, energy efficiency and biodiversity, leading to more precise and sustainable urban environments<br>- AI can aid in designing biophilic elements at the micro-scale, such as building orientation, pocket parks and building facades, enhancing the overall biophilic character of urban spaces<br>- AI can analyze large datasets, including environmental and climate data, providing valuable insights for informed decision-making in urban planning<br>- AI can inspire innovative and creative designs by simulating natural patterns and incorporating them into architectural and urban planning concepts | - While AI can generate various design options, it may lack the human ability to understand and incorporate the nuances of cultural context, aesthetics and social needs<br>- AI-generated designs may lack the intuitive and emotional understanding that human architects and planners bring to their work, potentially leading to designs that feel sterile or disconnected<br>- Overdependence on AI could lead to neglecting the expertise and experience of urban planners, architects and landscape designers, potentially overlooking crucial aspects of the design process |
| **Opportunities** | **Threats** |
| - Biophilic urban design with AI can contribute to creating healthier and more sustainable cities by optimizing for natural light, ventilation, green spaces and promoting sustainable mobility, walkability and healthier lifestyles<br>- AI-driven tools can facilitate public engagement in the planning process, allowing residents to visualize and provide feedback on design proposals, fostering a sense of ownership and community<br>- AI can be integrated with other technologies like building information modeling (BIM) and geographic information systems (GIS) to create a holistic approach to biophilic urban design and planning<br>- AI can be used to design urban structures that are resilient to climate change, such as optimizing for flood mitigation, heat island reduction and promoting energy efficiency<br>- AI can provide a platform for interdisciplinary collaboration, allowing experts in urban planning, architecture, ecology and AI to work together for holistic and integrated solutions<br>- AI can help create adaptable urban spaces that respond to changing environmental conditions, promoting resilience in the face of climate change and evolving community needs<br>- AI can be utilized to create interactive tools and simulations, engaging the public in the urban planning process and fostering understanding of biophilic design principles | - AI algorithms can perpetuate existing societal biases if not carefully designed and trained, leading to discriminatory or exclusionary outcomes in urban planning<br>- If the training data for generative models is biased, it may lead to biased design recommendations, potentially excluding certain communities or neglecting diverse perspectives<br>- Over-reliance on AI for design tasks could lead to job displacement in the urban planning and design professions, requiring workforce development and adaptation strategies<br>- The use of personal data in AI models for urban planning raises concerns about privacy and data security, requiring robust safeguards and ethical frameworks<br>- Dependence on specific AI software or service providers could limit flexibility and innovation in the long run, fostering vendor lock-in and hindering competition<br>- Excessive reliance on generative AI without human oversight may lead to overemphasis on technological solutions, potentially overlooking the importance of community input and human experience |

In order to avoid or mitigate the identified weaknesses and threats, Robu-Movilă (2025) recommend re-inserting the meaningful subjective human values and feedback into the generative designing processes as well as a tools for analyzing the effects of urban design solutions on human perception and behaviors (Robu-Movilă, 2025). According to Landes (2022), it is necessary to ensure that the designer still plays a pivotal role in the final output when dealing with generative AI aided design: designer's architectural intuition encompasses numerous latent factors that contribute to the quality and functionality of design. These factors may include perceiving how a site interacts with its surroundings, how people interact with the site, how the site may look like over time (Landes, 2022). Questions about the role and creativity of the designer and the aesthetic aspect should be taken into account. Landes (2022) underlines that introducing generative AI based design tools into user workflows can be a delicate process. In case when users are shown only the best-performing generated designs, the design that performs the best based on certain criteria does not perform well with respect to any number of intangible factors, for example it is visually unappealing (Landes, 2022). In the situation where a designer would go through thousands of AI generated designs before selecting the best one, Landes (2022) raises the questions: is time really being saved and are the creative impulses and skills of the designer being employed in an optimal way? General issues around data privacy, security and the digital divide must be considered as well. Planners must ensure that AI-driven development does not exacerbate inequalities and that all community members benefit from smarter urban planning (Babin, 2024).

## 6. Conclusions

The research has demonstrated that AI and especially generative AI have numerous application possibilities in the processes of biophilic urbanism and in creating nature-based solutions in cities. The analysis of literature and examples as well as idea generation using LLMs allowed concluding that AI can be applied in all the stages of biophilic urban planning and design: from general research and analysis to pre-design, design and post-design phases:

- In the stage of analysis, the following possible applications were identified: analysis of effects of biophilic architecture and urban spaces on humans using virtual reality tools and AI generated images or video; sentiment analysis of texts, facial emotion recognition application to analyze human emotional responses to biophilic designs and environments; analysis of photographs, drawings, video material using AI tools in order to understand better their biophilic features.
- In the stages of pre-design and design the following possible applications were identified: analysis of vast amounts of data related to natural patterns, urban design solutions, local conditions, population preferences etc.; simulation of natural (or even social) processes; ideation and participatory sessions using text-to-image algorithms; idea elaboration and visualization using algorithms trained on large datasets and text-to-image algorithms. The possibilities to obtain quantitative data for generative AI based design of urban structures that would allow the creation of biophilic and culturally sensitive structures was illustrated by the quantitative comparison experiment of urban structures. The comparison based on isovist concept has revealed the genotypic similarity between the form of a medieval European city and the park. This demonstrates the

relevance of study of historic urban structures in order to create inheritable (Mazzola, 2019) biophilic urbanism.

- In the stages of post-design - monitoring, operation, maintenance, user experience - the following possible applications were identified: monitoring of plant species, plant health, urban wildlife, environmental quality factors etc.; real-time response to environmental conditions and user's preferences; educational activities.

Despite the above-mentioned possibilities and the potential of AI tools to integrate nature into data-driven urbanism of the future, the threats of technocentric approach to urbanism, data quality related biases, undervaluing the role of professional designers and planners etc. must be taken into account.

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