*urban science*

Article

# Simulative Modeling of Psychologically Acceptable Architectural and Urban Environments Combining Biomimicry Approach and Concept of Architectural/Urban Genotype as Unifying Theories

**Kęstutis Zaleckis [1,*], Indrė Gražulevičiūtė-Vileniškė [2] and Gediminas Viliūnas [1]**

1 NEB Research Center, Vilnius Academy of Arts, 01124 Vilnius, Lithuania; gediminas.viliunas@vda.lt
2 Faculty of Civil Engineering and Architecture, Kaunas University of Technology, 44249 Kaunas, Lithuania; indre.grazuleviciute@ktu.lt
* Correspondence: kestutis.zaleckis@vda.lt

**Abstract:** This research explores the integration of biomimicry and architectural/urban genotype concepts to model psychologically acceptable environments. Drawing on foundational psychological theories—Gestalt, Attention Restoration, Prospect-Refuge, and Environmental Psychology—this study examines the private–public interface at the various urban resolutions, encompassing land plots, buildings, and urban structures. Biomimicry serves as a unifying framework, linking these theories with principles derived from natural systems to create sustainable and psychologically beneficial designs. The methodology incorporates simulative modeling, employing space syntax and isovist analysis to quantify key spatial features such as proximity, complexity, and refuge. This study evaluates traditional historical architectures from diverse cultural contexts, such as Islamic medina, Medieval European town, and modernist urbanism, to identify patterns of spatial organization that balance human psychological needs and ecological sustainability. Findings highlight the fractal and hierarchical nature of spatial structures and the importance of integrating human-scale, culturally relevant designs into modern urban planning. By establishing a replicable framework, this research aims to bridge theoretical and practical gaps in environmental psychology, biomimicry, and urban design, paving the way for resilient and adaptive environments that harmonize ecological and human well-being.

**Keywords:** biomimicry; architectural genotype; urban design; environmental psychology; simulative modeling; space syntax; isovists; psychological well-being; fractal urbanism; preferred environments

check for updates

Academic Editor: Laura Cirrincione

Received: 20 November 2024
Revised: 21 February 2025
Accepted: 3 March 2025
Published: 7 March 2025

**Citation:** Zaleckis, K.; Gražulevičiūtė-Vileniškė, I.; Viliūnas, G. Simulative Modeling of Psychologically Acceptable Architectural and Urban Environments Combining Biomimicry Approach and Concept of Architectural/Urban Genotype as Unifying Theories. *Urban Sci.* **2025**, *9*, 75. https://doi.org/10.3390/urbansci9030075



## 1. Introduction

The growing complexity of modern urban environments and their psychological impacts on inhabitants highlight the urgent need for designing spaces that foster well-being, sustainability, and inclusivity. Theories of human environmental preferences, such as Gestalt theory, Attention Restoration Theory, Prospect-Refuge Theory, and Biophilia, provide a robust foundation for understanding human–environment interactions. Biomimicry is a design philosophy with an increasing interest in sustainability in architectural and urban design practices [1]; it draws inspiration from natural systems and offers a unifying framework for integrating these theories into architectural and urban practices. By reflecting characteristics inherent in nature, such as form fits function, catalysis of cooperation, local contextuality, continuity, diversity, integrity, self-organization, redundancy, decentralization, multi-functionality, less energy consumption, hierarchy, and fractality [2], biomimicry has the potential to create environments that are both ecologically sustainable and psychologically restorative.

Despite growing recognition of the psychological impacts of urban environments, contemporary urban design often lacks a structured, quantitative approach to integrating human cognitive and emotional needs into spatial planning, resulting in environments that contribute to stress, social isolation, and reduced well-being. Existing methodologies remain fragmented, failing to provide a unifying theoretical framework that bridges environmental psychology, biomimicry, and quantitative spatial analysis, limiting their applicability in evidence-based urban design. Urban planning that disregards psychological and ecological factors can create a range of intertwined problems. A notable issue is the decline in overall well-being among residents, often fueled by limited green spaces and the absence of natural elements [3]. This shortfall can heighten stress, anxiety, and mental fatigue, revealing the importance of incorporating nature into built environments. Meanwhile, the excessive use of concrete combined with sparse vegetation contributes to the heat island effect, which not only raises urban temperatures, but also drives up energy consumption and worsens air quality [4]. Ecologically uniform or "monoculture" landscaping and fragmented habitats reduce biodiversity by displacing local wildlife and plant species [5]. Poorly integrated natural water systems often lead to frequent flooding and soil erosion, highlighting a need for better resilience strategies [6]. Socially, homogenized, car-centric designs cut down on meaningful community interaction and erode a shared sense of place [7]. Several real-life cases illustrate how neglecting these aspects can be detrimental. The Pruitt-Igoe Housing Complex in St. Louis, for example, relied heavily on stark concrete structures, providing little regard for resident well-being, eventually becoming a prominent example of social and structural collapse [8]. Likewise, the rapid urban sprawl in Dhaka, Bangladesh, lacks adequate ecological planning, leading to recurrent flooding, pollution, and heightened stress among inhabitants [9]. Adopting a biomimicry framework helps address these pitfalls by drawing inspiration from natural systems and circular processes. This approach encourages resilient infrastructures that reduce waste and preserve resources, while also promoting human-centered designs, such as fractals and organic forms, that improve mental health. Nature-based solutions, like wetlands for water purification, can tackle urban challenges with minimal environmental impact. Overall, aligning urban development with ecological cycles paves the way for long-term sustainability, enhanced livability, and healthier communities.

The aim of this research is to develop and validate an innovative methodology for simulative modeling of psychologically acceptable urban environments that integrates biomimicry principles with architectural and urban genotype concepts. This study employs space syntax and isovist analysis to quantify key spatial features such as proximity, complexity, and refuge. It innovatively analyzes the interplay between urban structures (cities) and individual architectural units (houses) as interconnected systems, exploring their spatial and psychological coherence. The objects of analysis include historical traditional architectural forms, such as Islamic medina, Medieval European town, and modernist urban settlement of the 20th century, providing a culturally diverse context. By examining the transition between private (building interiors) and public (urban spaces) environments, this research bridges gaps in current methodologies, offering insights into the fractal and hierarchical nature of spatial systems. This dual focus on cities and houses in combination represents a significant advancement in the field of biomimicry-based urban and architectural studies. The findings of this study aim to bridge gaps in environmental psychology and biomimicry research by offering a practical, interdisciplinary methodology for designing urban and architectural spaces that align with human psychological and ecological needs.

## 2. Materials and Methods

### *2.1. The Importance of Relations Between Humans and Their Environment from a Psychological Perspective*

In the fields of environmental psychology and landscape aesthetics, nature is often seen as the benchmark for a preferable environment due to its inherent ability to contribute to human well-being, reduce stress, and support cognitive restoration presented in several influential theories [10,11] and proven by researchers [12,13]. For example, the hypothesis of Biophilia, coined by Wilson [14], on the inherent human affinity with nature, suggests that humans are evolutionarily predisposed to prefer natural environments or artificial environments that mimic natural elements and characteristics. Other evolutionary landscape theories also underline that the most preferred environments created or transformed by humans somehow echo or imitate natural environments that were favorable for the survival of the human species: "the commonality of park-like environments in our recreational areas and backyards and the pleasure derived from viewing pastoral-type landscapes with large scattered trees amidst grass reflects, according to the evolutionary aesthetics argument, the prevailing landscape of the East African plains on which humans evolved" [11]. This view of nature as a benchmark of preferable environment encouraged the emergence of such research and practice trends as biophilic design and biomimicry, which draw inspiration from nature's designs and systems, highlighting how emulating these characteristics and patterns in architecture and urban planning can create spaces that feel more harmonious and positively affect the human psychological state. However, despite the existing advances in empirical research on preferred environments, there is still a lack of a unifying approach that would allow one to understand and both qualitatively and quantitatively evaluate the features of the built environments from the point of biomimicry urbanism. In order to formulate such an approach, first of all, the main theories explaining human psychological preferences towards environments were selected and analyzed, including gestalt theory, attention restoration theory, prospect-refuge theory, preferred environment framework, and the above-mentioned biophilia and biomimicry.

Gestalt theory focuses on how people perceive objects, shapes, and forms as whole entities rather than separate parts, and emphasizes how humans naturally perceive patterns and organization in their environment. In the context of architecture and urbanism, the following relevant principles of gestalt psychology were distinguished: proximity, similarity, continuity, closure, symmetry, figure-ground, common fate, and simplicity [15,16]: the principle of proximity means that there is a tendency to visually group the objects—objects close to each other are perceived as a group; the similarity principle states that elements that are similar in appearance (similar qualities such as size, shape, color, and texture) are perceived as part of a whole; the continuity principle maintains that items arranged similarly towards a certain direction tend to be perceived as a group; the principle of closure states that if there is a clear surface limited by direction, boundary, or intermediate spaces, the elements that define it tend to be perceived as a whole or a unit; the symmetry principle means that humans perceive and organize visual elements into patterns in a balanced, symmetrical order; the figure-ground principle states that people tend to distinguish objects from their backgrounds; the common fate principle means that in a composition consisting of elements creating sensation of movement to different directions, the elements with same or similar directions are perceived as a group; and the simplicity principle states there is a tendency to perceive complex things as simplified forms [15–17]. Gestalt principles, such as proximity, similarity, and figure-ground organization, could potentially influence urban design by enhancing spatial legibility and coherence, ensuring that built environments are perceived as structured, navigable, and visually harmonious.

According to attention restoration theory, natural environments help to restore diminished attentional capacity [10]; thus, this theory explains why natural environments are so effective in restoring mental focus and relieving cognitive fatigue, and underlines the relationships between the naturalness of a scene and human restoration or stress recovery [18,19]. This theory presents the characteristics of restorative environments, such as fascination, being away, extent, and compatibility [10,20,21]. Fascination is characterized by a state that requires little mental effort to pay attention. In restorative environments, people experience stimuli that are "softly fascinating". For example, nature's softly captivating elements (like flowing water, rustling leaves) engage attention effortlessly, allowing for mental restoration. Being away characterizes distancing from everyday stress—a change from everyday urban settings to natural environments offers a mental break, supporting psychological recovery. Extent means the experience of expansive spaces and contexts. The environments that are rich and immersive, offering a sense of vastness or connectedness, foster deeper restoration, as nature often provides diverse and continuous experiences. Compatibility means the engagement in activities that are compatible with our intrinsic motivations; thus, environments that align with a person's needs and desires are more restorative [10,20,21]. By emphasizing the restorative effects of nature, attention restoration theory can promote the integration of green spaces, water features, and dynamic visual elements into urban settings to reduce cognitive fatigue and promote psychological well-being.

Prospect-refuge theory analyzes how humans are instinctively drawn to environments that balance opportunities for viewing the surroundings (prospect) and safe, enclosed spaces (refuge), and underlines the evolutionary role of humans as both predator and prey, which results in a preference for landscapes offering both prospect and refuge, i.e., the possibility to "see without being seen". According to prospect-refuge theory, landscapes offering this feature provide a source of aesthetic pleasure [18,22]. In this theory, open spaces that allow for observation and a sense of control, evoking feelings of safety and comfort, are considered as prospects; sheltered areas that provide protection and a sense of security, reducing stress and anxiety are identified as refuge. In design, the combination of the features of prospect and refuge would be an integrated composition of open and sheltered spaces, which increases psychological comfort, recreating the way humans seek environments that offer both opportunities for exploration and safety in nature. Transition spaces that allow moving between prospect and refuge creating a sense of continuity and comfort in the environment are also relevant to this theory. Prospects, according to this theory, can be direct or indirect and include panoramas and vistas, while refuges, such as hides and shelters can be classified by function, by origin (natural or artificial), by substance (in the earth as caves or in vegetation), by accessibility, and by efficiency [11]. This theory can potentially influence urban design by guiding the balance between open, observable spaces (prospect) and sheltered, enclosed areas (refuge), creating environments that feel both stimulating and secure.

Preferred environment or information processing theory states that the perceptual process involves extracting information from the surrounding environment and suggests that humans seek to make sense of the environment and to be involved in it. This theory identifies four predictor variables, two of which (coherence and legibility) help one understand the environment, and the other two (complexity and mystery) encourage its exploration [11,23]. The appreciation of landscapes with properties that make them easily readable would hence be favored by natural selection, and the genetic bases for such landscape preference would still be inherent in people today [18]. Legibility is the ability to predict and to maintain orientation as one moves more deeply into a scene. Legible environments are easy to navigate and understand, and reduce cognitive load. Complexity is the involvement component, a scene's capacity to keep an individual occupied without being bored or overstimulated. Complex, rich, and varied environments stimulate the mind without overwhelming it; they engage curiosity while offering clarity. Coherence is the ease of cognitively organizing or comprehending a scene. The environment, where elements are well-organized and interconnected, creates a sense of order and stability, often found in structured systems in natural environments that can be seen as coherent. Mystery is the promise that more information could be gained by moving deeper into the setting. Mysterious environments evoke curiosity and engagement and suggest further exploration, much like a winding path or concealed natural spaces [11]. Demonstrating the role of coherence, complexity, legibility, and mystery in environmental preference, this theory reveals the importance of designing urban spaces that balance order and intrigue to foster engagement, ease of navigation, and a sense of place.

Biophilic design and biomimicry focus on integrating nature's principles, features, characteristics, and forms into human environments. Biophilia or biophilia hypothesis by Kellert and Wilson bases aesthetic appreciation of the environment on the innate human biological need to affiliate with nature. This theory emphasizes the importance of natural diversity of species and of landscape types and the tendency naturally inherent in people through evolutionary history to focus on and appreciate life and lifelike processes [19]. By advocating for direct and indirect connections with nature, biophilic design principles encourage the use of natural materials, daylight access, and organic patterns in urban environments to improve human health and sensory experience. Meanwhile, biomimicry in the context of architecture and urbanism involves learning from nature and using its principles to design sustainable and self-sufficient built environments [24,25]. The following characteristics from biophilic design and biomimicry approaches closely related with the above presented theories were distinguished: prospect and refuge [26], transition spaces [27], complexity and order [28], and place-based design [29]. For example, reflecting the prospect-refuge concept, biophilic design incorporates open spaces and protective enclosures that reflect spatial characteristics of nature and support human psychological needs for exploration and safety [26]. Biomimicry urbanism emphasizes the importance of designing transitions in a way that mirrors natural ecosystems, creating flow and continuity between different spaces [27]. Complexity and order are expressed in the richness of natural forms combined with their inherent order that appeals to the human preference for environments that are both stimulating and harmonious. Place-based design in biomimicry urbanism encourages solutions that respond to the local environment conditions and its natural features, creating a sense of connection between people and places. Inspired by the adaptive strategies of nature, biomimicry may additionally influence urban design by promoting self-sustaining, resilient ecosystems in the city and urban environments themselves, leading to energy-efficient, multi-functional spaces that optimize environmental performance and human comfort.

Implications for urban sustainability. The integration of biomimicry principles and psychological theories in urban and architectural design not only enhances human well-being, but also aligns with sustainability goals, particularly in addressing energy efficiency and carbon emissions. As urban areas and buildings significantly contribute to global energy consumption and emissions, innovative approaches that could reduce environmental impact while maintaining psychological acceptability are essential. Recent studies highlight the need for a global transition towards net-zero buildings, emphasizing challenges and opportunities in reducing carbon emissions throughout the life cycle of a building, especially during the operational phase [30]. The renovation and adaptation of existing building stocks are also seen as key strategies for sustainable urban development, allowing for emission reductions without excessive new construction [31]. Biomimicry-based urbanism offers a framework to enhance energy efficiency by mimicking ecological processes such as self-organization, redundancy, and multi-functionality, which can optimize resource use and spatial adaptability. Moreover, integrating principles of environmental psychology into urban planning can contribute to the creation of restorative environments that improve well-being while reducing urban energy demand, particularly through passive design strategies inspired by natural systems.

### *2.2. Biomimicry as a Unifying Concept and Its Translation into Spatial Rules*

The analyzed theories underline that designed environments reflecting the patterns, balance, and diversity found in nature are most psychologically acceptable, justifying the idea that nature serves as the benchmark for preferred environments. In this context, biomimicry, the practice of drawing inspiration from designs of nature to solve human challenges, offers a unique pathway for addressing both psychological and ecological issues within urban environments. By emulating resilience and adaptability of nature, urban planners can reduce resource consumption and pollution while improving community well-being [24]. For instance, integrating green spaces that mimic forest ecosystems fosters mental health benefits, as exposure to greenery has been linked to lower stress levels and enhanced cognitive functioning [12]. Furthermore, nature-inspired architectural elements, like fractal patterns, can induce a calming effect and help people feel more connected to their surroundings [32]. On the ecological front, biomimicry-informed designs emphasize circular resource flows, much like the closed-loop systems found in natural habitats [33]. These strategies promote urban habitats that support biodiversity, conserve energy, and manage waste more efficiently. By echoing the interconnectedness and self-sustaining principles of natural ecosystems, cities can become both more livable and more robust in the face of climate change. In this way, biomimicry stands out as a holistic approach that simultaneously addresses pressing ecological demands and fosters the psychological well-being of urban populations.

Considering this, biomimicry can be viewed as a unifying theoretical framework in this research, as it is based on forms, patterns, and principles found in nature, which resonate with the grounding of the other theories (Figure 1). Thus, it is not surprising that the idea of applying biomimicry to cities is attracting increasing attention as a way of achieving not only sustainability, but also positive effects on human psychological well-being. Some biomimicry urbanism approaches suggest evoking natural models, for example the forest [34], in the urban environments. However, there is also a hypothesis that characteristics of natural environments and ecosystems, such as form fits function, catalysis of cooperation, local contextuality, continuity, diversity, integrity, self-organization, redundancy, decentralization, multi-functionality, less energy consumption, hierarchy, and fractality, often identified in the context of biomimicry research [2], could be created without directly emulating natural features, or could even be inherently present in some urban forms, including historic urban structures.

The characteristics of natural systems, such as hierarchy, fractality, decentralization, self-organization, etc. [2], align closely with various urban models, reflecting the intrinsic biomimetic potential of traditional and contemporary urban structures. The analysis of urban theories, such as New Urbanism, Smart Growth, and others, reveals that many of these models inherently support biomimicry principles by promoting multi-functionality, continuity, and local contextuality, even if not explicitly designed with biomimicry in mind. For instance, fractality, observed in natural growth patterns, is mirrored in the self-similar structuring of urban spaces, ensuring adaptability across different scales. Similarly, hierarchical organization in ecosystems translates into urban planning through spatial stratification, where functional zoning and layered accessibility optimize urban efficiency and resilience [35].

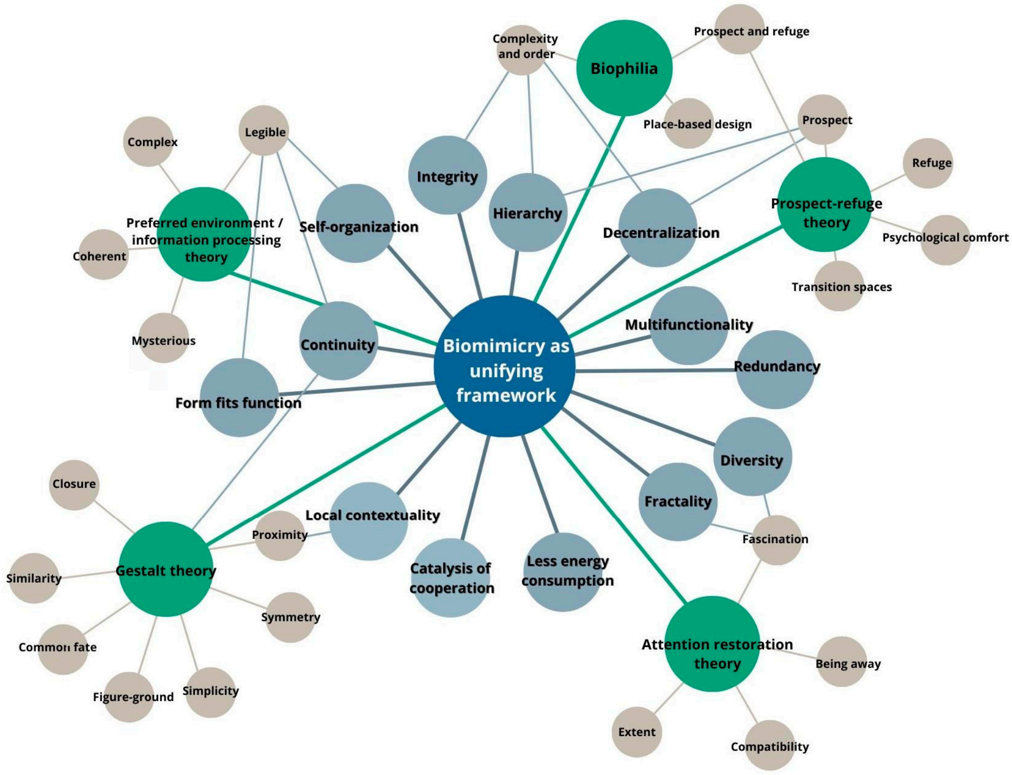


**Figure 1.** Visual representation of the interconnections between the psychological theories and the features of natural systems grounding the idea of biomimicry as a unifying concept in this research.

From a mathematical graph-based perspective, the structural features of natural systems correspond to key graph centralities, such as Betweenness Centrality, which captures movement potential and accessibility within spatial networks, and Closeness Centrality, reflecting the efficiency of spatial integration. These indicators provide a quantitative means of evaluating biomimetic urban patterns, revealing how spatial structures facilitate cooperation and redundancy in urban movement. Connectivity centrality, often associated with self-organization, demonstrates how distributed networks in nature and cities support resilience by enabling multiple interaction pathways. Such graph-based urban simulations offer a way to systematically apply biomimicry to urban planning, ensuring sustainable and psychologically cohesive environments, as demonstrated in previous research [2].

The relationship between biomimicry and genotype theory by Hillier [36,37] emerges in the way that biomimetic principles influence distributed and non-distributed spatial rules. The conceptualization of urban genotype by Hillier [36,37] highlights how spatial structures evolve through generative processes that balance bottom-up (self-organizing) and top-down (hierarchical) constraints. Biomimicry further strengthens this approach by illustrating how spatial configurations can mimic natural efficiencies, such as form fits function, ensuring that spatial structures evolve in response to human and environmental needs. By integrating biomimicry with genotype theory in the following sections, this research proposes a unified methodological framework that integrates ecological, psychological, and spatial principles to create sustainable and adaptive urban environments.

### *2.3. The Urban Genotype Concept by Hillier and Research Methodology*

If the essential features of natural systems could be reflected either directly or indirectly applied or inherited in urban and architectural spaces, then they should be definable by architectural genotype as well. Genotype is defined by Hillier [36] as abstract transpatial rules underlying spatial forms of both buildings and cities. The term transspatial refers to the nature of the genotype which extends across or transcends multiple spaces or spatial boundaries. It implies a relationship or interaction not confined to a single, isolated space, but across different areas, locations, or spatial domains.

The idea of genotype as a collection of rules was based by Hillier on observing some degree of randomness and its relation to architectural form. According to him "... (even) simple experiments on how restrictions on a random process of aggregating cells (as elementary "bricks of architectural space)" could lead to well-defined global patterns that bore some resemblance to patterns found in real buildings and settlements." [36]. It was noted that restrictions on an otherwise random process are a very important part of the rules as well, meaning that the genotypic collection of rules includes both non-order (generated in a bottom-up way) and order (restricted in a top-down way) in its basic axioms. The interaction of bottom-up generative rules with restricting top-down rules in essence helps to understand how hierarchical spatial urban structures are created. A simple historical example from Vedic urbanism of Ancient India could be presented as a clear example: the Vedic sacral texts provided certain patterns describing principle allocations of the main buildings in regard to each other and the rest of urban structure, e.g., the main temple in the center, palace—located to the north, housing of certain social groups in specifically described situations, etc. [38]. Such requirements established limits for generative bottom-up rules and assured functional and compositional dominance of the objects essential for city functioning while establishing limits for generative bottom-up processes. Similar processes could be seen in the town planning of Ancient China based on research [39], or potentially identified in Medieval European urbanism based on logical analogy. On the other hand, fractality of urban and architectural structures is assured by application of at least partially the same generative rules for random processes of spatial formation applied for different urban and architectural objects. Organization of the spatial structures of living houses, palaces, and even temples based on the same "Pavilion" principle when a single room or groups of rooms form one pavilion, which is allocated around the central open space of the courtyard, could be a good example in this case. We believe that the initial observation of randomness and its influence on spatial form conducted by Hillier could be expanded and applied to natural structures with the similar results, e.g., growth and branching patterns of trees or even whole forests, termite structures, river networks and erosion, etc., could be described in a set of relatively simple rules that either could be similar to rules of organic architectural or urban structures, or rules identified on the basis of natural systems, could be at least tested in urban and architectural environments.

While attempting to apply the initial idea of the genotype, Hillier noted two in essence different conditions of the applications of the genotypic rules: generative processes happening inside and outside the initial cell. Those different ways in which random process could be restricted more precisely: "...in the one case cells were, as it were, 'glued' together by space which they defined between them (generation outside of a cell); in the other cells were 'bound' together by having higher-order cells superimposed around them (generative process happening inside of a cell)" [36]. Those two types of cells were called distributed and not distributed, respectively. Later on, while creating space syntax theory based on the genotype concept and mathematical graph theory [37], distributed genotypes were "naturally" related to urban structures and not distributed—to genotypes of buildings. The same two types of distributed and not distributed "cells" could be used to classify generative and random processes in nature, e.g., growth of a tree or construction expansion of termite structure would be an example of a distributive process, while a wild bee honeycomb inside a tree could be seen as a result of non-distributive process. At this point, especially while looking at nature's examples, we should note that such typology of relations between genotype typology and spatial structures is very simplified. In our research, we advocate for the fact that the relation between distributed and non-distributed codes is more complex and not always clearly dualistic and excluding each other. The above presented example of a wild bee honeycomb is a good illustration: if it is made inside a tree cave—it should be named not distributive; if it is attached to a tree branch—then it should be called distributive. Similar situations where such situations could be observed in architectural structures could be identified. The initial idea that grounded the creation of the typology of two codes was based on the presence of top-down restrictions in a genotype that can act as a cell of higher, superimposed order on an otherwise bottom-up generated cell. We can observe at least two borders of restricting or superimposed cells at two different hierarchical levels in any ancient or medieval walled city: building walls and city walls. Furthermore, if it is a multicultural and multinational city that has quarters of different social-cultural groups such as Hellenistic Alexandria [40] or Medieval Jerusalem, then restricting borders appears inside a city as well as defining generations of urban blocks inhabited by specific social-cultural groups. Such inner restricting borders, based on cultural, social, or other criteria, could be present even in the most restrictive form as a wall, e.g., controlling walls around wards of Ancient Chang-An; walls around some parts of the Ancient Egyptian cities as workers' districts or temples districts; walls separating territories of different magistrates in medieval European cities such as Torun (Tornau), etc. It could be argued that even contemporary "open" cities with no perceivable physical border have administrative borders that define the limits of planned territory. Despite the presented above examples and argumentation, it could still be asked if and why a more complicated vision on the relation of distributed and not distributed genotypes is needed, and if it could be simply related to restrictive rules of the genotype. In our opinion, such a complicated and complex perspective demonstrates the fractal nature of relations between a building and a city, which is little investigated in urban and architectural settings, but is seen in natural structures where all hierarchical levels interact and intertwine with each other. Most often, the smallest scale urban analysis and modeling is limited by morphological types, densities, and intensities of single plots or groups of plots, but, if we see the city as a fractal or living system within a biomimicry perspective, it would be logical to investigate the genotypes of buildings and cities not separately, but look for possible typologies and regularities of interaction between both. The potential importance of such an approach is in essence supported by the property of symmetry describing neighboring and spatially/functionally directly connected cells: "... if A is a neighbor of B, then B is a neighbor of A—the property that mathematicians call symmetry." [36]. According to Hillier's idea and definition, symmetry between spaces enables direct interaction between users of those spaces. At the same time, it should be noted that the entrance to the house creates symmetry between interior space and exterior space, and allows us to see and investigate them as a spatial continuum even if "The space within the boundary(building) established a category associated with inhabitant; the boundary formed a control on that category and maintained its discreteness as a category: the world outside the system was the domain of potential strangers, in contradistinction to the domain of inhabitants" [36], but at the same time "... the space outside the entrance constituted a potential interface between the inhabitant and the stranger: and the entrance was a means not only of establishing the identity of the inhabitant but also a means of converting a stranger into a visitor." [36]. If an analogy with the earlier discussed biomimicry-based theory is used, such open urban space—the interior of a building system could be seen as a prospect-refuge analogy. Here we can point out again that the concept of symmetry as the basic link between architectural spaces, which creates potential for interaction between them, could be easily applied to natural systems.

A straightforward illustration of such an application is the first simulative model of the human brain, which was created 15 years ago [41]. It employed the mathematical graph model, which was contracted out of nodes representing neurons, and edges representing links between them. Hillier suggested using the same mathematical tool to analyze symmetry and asymmetry in urban and architectural spatial structures based on links between neighboring spatial "cells" [36].

Finally, Hillier points out that the architectural genotype differs from the biological one in a way that it is not carried as information in the object itself, but generated by social-cultural reality as ". . . each society constructs characteristic encounter patterns for its members, varying from the most structured to the most random (and in those patterns) we recognize an aspect of the social for that society." [36]. These statements support the potential usefulness of the idea of investigating the interior of a building and urban structure as one spatial continuum while using the same genotypic model.

How could the spatial genotype be described precisely? Hillier suggests the concept of the morphic language, which ". . . aims to understand how the morphology may be generated from a parsimonious set of elementary objects, relations, and operations." [42]. This was developed into two primary mathematical graph-based models of architectural space, axial graph and convex graph, traditionally using the first one for urban structures of distributed genotypes and the second one for interior spaces or non-distributed genotypes with the third model of visual graph, which in essence is equally suitable for both types of genotypes offered around twenty years later [43]. As mentioned earlier, the same graph model, in essence based on similar arguments, could be used and is used for the mathematical modeling of natural systems.

The idea of the isovist or viewshed was based on an earlier idea by Gibson to define the visual environment as a system of objects that structures the light as a source of stimuli for human (and every other animal who relies at least partially on visual perception of the environment while looking for prey or potential danger) perception [44]. Benedikt, based on the above-mentioned ideas of Gibson, offered the concept of isovist as ". . . a method for recording landscape" [45] where isovists are defined as a volume of space visible from a single point. Features of such a form could be analyzed either in 3D volume or 2D planes either horizontal or vertical. Each point within a spatial structure has its own isovist. According to Benedikt ". . . various perceptual and cognitive factors are well presented by certain numerical measures of shape and size attached to the isovist" [45]. Finally, Franz and Wiener [46], based on empirical investigation, proved that isovists could be seen ". . . as objectively determinable basic elements" of the visual environment, which ". . . capture environmental properties of space that are relevant for spatial behavior and experience" [46]. Space Syntax and other simulative models identify isovists while using a mathematical graph model in the following steps: space is divided into identical square cells while using the same steps, e.g., 1 m, 2 m, etc., depending on map size; each cell is transformed into a graph node while visibility relations between them make graph links or edges, e.g., if cell A is visible form cell B and vice versa then they both have a common edge; the isovist that is visible from each node properties are calculated as node centralities, e.g., the number of connected nodes of connectivity represents the isovist's area, etc. The exact isovist properties and formulas will be presented in the next section. The possibility to bridge isovist analysis with one of the earlier discussed psychological theories (prospect and refuge) and environmental psychology in general was demonstrated by Psathiti [47], while just focusing on the interior working spaces, thus supporting the methodological idea presented in this research.

### 2.4. Biomimicry-Based Features of Acceptable Space and Corresponding Visual Graph Centralities

The presented research is a pilot investigation that has to test the idea and prove or deny its applicability and sensitivity to different urban and architectural contexts. While having this in mind, generalization of the list of the features of the preferred or acceptable environment according to the psychological theories discussed in Section 2.1 for further research was generalized based on the following criteria: the possibility of relating them to the isovists' properties clearly and logically; aim to minimize the number of the investigated aspects just to the most important with the aim to make the research result more manageable and eliminate partial overlaps between them when similar spatial preferences are named differently in different theories.

Proposed connections between visual graph centralities and selected aspects of the environment named by theories of psychology:

- Proximity as the feeling that the observer is in a coherent environment where all parts are close to each other should be related not directly to the properties of individual isovists that cover just part of the integral spatial structure, but the spatial network which is conceptually perceived as a whole, e.g., by creating mental maps of a whole structure besides directly perceived viewsheds. In more simple terms, spatial proximity refers to the relative nearness of objects, spaces, or elements within a given environment. It plays a crucial role in spatial organization, influencing human behavior, movement patterns, accessibility, and interactions within both natural and built environments. Proximity could be measured based on geometry, functional or social relations, and visibility, which could be addressed via the isovist model. Of course, the visual spaces described by the isovists could be visible just from neighboring spaces in the bigger structures, but, if a space is easier to reach while other spaces should be crossed then we can say that it has a higher proximity or closeness in relation with the rest of the spatial structure. Space Syntax Visual Graph Analysis offers more than one indicator that allows one to compare the closeness of a spatial network, or each isovist in our case, to the most reachable point: it could be the Total depth or closeness centrality in the Graph theory terms as a sum of distances from each node to the rest of the nodes where the smallest sum demonstrates the most reachable point and the mean value (Mean Depth) of the sum gives an overview of the proximity of every node to the rest of a network or even Integration as a form of normalized Mena Depth. In the presented case, the Total Depth was chosen as the most straightforward and simple indicator based on the principle stating the following: if two models could be used and both are equally effective, then the simplest should be preferred. In the case of the visual graph and the isovist-focused model such a distance is measured in a number of the edge points of different isovists that should be crossed in order to see the generation point of the isovist for which the calculation is made. The problem is that neither Total Dept nor Mean Depth are normalized, thus not allowing us to directly compare visual graphs of different sizes, e.g., buildings of different sizes or even building and urban spaces. In this case, Space Syntax offers Integration, which is normalized while comparing a precise spatial configuration with statistically probable configuration of the same size. Integration is calculated in five steps based on five formulas, which are described by Koutsolampros [48]. To not expand the explanation, it just should be pointed out that in essence, integration is based on the calculation of Total Depth as a sum of the distance from every node to the rest of the nodes in the Visual Graph while using the formula [49]:

$$TD_i = \sum_{j=1}^{n} d_{ij},\ j \neq i$$

where *TD* marks the Total Depth calculated for node *i* to every other node *j*, and $d_{ij}$ marks the shortest distance between I and every *j* measured in a number of turns. Integration simply normalizes this value and transforms the scale in a way that a bigger number, but not a smaller number shows the most reachable point. Bigger normalized integration in a spatial network demonstrates its bigger proximity.

- Fascination (Attention restoration theory), Figure-ground (Gestalt theory), and Prospect (Prospect-Refuge Theory) as aspects of space are related to the attraction of attention based on diversity and contrast, the offer of unexpected experience, and activation of imagination because of some hidden parts. It could be found in spaces which offer more and diverse visual information: more different views, hiding part of visible space behind some elements (e.g., columns), offer both long and short visual perspectives, etc. A forest or park can serve as an example of such a fascinating environment. It could be expected in the isovists with more complicated and complex forms (e.g., more star shaped viewshed). A combination of two VGA indicators could be directly connected to those spatial properties: perimeters of the isovist as it means more visual information, and occlusivity of the length of invisible boundaries that appear when some physical elements block part of the viewshed (e.g., the forest could be seen as a spatial structure where occlusivity of the isovists reaches very high values). To combine both indicators, we propose to multiply the isovist perimeter value by its occlusivity. In order to make isovists of different sizes comparable and reflect fascination just based on spatial configuration but not size of space, the result was divided by isovist area. "Given that an isovist is a polygon, the metrics *Isovist Area* and *Isovist Perimeter* measure those properties for that polygon. Note that isovists are simple polygons; thus, for every isovist with n vertices on its boundary and $x_i$, $y_i$ the coordinates of each vertex calculate the above using" [48]:

$$Isovist\ Area = \frac{1}{2}\sum_{i=0}^{n-1}(x_i y_{i+1} - x_{i+1} y_i), where (x_n, y_n) = (x_0, y_0)$$

$$Isovist\ Perimeter = \Pi = \sum_{i=0}^{n-1}\sqrt{(x_{i+1} - x_i)^2 + (y_{i+1} - y_i)^2},\ where (x_n, y_n) = (x_0, y_0)$$

Isovist Occlusivity is simply calculated by the same formula as *Isovist Perimeter* while excluding the visible part of it.

- Being away (Attention restoration theory) and Refuge (Prospect-Refuge Theory) features are created by quiet, safe, meditative, and introvert spaces or kind of small rooms that are hidden from the rest of the network but viewed all immediately when entered. In VGA analysis, it could be represented by the clustering coefficient that "was expressed as the ratio of the number of cells in an isovist that can see each other to the total possible connections that could exist between those cells" (i.e., all-to-all connections). This metric seems to have been developed to measure convexity and compactness as it points out the spaces where all are visible to all (coefficient is 1), but it also seems to be able to point out junctions (low coefficient: standing on a corner where one can see two spaces but the spaces cannot see each other)." [48]. In terms of the Prospect-Refuge theory, a high clustering coefficient means a person in space can see all other parts of it but remains enclosed inside it, aligning with the refuge concept. On the other hand, spaces with a balance of high clustering and moderate visibility directly from them or after a small step or peek outside them over neighboring spaces, provide a sense of safety without excessive isolation. A simple example of such a space in architectural and urban terms could be a positive outside room which has limited visibility from other space or outdoor room in terms of patterns described by Alexander [50] as more private space beside a street, etc. It is calculated by the formula:

$$Visual\ Clustering\ Coefficient = C_i = 2e/n(n-1)$$

where $e$ represents the mutually intervisible cell of the visual graph and $n$—number of nodes visible from the node $i$ for which calculation is conducted. It is important to point out that no normalization, in this case, is needed as the clustering coefficient is equal to 1 when all cells of the isovist are mutually intervisible and decreases when the degree of intervisibility is lower.

- Simplicity (Gestalt theory) is described as the possibility of perceiving spatial configuration as a simple form. There are two essential types of simple spaces in architecture: prolonged spaces with straight corridors as their simplest form and compact rooms with circles as their simplest form. VGA allows identification of both types of isovists. Elongation is counted as skewness or *Point First Moment*, which is calculated by the formula [48]:

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

where $d(v_i,v_j)$ is the distance between the generative point of the isovist and all other vertices $j$. A bigger sum potentially shows more prolonged isovists according to the observation of various VGA analysis results. Normalization of the indicator was achieved by dividing it from the isovist area.

The circular convex form of an isovist is reflected by its compactness calculations in VGA. It might look similar to the clustering coefficient presented earlier, but the clustering coefficient focuses on analysis of internal visual relations inside more closed space, while compactness analyzes just forms. The clustering coefficient represents more refuge-type spaces while compactness represents spaces perceived as more stable because of the form. The following formula is used for calculation [48]:

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

where $A$ is the isovist area and $\Pi$ is the perimeter. Calculation compares ratios of the area and perimeter of the isovist with those of the circular isovist. As it is based on the ratio of two indicators and can reach a maximal value of 1 if the isovists is ideally circular, no normalization was needed.

- Common fate (Gestalt theory) and Continuity (Gestalt theory) are explained as an expression of the perceivable similar dynamic character of spaces. It would be logical to assume that spaces that are more commonly visible from different positions create some kind of common identity and could be related to the common fate aspect. Traditionally, if urban structures are analyzed, such spaces are used for commonly important landmarks as monuments or iconic buildings, which potentially can become significant elements of the mental city image according to Lynch [51]. If something is added or changed in such places, then it is visible from many points. VGA analysis offers through vision as an indicator of the most exhibited and commonly viewed spaces. Through vision of a node visual cell is calculated simply by counting how many times it appears on a line of mutual intervisibility between all the other cells. A higher value means a higher degree of exhibition.

Two more aspects should be considered when analyzing genotypes of acceptable spaces:

- The Combination of Prospect and Refuge (Prospect-Refuge Theory) as demonstrated by the close connection yet clear separation between in essence two different types of spaces, one which, according to the above proposed methodology is presented by, e.g., high occlusivity and clustering coefficient. Analysis of combinations of those features could be useful and will be used for a more general view and interpretation of the results in a more complex way. Such a decision is grounded on the potential analogy between non-dispersed and dispersed codes that together make a city and refuge and prospect spaces, which both are needed for human comfort. If the above-mentioned analogy is applied directly, it could be assumed that buildings make refuge spaces while the city provides prospects. If, as discussed earlier, the distinction between non-dispersal and dispersal codes obtains a kind of fractal relation and cannot be separated so clearly, then the Combination of Prospect and Refuge, as a kind of basic complex feature of acceptable environment can be even more helpful in understanding regularities of the investigated architectural-urban systems.
- Compatibility (Attention restoration theory) shows the correspondence of spatial layout to its function or, in terms of Salingaros—the correspondence between function and composition as one of the three laws of architecture identified by him [52]. It could be addressed while looking for the correspondence between the functional logic of the investigated structure and spatial patterns presented by the isovist indicators described above. Because of the relation to all employed in the research VGA indicators analysis of compatibility between functionalities of real investigated structures and Space Syntax results will be used for at least initial validation of the model while overlapping of "syntactic" and "functional" layers and checking if modeling results are explaining and helping to understand the functional logic of real structure better. Such analysis could be seen as Quantitative-Qualitative Synthesis of two types of data; as an alignment with Real-World Functionality; and as Predictive Capability Assessment meaning that if space syntax indicators consistently correspond with certain functional zones across different cases, it can confirm the model's potential to predict how spatial configurations may perform or adapt in similar functional contexts.

### *2.5. Investigated Objects, Data Used, and Software*

The presented pilot research, as was briefly mentioned earlier, has the following objectives: validate the proposed model and establish a theoretical-methodological framework for further investigation; evaluate the model's practical applicability; check if it is sensitive enough to different contexts and identify its limitations and challenges. Based on the above-mentioned objectives and while focusing on the amount of data which is at the same time relatively easily manageable for calculation and still represents some diversity of architectural-urban genotypes, the following criteria were used for the selection of the analyzed cases:

- At least three cases should be used to see if the model is sensitive to different spatial-social systems.
- The investigated urban structures should represent different cultural contexts with different architectural genotypes.
- Because both urban structures and living houses as the basic fundamental architectural cell will be investigated in limited numbers, then the selected cases should demonstrate a kind of homogeneity on both dispersed and not-dispersed genotypes. In addition to this, the transspatial nature of the genotype should be observable. In other words, selected cases should be seen as good candidates for the typical representation of the

architectural-urban features of represented cultures and urban planning ideologies with relatively similar patterns of living houses.

- Because of the earlier discussion of complex interrelation and mix between distributed and non-distributed codes, it would be good that the selected cities would have clear boundaries that would allow us to see them as a result of both types of genotypes.
- Last but not least: availability of data for space syntax modeling and validation of the results in terms of functional structure, etc.
- Based on the described criteria, the following three research cases were selected:
- Sfax in Tunis is representative of the medieval Islamic city with its specific labyrinth-like street network which aims to not generate accidental transit in housing clusters, introvert houses demonstrating very similar or even identical patterns focused around the living courtyards, clear functional zoning of urban structure and hierarchy which combines public, semi-public, and semi-private spaces, etc. In terms of morphology, it represents the highly enclosed irregular grid of streets and introverted housing. It is important to note that, according to Hakim [53], such urban forms were created based not on spatial plans, but on a kind of generative cultural codes and rules, thus making it especially interesting for urban genotype-based analysis. Strict social-spatial zoning based on residential privacy vs. public space opposition makes this case interesting for the presented research where both urban public spaces and interior spaces are investigated while using the same models. Extreme climatic adaptation through a compact design and shading or internal courtyards function as microclimate regulators, and minimal land consumption make Sfax, and other Medieval Islamic cities, good samples for the presented pilot study even if those aspects are not investigated directly but just via perspective of spatial perception. In terms of spatial perception, Sfax represents a potential refuge-dominated space made of introverted courtyard housing, enclosed pathways, and different degrees of privacy of streets, with public spaces unfolding gradually, thus potentially creating a secure environment. On the other side, the city form demonstrates cognitive complexity: maze-like streets create a high spatial depth, which is mentally stimulating but can be disorienting.
- Medieval Cracow in Poland is a good representative of European historical urbanism: its street network demonstrates features of both organic and regular gothic city plans; medieval living houses, despite the diversity of architectural forms, demonstrate the same typology and functional patterns; in contradiction to the Islamic city, spatial structure offers a much bigger number of transit options; the city has double-centric structure focused on market square and the castle. In terms of morphology, it represents a compact and walkable urban form with a regular street network in the bigger part. A well reachable marketplace (Rynek Główny) could be seen as a hub of economic and social life. Two different parts representing two stages of evolution are presented in a plan: a more organic part close to the castle and a regular one around the marketplace. Despite its compactness, if compared to Sfax, urban structure is much more regular, with longer open perspectives and bigger spaces, so it is interesting to compare how such changes affect psychological acceptability. On the other hand, we can assume that the regular part of the city was planned based on some simple blueprint of street layout, but an increase in densities, and changes of configurations of land plots and buildings could be seen as random, bottom-up generated processes, thus allowing one to expect some genotype-based similarities with biomimicry systems. In terms of spatial perception, the city could be seen as a system of balanced prospect-refuge spaces which differ from Sfax: enclosed streets provide refuge, while the central square offers openness and collective engagement;

relatively easy wayfinding assured by a regular street network and similar accessibility of the streets from houses, etc.

- Elektrėnai in Lithuania was built as a settlement of power plant workers in 1960-1968. It represents characteristic features of the modernist city: monofunctional zoning, buildings placed "in a park"; separation of pedestrian and transport flows; limited typology of living flats based on typical, repeated projects of houses; etc. In addition to such features, the city has a clear boundary formed by surrounding natural territories. In terms of morphology, the city differs significantly from the other two examples. It represents modernist zoning with a clear separation of residential, industrial, and green spaces, with even pedestrian and car routes separated from each other. Houses are placed freely as "stones" in a park according to the modernist urban planning principles. The selected example represents a pure case of top-down urban planning even if organic formal forms were somehow respected. In terms of ecology, the city has high energy dependence: it was designed around an electric power station, prioritizing industrial output over ecological considerations and it promoted a car-dependent life model. On the other hand, integration of green spaces can be seen as a positive aspect. In terms of spatial experience, Elektrėnai could be described as a high prospect and low refuge: large, open spaces create potentially an exposed psychological experience (weakening enclosure).

While summarizing the arguments for case selection, it could be said that the tree cities cover the essential variety of urban typologies starting from the organic, bottom-up generated and extremely compact one; continuing to compact as well but more regular and not so introverted one; and finishing with top-down planned, based on monofunctional zoning, dispersed structure.

The following data were used for modeling and analysis:

- OSM data on the UNESCO heritage site in Sfax together with historical city plans which include layouts of individual buildings [54].
- The precise Cracow plan which shows the 18th century situation with defensive wall still standing and morphological structure in essence not changed much from the Middle Ages, with additional information about functional aspect used; plans of buildings in Cracow were taken from the web page focused on 3D reconstruction of the city [55].
- OSM data were used to obtain the Elektrėnai plan. Plan of the typical flats were taken from the publication about Soviet modernistic housing by Drėmaitė [56].

Space syntax analysis was conducted using DepthmapX (v0.8.0) [57], a software developed for visual and spatial network analysis. All plans were prepared in dxf format with just boundaries made by walls mapped.

## 3. Results

### 3.1. Validation of the Syntactic Models Based on Compatibility to Form Fits Function Principle

Several indicators from the Visual Graph Analysis (From VGA) and additionally conducted axial graph analysis were selected for validation of the modeling results while looking for some logical coincidence of syntactic and functional patterns. The idea was simply to overlap the results of VGA modeling, which could be easily related to functioning of city spaces, with the available data on functioning of those structures such as location of the main objects, functions, densities, the main routes, etc. The aim was to see if at least some of the data demonstrate clear overlapping which could be observed, and if models are sensitive to the essential differences of the investigated cities.

From VGA, the following metrics applied:

- Connectivity—measures the number of visual connections from a specific point where bigger numerical value means bigger area of the isovist visible form the point. In real cities, spaces with higher connectivity represent more in terms of spatial composition and potentially functionally important spaces, which bring people and functions together, create more possibilities for visual contact, etc., e.g., market or town hall squares, the main streets, other formally or informally representative spaces, areas of visual landmarks, etc.
- Point Second Moment—evaluates the distribution of visible distances, determining spatial homogeneity or heterogeneity where higher numerical values mean less compact form. It is counted in a similar way as the Point First Moment described earlier, just with values squared. The indicator could be seen as one combining occlusivity and connectivity—it was not used in the modeling of the features of acceptable environments, but found useful for more generalized comparison of functional and syntactic zones. According to the VGA model, spaces with a bigger Second Point moment values have stronger expressed star shape form: they offer more diverse visual experience, higher variety of close and far locations; they are more extroverted, etc. In cities, such spaces potentially coincide with the most multi-functional spaces such as market zones and the main streets. On the other hand, this indicator could be useful to see different character and logic of spaces in different urban zones, e.g., more extraverted spaces in a multi-functional center and more introverted spaces in quiet housing neighborhoods.

The Axial analysis, which is based on modeling of visual axes, was used as an additional tool for validation. This supplementary model was employed because of two reasons:

- The functioning of urban structure, even relatively small such as the selected cases, is not possible without movement of people and vehicles. The isovists and VGA models do not reflect and simulate movement of people directly in a straightforward way.
- The axial graph, as well as the visual graph, is based on visual connections. The essential difference is that, in the first case, the node of the graph or "cell" of urban space is a small part of space, while in the second case—visual axis. Connections between the nodes are represented, as it was mentioned earlier, by mutual intervisibility between parts of visual space in the VGA model and intercessions allowing visibility between axes in the axial model. In such a case, the axial model could be seen as a kind of more generalized version of the VGA model, which, in addition, offers indicators based on simulation of movement of people from every axis to all the other axes.

The axial graph model was chosen over the most often in space syntax modeling of urban structures used segment analysis as more suitable in the presented case because of the focus of the presented research on visibility, relatively small size of the investigated urban areas where topological distances are at least of equal or even higher importance than metric distances, and, at the same time, simulating concentration of people, movement, etc. The metrics applied were as follows:

- Relativized Entropy (further Entropy)—indicates the diversity of routes and navigation choices, for the mathematical definition, see Hillier et al. [58] (p. 365) and Turner [28] (p. 8). In essence, the biggest entropy shows the most hidden, potentially the most private areas of the spatial structure which are the most hard to find accidentally. It is expected to overlap with the most private housing areas, the most specialized and monofunctional zones, etc.
- Intensity—assesses reachability potential in key locations presented in normalized form, "It also aims to capture the movement efficiency given the distance one must travel in the network" [59]. As it is an alternative and more precise for calculations

of integrations—the most reachable areas in urban structures which, if the model is working well, should coincide with the most functionally intensively used, the most important key areas of the spatial structure as business districts, market squares, etc.

- Choice—measures how frequently certain segments are used as the shortest path [58]. If the model is working well, high choice values should overlap with the main transit streets.

City and Building Plan Analysis:

Elektrėnai. Visual Connectivity: the strongest visual connectivity was observed at the main city entrance junction, thus reflecting the importance of symbolical spaces which could be called “city gate” (Figure 2). Importance of those spaces could be confirmed by the sculptural composition “Elektra” located at the main entrance to the city. Point Second Moment: courtyards of multi-story buildings were homogeneous, with relatively little variation between near and far visible points. It corresponds to observed facts that even while applying concepts of modernist urbanism in Soviet Lithuania, the attempt to make courtyards of multi-flat houses more private and compact, was made. Of course, it does not mean that modernistic courtyards were as compact and homogenous as some spaces of the medieval city—for such comparison, normalization of values would be needed as discussed in the methodology section, but spatial allocation of not normalized values correspond to in situ observed differences in character of public spaces of the city. Building plans revealed the strongest visual connectivity at staircase junctions (“apartment crossroads”) and the weakest in sanitary facilities.

Sfax (Tunisia). Visual Connectivity: strong connectivity was observed at a single point—the religious center with a prominently expressed main street. Point Second Moment: high heterogeneity was noted near market areas, with significant differences between points located close to each other. Entropy: the street network demonstrated high values, thus reflecting the functional hierarchical zoning of public spaces: public with the least entropy and semi-private, located deep inside living quarters with high entropy. Choice: in essence, only the real main streets which connect city gates and the main objects such as Mosques and Souks demonstrate high values. The low values in the living quarters correspond well to the attempt to avoid concentrated transit flows there. Intensity: high reachability or closeness was observed at the most important (around Mosques, Souks) zones. Building Plans: centralized layouts dominated, with living rooms-courtyards serving as hubs connecting other spaces. The center exhibited strong visual connectivity, contrasting with the corridor-based street network.

In essence, while looking at the overlapping maps (Figure 2) it could be concluded that the higher entropy values in Sfax and Cracow correspond to more quiet zones of housing, while lower entropy values correspond to the most central, multi-functional areas. The same specialization of spaces in two cities is additionally confirmed by higher values of choice (the main street) of core urban centers and intensity, which was expected to show urban cores of the investigated areas. The isovist-based indicators show clear differentiation—bigger and more complex in terms of shape, isovists are observed in the zones that attract the biggest amount of functions and people in Sfax and Cracow. Meanwhile, Elektrėnai presents not so clearly overlapping results, as Choice just partially corresponds to the main streets, but intensity and entropy correspond to the allocation of the main functional nodes quite well.

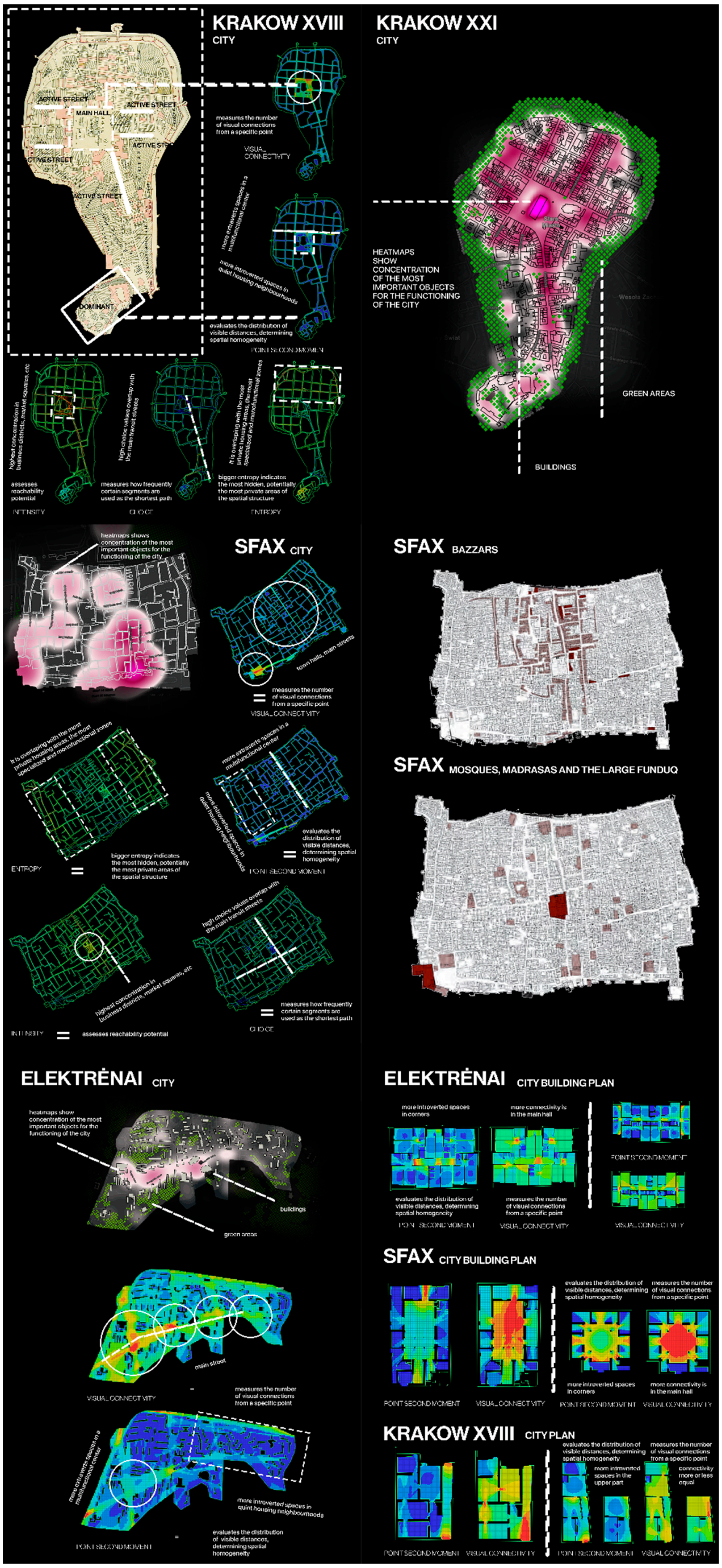


**Figure 2.** Space Syntax analysis for three cities (Cracow, Poland; Sfax, Tunisia; Elektrėnai, Lithuania). Red colors show high and blue colors show low numerical values. Specific terms: bazzars—markets in the Islamic city, funduqs—commercial spaces, serving the needs of merchants for lodging, storage, and security.

In the case of the investigated houses, the biggest and most complex isovists correspond to the main functional nodes, which are important for all house-users as living courtyard in the Islamic medieval house and medieval house in Cracow. A slightly different situation is observed in the modernist flats in Elektrėnai: the results show a completely different logic of spatial structure made of isolated rooms, represented by low complexity of the isovists, connected just by logistic corridors without additional common function. Such a result echoes quite well to the idea of monofunctional zoning in urban modernist structures. More detailed analysis of the results of every city are presented further.

Cracow (18th-Century City Plan). Visual Connectivity: a strong connection was observed in the Town hall/Market square, characterized by high intensity of the axial map as well, thus demonstrating overlapping patterns of syntactic indicators and higher functional importance. Entropy: the lower part of the city, particularly Wawel Castle with some peripheral streets in the southern part of the city, stood out as the hardest to find zones. In this case, it reflects the real situation: more quiet and specialized character of the peripheral streets and allocation of the castle which gives it a certain degree of both functional and compositional autonomy supporting its role as the strongpoint for defense against potential attacks from outside as well as from inside. Such patterns of allocation of palaces and castles could be observed in many medieval cities. Point Second Moment: streets exhibited high values due to the straight corridor-like street network. "Closed" gothic squares with streets entering their corners showed low values, indicating spatial homogeneity with minimal differences between near and far points. Choice: low in squares but slightly higher in streets, and especially high in the main streets connecting the main city points: some gates, Town hall square, Wawel. Building Plans: visual connectivity within buildings was not very much differentiated, but correspondence of slightly higher values in the main living rooms was noted. The Point Second Moment metric indicated high heterogeneity in some building corridors or connecting spaces and could be associated with the need to make space clearer in terms of visual navigation.

This analysis revealed the spatial characteristics of the three cities which corresponded to the results of space syntax modeling as presented in Table 1:

- Elektrėnai: strong visual connectivity in key nodes, thus possibly representing a car-oriented city plan with representative spaces at the entrance points and buildings, emphasizing spatial homogeneity and uniformity.
- Sfax: centralized religious and market areas contrasted with corridor-dominated street structures.
- Cracow: syntactic modeling clearly correlated or overlapped with the main functional zones and streets quite well representing dual functional patterns constructed based on segregation of Town hall square and the castle.

Contextual Framework. The analysis was guided by N. A. Salingaros's architectural principles [60–63], emphasizing:

- Hierarchy and Structure—connections between networks and scales.
- Fractal Design—repeating patterns across scales.
- Information Richness—the importance of detail and complexity.

The more detailed aspects demonstrating peculiarities of the investigated spatial structures were offered and evaluated by the authors on a 10-point scale, where 10 means strong presence of analyzed spatial features.

Elektrėnai (Total Score: 65). Human Scale Compatibility (8/10): the city's layout and building plans are well-suited to human proportions, providing functional and comfortable spaces for residents if compared to the other modernistic cities. Connections and Networks (8/10): strong visual connectivity at key nodes, such as the main entrance junction, ensures efficient movement within the city. Focus on User Experience (7/10): the city provides a functional and straightforward layout, making an attempt to contribute to user comfort. Fractal Design (5/10): the city lacks the intricate repeating patterns often seen in more naturally inspired designs. Information Richness (6/10): the homogeneity of spaces, especially in courtyards and apartment layouts, limits the richness of visual and spatial experiences. Resilience and Longevity (6/10): while functional, the lack of architectural diversity and long-term adaptability reduces its longevity potential.

Sfax (Total Score: 79). Hierarchical Structure and Scale Relations (9/10): a clear hierarchy is evident with the central religious node and main street dominating the layout. Connections and Networks (9/10): the city exhibits a well-connected street network, with significant links between central nodes. Adaptation to Context (9/10): Sfax reflects its cultural and historical context, integrating traditional architectural styles and functional urban design. Information Richness (8/10): the markets and central spaces offer diverse and stimulating environments. Human Scale Compatibility (6/10): while some central areas are well-proportioned, the corridor-like street system can feel restrictive and less accommodating. Importance of Natural Light and Forms (8/10): although strong in religious and market areas, this criterion is less emphasized in other parts of the city.

**Table 1.** Subjective analysis of three cities using N. A. Salingaros's architectural principles [60–63].

| Architecture Principle | City and Compatibility (1–10) |
|---|---|
| Hierarchical Structure and Scale Relations | Cracow, Poland (8); Sfax, Tunisia (9), Elektrėnai, Lithuania (7) |
| Information Richness | Cracow, Poland (9); Sfax, Tunisia (8), Elektrėnai, Lithuania (6) |
| Fractal Design | Cracow, Poland (8); Sfax, Tunisia (7), Elektrėnai, Lithuania (5) |
| Human Scale Compatibility | Cracow, Poland (9); Sfax, Tunisia (6), Elektrėnai, Lithuania (8) |
| Adaptation to Context | Cracow, Poland (10); Sfax, Tunisia (9), Elektrėnai, Lithuania (7) |
| Biological Analogy | Cracow, Poland (8); Sfax, Tunisia (7), Elektrėnai, Lithuania (5) |
| Connections and Networks | Cracow, Poland (9); Sfax, Tunisia (9), Elektrėnai, Lithuania (8) |
| Importance of Natural Light and Forms | Cracow, Poland (9); Sfax, Tunisia (8), Elektrėnai, Lithuania (6) |
| Resilience and Longevity | Cracow, Poland (9); Sfax, Tunisia (8), Elektrėnai, Lithuania (6) |
| Focus on User Experience | Cracow, Poland (9); Sfax, Tunisia (8), Elektrėnai, Lithuania (7) |
| Total | Cracow, Poland (88); Sfax, Tunisia (79), Elektrėnai, Lithuania (65) |

Cracow (Total Score: 88). Adaptation to Context (10/10): the city's layout seamlessly integrates historical and cultural elements, including its central hall, Cathedral Square, and Wawel Castle. Information Richness (9/10): the diversity of architectural styles, public spaces, and historical sites ensures a stimulating urban experience. Connections and Networks (9/10): the street and square network is well-organized, linking important city nodes efficiently. Human Scale Compatibility (9/10): the city's layout, particularly its central areas, provides a welcoming and human-centered experience. Resilience and Longevity (9/10): Cracow's historical structures and thoughtful urban planning demonstrate its capacity for long-term sustainability. Fractal Design (8/10): while the city exhibits some fractal properties in its street network, this aspect is not as pronounced in building layouts.

In essence, it could be concluded that even based on selected analysis of some aspects of the three cities, and expert-based evaluation, it seems that the presented models are sensitive to differences of real structure, reflect at least some essential aspects of functional logic, and could be used at least as logical abduction-based explaining models.

### *3.2. Genotypes*

The visualized full results of the modeling are presented in Figures A1–A6 in Appendix A. In all cases, the results of the calculations are visualized while using a standard deviation size. In the case of 1 standard deviation and more, note either 15.9 percent of the highest or the lowest values allowing the most important areas for the precise aspect of the acceptable space. The scatterplots with the summarized comparison of the results are presented in Figures 3 and 4.

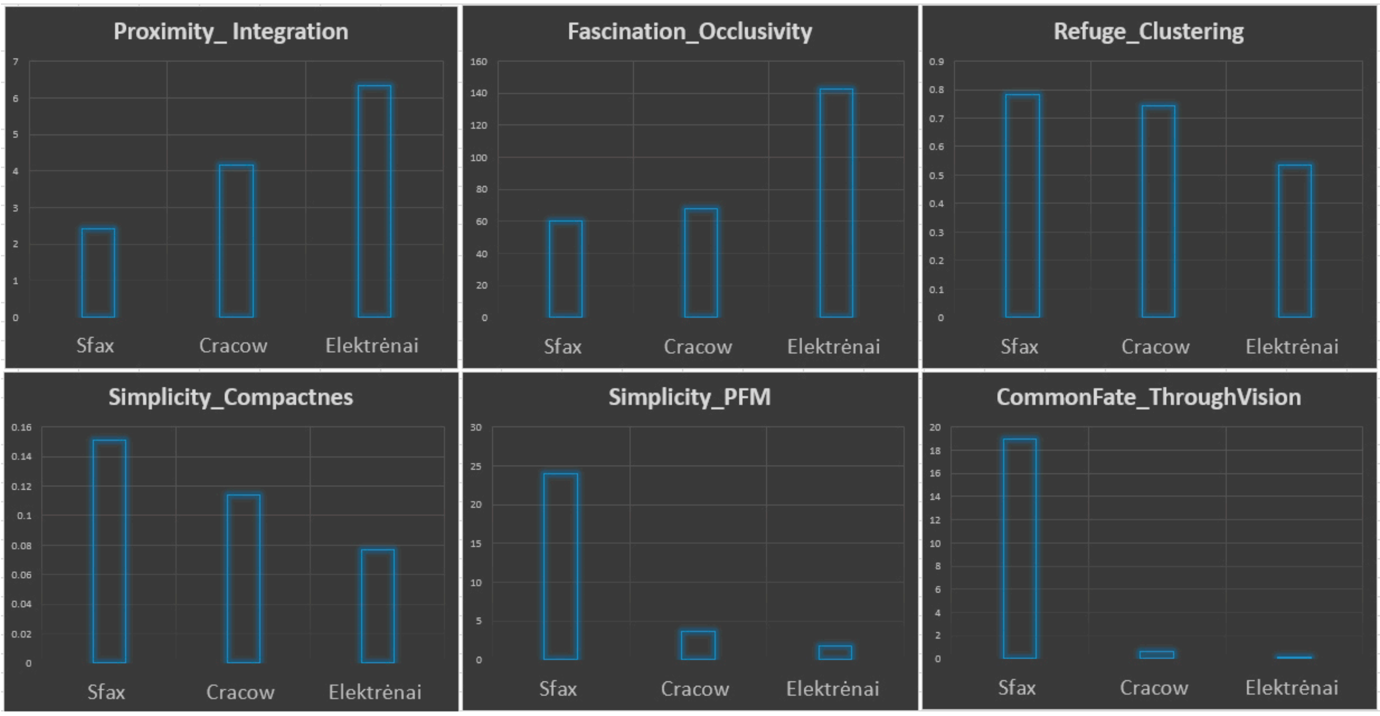


**Figure 3.** Comparison of space syntax normalized indicators representing six aspects of the acceptable spatial environment in the cities.

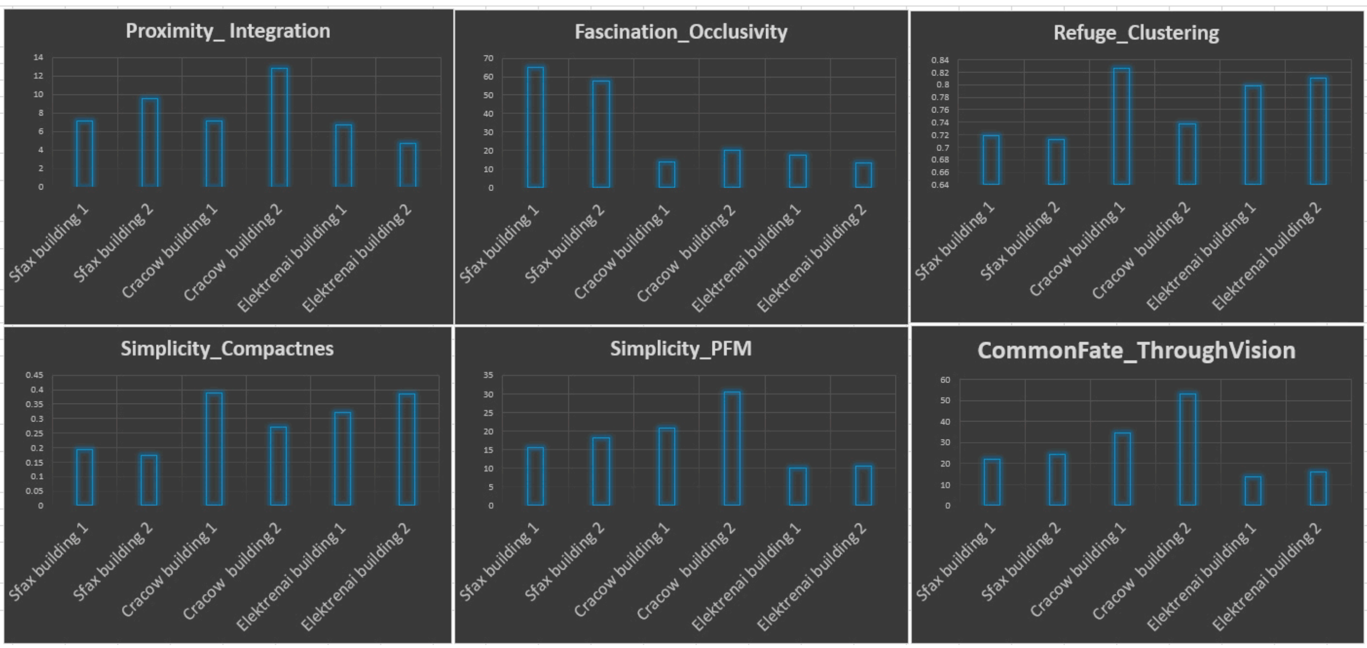


**Figure 4.** Comparison of space syntax normalized indicators representing six aspects of the acceptable spatial environment inside houses.

If just urban structures are compared (Figure 2), then the following results could be pointed out:

- Proximity as Integration: the low values in Sfax reflect its labyrinth-like structure and functional specialization (public, semi-public, semi-private, private open spaces, functional zoning, etc.); medium results in Cracow correspond to a more integrative nature of the gothic city plan with more functional and spatially homogeneous structure; high values in Elektrėnai well reflect the idea of modernist urbanism when houses are seen as placed in continuous open spaces such as parks or fields.
- Fascinations as occlusivity: low to medium values in Sfax and Cracow demonstrate some kind of control, potentially not overloading with visual stimuli, organized in recognizable patterns of high occlusivity features; high values in Elektrėnai speak about potentially overloaded and possible visually overstimulating spatial structure.
- Simplicity as PFM: high values in Elektrėnai, low-medium in Cracow, and low in Sfax. In essence, it reflects openness and degree of visual axis-oriented spatial composition. It could be seen as a kind of clearness of the call or information for a movement of spatial configuration, or let us call it dynamic simplicity. If plans of cities are compared, then it should be noted that such simple axial lines are clearly defined by contrast with buildings, a limited number of from one-point visible axes, and consistent sequence of presentation of spaces "axe after axe" in Sfax and Cracow. In Elektrėnai, a lot of potential axes are visible from the same spots.
- Simplicity as compactness: high values in Sfax, medium in Cracow, and low in Elektrėnai. If combined with PFM-based form simplicity, it shows the degree of introversion of spaces which, because of simplicity, allows one to focus on internal processes with less disturbance from neighboring spaces. We can call it static simplicity.
- Refuge as clustering: big values in Sfax and Cracow as a reflection of clearly perceivable in situ combinations "visible and clearly definable here" spaces in terms of Cullen [64], and quiet "pockets" or outside rooms in terms of Alexander [50]. Medium values in Elektrėnai demonstrate that modernist urbanism still made an attempt to create quieter or refuge spaces, but either closeness is lower or perspectives of visible "there" are much longer if compared to the other two samples. Possibly both are true.
- Common fate as through vision: high values in Sfax, medium to low in Cracow, and low in Elektrėnai. A tree-like street network with a small number of alternative movement routes between origins and destinations of movement and clear separation of various functional zones could be seen as corresponding and explaining the logic behind such results in Sfax. Medieval Gothic plan city focuses on creating more equal alternatives for functions, movement, etc. Modernistic urbanism creates the biggest number of spatial alternatives to look and move, thus making features of the common fate hardly perceivable and creating competition between spaces.

We can generalize that the proposed indicators quite well reflect essential differences in urban genotypes of three cities with a kind of controlled proximity, fascination, and dynamic simplicity in Sfax and Cracow. Elektrėnai demonstrates a little paradoxical situation in this case, with all three features having high values and reflecting a kind of potential visual stimuli overload or unbalanced situation. Strong expression of common fate in Sfax and more alternatives in Cracow, while very "plural" spatial structure in Elektrėnai, etc. It looks like some strongly expressed features are compensated by low expression of the other features in Sfax and Elektrėnai as two radical opposites. Cracow could be seen as some kind of balance between the different features.

What does it mean in terms of biomimicry? Possibly, if extreme maximums would be treated as some kind of less balanced experience, then Cracow represents the genotype which creates the most balanced spaces in terms of perceived features. The question is, to which natural landscapes of environments it could be compared? On the other hand, it could not be said that Sfax or Elektrėnai do not possess at least some of those features, but the lack of balance between them is quite obvious.

A comparison of buildings is presented in Figure 4. The results could be summarized as follows:

- Proximity as integration: Sfax and Cracow living spaces demonstrate in general a tendency of bigger proximity (mean-max) in comparison to the modernistic flats (mean-low). It is interesting, as the first two groups are represented by, in essence, bigger spatial structures if compared to Elektrėnai, and demonstrate the significance of spatial organization despite size for proximity perception and possibly for the other features.
- Fascinations as occlusivity: high values in Sfax buildings reflect the most sophisticated spatial organization around the living courtyard in the investigated groups of the medieval Islamic living house. Low values in the other cases reflect the very simple yet functional structure of medieval living houses and modernistic Soviet flats.
- Simplicity as PFM: medium dynamic simplicity of the Islamic house and medium-high values of the European medieval houses. Low simplicity in the modernistic flats. The modernistic flat low values are a little unexpected, as they are based on the so-called corridor system where the axis of a corridor puts the rest of the rooms together, but, probably, the treatment of rooms as autonomous units and employment of the corridors just as spaces for logistics without the other functions might explain that.
- Simplicity as compactness: medium to low values in the Islamic house with its sophisticated diverse spatial configuration; medium to high values are observed in the other cases, as living spaces there are organized out of autonomous cell rooms.
- Refuge as clustering: low values in the Islamic city, thus reflecting its interviewed functional structure, common usage of space (at least by some groups of inhabitants), etc. High-low values in Cracow reflect the focus on autonomous rooms from one side and compositionally important axial connections between them from the other side. High values in Elektrėnai where typical flats could be seen as a collection of autonomous rooms that could be connected by the corridor in one or another way. The shift of this feature could be related to more family as unit-oriented or individual-oriented preferences while creating living spaces as well.
- Common fate as through vision: lowest value in Elektrėnai—it reflects well the structure of autonomous rooms that are connected just by narrow functionally oriented space-corridors. Medium values in the Islamic house are a little unexpected because of its focus on functionally and compositionally dominant living courtyards. Maybe it could be related to the need to segregate certain functions in a living structure. Medium to high values are found in the medieval house.

We should note clear genotypic differences in the three groups of living spaces. Regularity or tendency to compensate high values of one feature by the low values of at least some other features could be noted: the modernistic flats are less fascinating as spatial structures, less integrated, and less dynamically simple, but offer clearer refuge spaces, etc.

A summarizing generalized matrix with the results of both cities and buildings is presented in Figure 5. The exact numerical values are assigned to three categories (high, low, medium) while comparing them between themselves for cities and buildings to "decrease the resolution" of the results a little and to make the general tendencies more clearly visible. In all three cases, interesting regularity could be observed between two groups of indicators: if the group of indicators or features made of proximity, fascination, and dynamic simplicity (PFM) is higher in a city, then in general it is lower in buildings and vice versa. A more balanced situation could be observed in Cracow again. Such regularity could be explained and interpreted while using the idea of close interactions and combinations of prospect and refuge. We can assume that the optimal situation is when the prospect is not too big or visually controllable and easily observable. It could be explained and related to the concept of positive stress "... otherwise known as good stress or eustress, (which) is the type of stress response that we feel when we get excited." [65]. If loosely defining stress as anything that challenges our state of homeostasis, then too big a prospect makes a bigger visual challenge and has a bigger potential to cause negative stress. We can logically assume that stress is increased even more if, besides a big and hardly visually observable and controllable prospect, no refuge space could be found nearby in an urban or architectural structure. Such a situation is peculiar, according to the research results of Elektrėnai where the only refuge is a private flat. From the point of view of the prospect and refuge combination, the situation is much more balanced in Cracow and Sfax. If an analogy with natural landscapes and habitats is used then, from the discussed point of view, Elektrenai is similar to a desert, where if an inhabitant leaves their shelter, they become immediately exposed in a huge space, visible for potential predators from far away and with need to look around regularly. Sfax could be related to a dense jungle where inhabitants can easily hide not only in their own shelters, but outside them as well. The specific feature in this case is limitation of prospect, which can cause that if only visual perception is used, then unexpected dangers or predators could be met unexpectedly. Cracow in this case could be seen as an analogy to forest with both medium prospects and possibility to hide relatively easily in many locations both inside a shelter and outside of it. A final note regarding Elektrenai modeling and its results: space syntax Visual Graph Analysis was conducted, as in the case of Cracow and Sfax, based just on boundaries created by buildings. Are the results in this case correct if modernist urbanism puts a lot of attention to greenery between buildings? In order to give a precise answer, additional modeling at a finer scale with trees included would be needed, but a few things could be said already:

- We can argue that the situation is right in two cases: for the first decade or more years after the construction of Elektrenai when trees were just planted and made no boundaries for visual perceptions; for a cold season when trees shed their leaves.
- In summer, trees are visually active but still, we should recognize that in a city they form rather perforated but not solid wall, especially when courtyards of the houses were intentionally made intervisible so activities of children or other inhabitants could be observed through the windows, etc. In this situation, we can expect a decrease of the maximum values of the isovist properties, but there is a high probability that essential spatial patterns would be not changed.
- We can treat the presented results just as an analysis of pure architectural form created by anthropogenic elements.

What do the results say about the three investigated structures from the point of view of human psychological needs? The results of the space syntax VGA reveal significant differences in how Medieval Cracow, Islamic Sfax, and Modernist Elektrėnai fulfill human psychological needs, as interpreted through theories of Prospect-Refuge, Gestalt principles, Attention Restoration, Environmental Psychology and Preferred Environments, and Biophilic Design. Medieval Cracow achieves a strong balance between prospect and refuge, with its highly accessible main square offering openness and visibility, while its narrow, enclosed streets provide a sense of security and intimacy. The organic yet legible street network aligns with Gestalt principles by enhancing cognitive mapping and predictability. The alternating spatial sequences—from wide, open plazas to enclosed alleys—create fascination and support attention restoration, reinforcing the psychological appeal of the environment. In contrast, Islamic Sfax prioritizes refuge over prospect, with its enclosed, labyrinthine street network fostering a strong sense of security, but limiting visibility and navigability. The rhythmic contrast between shaded alleys and sunlit courtyards follows

Gestalt principles, helping to structure perception, while the gradual transition between enclosed and open spaces aids stress reduction, a key factor in environmental psychology. The presence of internal gardens and shaded walkways supports biophilic engagement, enhancing thermal comfort and overall well-being, which is perceived only if both private and public spaces are considered and experienced. Meanwhile, Modernist Elektrėnai, with its highly open and low-clustering spatial structure, creates excessive exposure, reducing psychological comfort by limiting a sense of refuge. Although its open layout potentially might improve wayfinding, the lack of spatial variation leads to monotony and cognitive fatigue. Furthermore, the large, open public spaces fail to support attention restoration, as they provide little enclosure and too much sensory engagement. While green spaces are present, their disconnection from the main streets diminishes their common accessibility and biophilic benefits. These findings suggest that while Medieval Cracow and Islamic Sfax successfully balance spatial complexity with psychological comfort through varied spatial sequences, Modernist Elektrėnai struggles to provide the same level of psychological support due to its overemphasis on openness and uniformity.

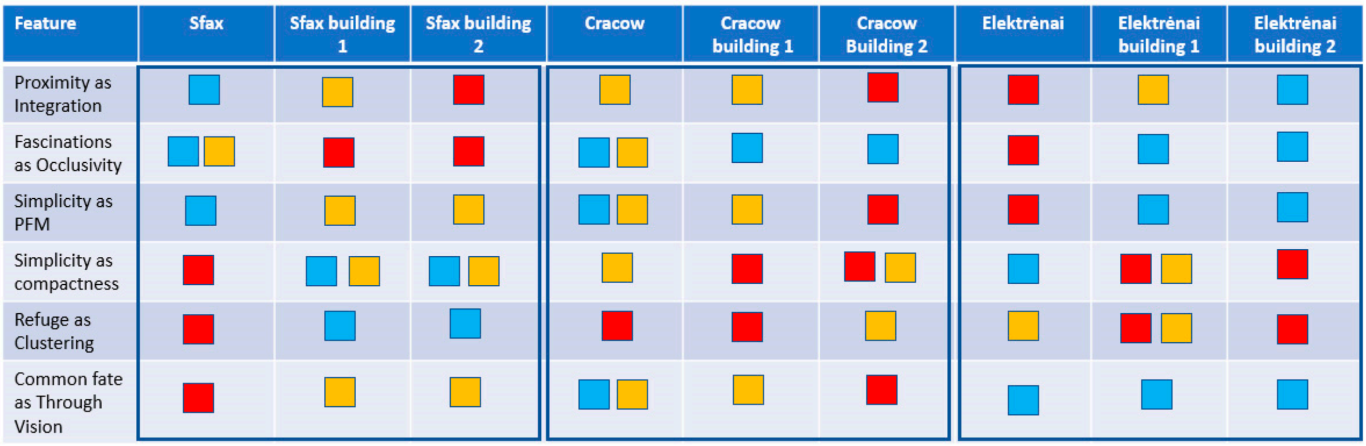


**Figure 5.** Summarizing matrix of the comparison of both cities and living houses. Red color means high, yellow—mean, and blue—low values.

For urban planners and architects, these insights highlight the importance of designing spaces that balance openness with enclosure. Future developments could integrate small-scale enclosed retreats within large urban squares, similar to Cracow's courtyards, offering refuge while maintaining visibility. Layered transitions between spaces, such as shaded arcades or semi-open corridors seen in Sfax, could help regulate sensory experiences and support attention restoration. In modernist layouts, introducing spatial variation through pocket parks, enclosed seating areas, and gradual changes in scale could counteract monotony and improve psychological comfort. Enhancing biophilic elements, such as integrating tree canopies along pedestrian paths or green buffers in open plazas, would further support well-being. By using space syntax tools to analyze spatial integration and clustering, planners can optimize urban layouts to create environments that foster safety, wayfinding, and restorative experiences for inhabitants.

## 4. Discussion and Conclusions

The presented results of the pilot research could be discussed and evaluated within a few theoretical frameworks. First of all, the model is based on the concept of the isovists or view shed, as was mentioned earlier [45]. It could be pointed out that isovist-based analysis of the architectural spaces in essence allows analysis and construction of spatial typologies through the eyes of the user and could still be seen as a kind of rare and innovative approach, which opened new perspectives in architectural modeling, as advocated by Batty [66]. Furthermore, the results of the isovist modeling could be and are related to various aspects of human perception through psychological theories. It could be proven by the presentation of the research by Ostwald and Dawes, where they analyzed the possibility to combine isovist analysis and Prospects Refuge theory. On one side, they concluded that "While the majority of the measures derived from isovists of the Heurtley house (investigated house) appear to broadly correlate with the prospect-refuge characteristics, (but), under close scrutiny they become problematic and, it must be concluded, that none of them are ideal for this purpose. Even those measures like skewness (PFM) and drift (Dynamic aspect of visual space), which might seem to capture some essence of prospect-refuge theory in a simple room, do not work for more complex spaces." [67]. At the same time, they agree that "Conceptually, prospect-refuge should be geometrically measurable using some combination of the strength and direction of the outlook (prospect), the proportion of the isovist that is bounded by solid surfaces (refuge), and that which is made up of occluded radials (mystery)." [67] and propose that "...combined measures must be verified through their application to more complex works of architecture (and urbanism?)" [67]. More similar attempts were made while applying the Prospect-Refuge Approach and isovist analysis for seat preferences in offices [50]. Other applications of the isovist model, more related directly to the analysis of logic of functioning of architectural spaces without searching for the specific ties with theories of psychology, validate the model: "We tested each of the metrics across a large sample of office spaces to unearth their relationship to two specific human behaviors: movement and interaction. We found that some metrics such as Visual Mean Depth play an important role for understanding the effects of movement, more specifically that more segregated floors and spaces tend to attract less movement. We also found that of the two activities movement is the easiest to predict, with many of the results applicable both to large-scale analysis but also on a per-site level." [48]. Research by Peponis and his concept of the cognitive frame, which was applied for the classification of the analyzed building, could be mentioned as well [68].

Within the described context, the presented research could be seen as the logical input into the mainstream of the research, as it does the following:

- Continues to investigate possibilities of applications of the isovist analysis for architectural spaces.
- Attempts to relate the results to various theories related to the perception of the environment and not limiting it to just a Prospect-Refuge approach.
- Expands the model by applying it not only for building analysis, but for urban analysis as well—it is not often made.
- Applies analysis on different urban-architectural-cultural settings.
- Attempts to relate the proposed models to the biomimicry framework, thus expanding possibilities to find more contact points with various theories and research in the future.

The second theoretical context of the presented research is the investigation of the preferred environment by Environmental psychology. The research with an attempt to identify quantitative indicators of various aspects of the preferred environment as legibility, complexity, mysteriousness, coherence, ephemera, naturalness, disturbance, etc., was made by Ode and Tveit [69]. While recognizing the significance of the above-mentioned research on environmental psychology, it should be pointed out that:

- Quantitative indicators were based on the usage of GIS-based descriptive data, which present a kind of "top-down" view on the map.
- It was focused on open, suburban, and rural landscapes.

- The presented research attempts to continue and expand the above-mentioned approach by investigating urban areas and adding isovist-based, users' visual experience oriented, simulative, and thus having predictive power, methodology. The model could be even more related to various theories of landscape perception in the future [11].
- The third theoretical framework is made by biomimicry investigation. As was demonstrated in the literature review, it could be stated that the presented research attempts to define the otherwise quite general principles of biomimicry in specific, not-so-often investigated urban scale and combinations with environmental psychology.

Last but not least, the theoretical context that should be mentioned is the idea of a city as fractal. According to Batty, it is one of the ways of abstraction of urban space that allows one to see a "naturally growing" or organic system [70]. In this case, the research presented in this article could be seen as a kind of "fractal view" on the investigated urban structures, as it does both: investigates potential regularities of relation of the single cell or house interior and urban spaces; models spaces from even smaller cells, thus increasing resolution of the model itself. Further illustrating these fractal-inspired principles is Federation Square in Melbourne, Australia, whose facade is composed of triangular panels arranged in fractal sequences, creating a dynamic visual effect that engages passersby [71]. This intricate tiling not only provides aesthetic appeal, but also helps mitigate heat gain through partial shading. In Barcelona, Antoni Gaudí's work at Park Güell and the Sagrada Família demonstrates fractal-like branching and tiling elements derived from nature, fostering a sense of harmony and connection with organic forms [72]. Such patterns have been shown to reduce stress by creating environments that subconsciously resonate with natural structures [73]. Another compelling case is the Al Bahar Towers in Abu Dhabi, which employ a responsive facade inspired by Islamic mashrabiya screens, often themselves based on fractal geometry. The shading devices open and close depending on sunlight intensity, reducing interior heat gain while delivering a visually captivating, layered pattern [74]. Similarly, Singapore's Gardens by the Bay features "Supertrees" that mimic the fractal branching of real trees, maximizing both shade coverage and spatial intrigue. These examples illustrate how fractal design principles can be integrated into urban environments to enhance visual interest, lower stress, and optimize resource efficiency, ultimately showcasing the multifaceted benefits of nature-inspired geometry.

The usage of the mathematical graph as the methodological base of the modeling creates a few important possibilities:

- It makes the results comparable with the other quantitative data, if available to obtain, which creates relatively good possibilities for further calibration of the proposed model.
- The simulative nature of the model means that it has not only analytical, but predictive powers as well. Such powers could be expanded into two directions, future and past, as it was demonstrated in this research.
- The mathematical basis of the model in essence allows us to combine it or include it into parametric architectural and urban design processes.

Combination of the results with the theoretical framework of biomimicry creates a background to expand the view on urban structures not only while using qualitative indicators, but even generalizing analogies, e.g., as it was mentioned earlier while comparing the modernist city to a "desert" in a similar manner as Bauman compared center of Brasilia to Gobi desert [75] and medieval cities to different types of "forest".

- Are the results of the presented model valid? Validation of the model could be approached from three perspectives:

- Based on deductive reasoning while stating that if a similar model were confirmed by other researchers, then, it is logical to expect that a similar methodology is working in our case.
- Based on abduction logic, which states that if an explanation given by a model looks logical then it should be accepted as right till better results are obtained or the model will be tested based on the other principles.
- Based on empirical data.

In essence, all three approaches were used. First of all, we can point out the earlier-mentioned sources that confirm that graph-based and isovist models correlate with human behavior at least in cities. Secondly, the construction of the model itself was based on both deductive and abductive reasoning. Thirdly, the modeling results were overlapped with the data on the functionalities of the investigated cities and buildings while using the layer overlap method (Section 3.1). The main idea was that if functional patterns and logic could be related to the obtained mathematical results, then there is a higher probability that the model is working rather than not. The main problem in this case was the availability of data for historical cases about more precise allocation of various functions. In essence, it was based just on the present cartographic sources. The same principle was applied in Elektrėnai, as even though the Open Street Map data is available, in essence it represents just the allocation and density of various objects that could be related to visual perception affecting human behavior indirectly only. Precise data on the movement of people and informal micro-functions of public spaces, possibly based on observation in situ, would be needed. This situation leaves the question of further validation open and should be addressed in future research. As isovists describe a human visual experience in a space, then one of the tools for validations could be measurement and analysis of human reactions, e.g., based on eye-tracking technology.

In terms of the limitations of the research, the following aspects should be pointed out:

- Three relatively homogenous cultural and spatial small urban structures were investigated. The question is how more complex urban systems should be modeled.
- Only one type of cell, the living house, was present in the model, but even in the investigated cities the variety of cells is much higher, e.g., churches, mosques, other public buildings, etc.
- As the review of similar research demonstrated, different interpretations of the features of acceptable or preferred environments by combinations of the visual graph indicators can exist. In our case, we used the principle common to all scientific models—it should be as simple as possible. As a result, we made an attempt to find just one indicator, if possible, for the description of the features of the visually perceived environment. It means that more possible combinations could and should be explored.
- The need for investigation of various possible combinations of the visual graph indicators for the features of an acceptable environment requires looking for quantitative methods of validation of the model in the future. As has been mentioned before, the authors see eye-tracking technology as the potential candidate for this task.
- While finalizing it could be generalized, that despite limitations and because of its nature as a pilot study, the presented results demonstrate sensitivity to the different cultural-urban situations and logical correspondence to features of those environments which could be pointed out by the subjective experience of the authors while walking in Elekrėnai, Old Town of Cracow, and medinas of the Islamic cities. The results fit into the context of biomimicry investigation and potentially expand the theoretical and methodological framework of the isovist modeling while using Visual Graph Analysis and relating it to the features of a psychologically acceptable environment.

What about the value of the findings of this research for urban planning? The obtained results could be used at least in the following ways:

- As bases for direct design inspirations and guidelines while offering quantitative parameters, which can help to create more psychologically preferable urban spaces and avoid mistakes such as disappearance of the Refuge spaces in modernist urbanism. Furthermore, the proposed indicators could be combined and used as a support system for the already existing urban models such as Alexander's Patterns, where higher clustering coefficient spaces beside the main street could be related to positive outside room patterns, etc.
- The proposed mathematical models and measures could be used for analysis and description of cultural heritage sites in order to learn and continue the existing cultural-spatial codes of urban fabric. It could be important as a tool for assurance of evolutionary, organic development of urban structures in such a way formalizing the cultural dimension of sustainable urban development. On the other hand, such a quantitative model potentially allows one to learn from the past with higher precision if compared to qualitative models, e.g., New Urbanism, based on historical samples, supports mixed land use and compact neighborhoods, but both aspects can have different degrees of expression in different cultures and locations, which are potentially acceptable in different local contexts.
- Sustainable urban development is not imaginable without public participation or at least reflection of the needs of all city users in the design of public spaces. One of the problems in this case arises when needs, including psychological, of a society should be addressed and assessment of the results of a design proposal made. The proposed model, at least in the narrow perspective of environmental psychology, is suitable for both situations: it can help to formulate the psychological needs while using architectural quantitative indicators and describe space as it is seen by a user; it can predict what will happen if certain changes to spaces will be made and how it will potentially affect human perception.
- The last but not least aspect is parametric design, which becomes more and more important with utilization of Computer Aided Design (CAD) and AI technologies: the proposed model, at least potentially, allows one to parametrize urban environments from a perspective of psychologically preferred spatial environment, contextual infill development, etc.

All of the above-mentioned ways of using the results of the presented research of course just open some perspectives which should be tested in the future and could form a background for many new investigations and articles focused on testing the model in more diverse urban environments, while examining it in more diverse, heterogeneous in terms of morphology, and more multicultural urban environments.

It is possible to conclude that by integrating environmental psychology theories through biomimicry principles with quantitative spatial analysis, the framework proposed in this research provides a systematic approach to analyzing and designing adaptive, resource-efficient, and psychologically supportive urban environments, potentially enhancing long-term sustainability and resilience in response to environmental and socio-economic challenges. This quantitative framework can potentially inform evidence-based urban policies by integrating biomimetic spatial metrics into zoning regulations and environmental design standards. By applying graph-based simulations and space syntax analysis, policymakers can assess urban layouts in terms of accessibility, psychological well-being, and ecological efficiency, enabling the creation of zoning guidelines that promote human-centered, resilient, and self-organizing urban forms aligned with sustainability goals.

The proposed biomimicry-based framework for psychologically acceptable urban environments can be potentially adapted to various urban contexts. For example, in rapidly growing cities, where unstructured expansion often leads to social fragmentation and environmental degradation, the framework can guide the development of self-organizing, decentralized spatial systems that balance density with human well-being. Meanwhile, in climate-vulnerable regions, such as coastal megacities with rising sea levels threats, biomimetic design principles, such as redundancy and adaptive resilience, the framework can be applied for searching spatial configurations suitable for flood resistance and ecological integration. Additionally, in historical urban cores, where modernization pressures threaten cultural continuity, the framework can be used to integrate traditional urban genotypes with biomimetic principles, preserving heritage while ensuring psychological and ecological sustainability. Building on these conclusions, urban planners can create more sustainable and resilient cities by drawing inspiration from nature, using biomimetic design strategies that enhance both functionality and aesthetics. For example, fractal geometry and biophilic architecture, made possible with parametric design tools like Grasshopper and Rhino, help design visually engaging spaces that promote well-being seen in the Eden Project (UK) with its geodesic domes modeled after organic cell structures. Adaptive facades, such as the dynamic shading system of Al Bahar Towers in Abu Dhabi, mimic how desert plants regulate sunlight, reducing energy consumption. Similarly, nature-based infrastructure, like New York's High Line Park, incorporates green corridors that function much like natural ecosystems, while bioswales and artificial wetlands help manage urban flooding by imitating natural water cycles. Beyond infrastructure, circular economy principles can transform urban metabolism, as demonstrated by Kalundborg Eco-Industrial Park in Denmark, where industries share resources in a closed-loop system inspired by nature's efficiency. Advances in biomimetic materials, such as self-healing concrete and bio-luminescent lighting, push sustainability even further, while passive cooling systems like Eastgate Centre in Zimbabwe, modeled after termite mounds, drastically cut energy use. By embracing these nature-inspired approaches, cities can become more livable, self-sufficient, and environmentally responsible, ensuring a better balance between urban life and the natural world. These are a few among other potential applications in diverse urban contexts that merit further research.

**Author Contributions:** Conceptualization, K.Z.; methodology, K.Z.; software, K.Z.; validation, K.Z. and G.V.; formal analysis, K.Z., I.G.-V. and G.V.; investigation, K.Z., I.G.-V. and G.V.; resources, K.Z., I.G.-V. and G.V.; data curation, K.Z.; writing—original draft preparation, K.Z., I.G.-V. and G.V.; writing—review and editing, K.Z., I.G.-V. and G.V.; visualization, K.Z. and G.V.; supervision, K.Z.; project administration, K.Z.; funding acquisition, K.Z. All authors have read and agreed to the published version of the manuscript.

**Funding:** This study is a part of the research and dissemination activities of the project of Vilnius Academy of Arts "Creative Interdisciplinary New European Bauhaus—NEB Research Centre" which was funded by the Research Council of Lithuania (LMT), agreement No: S-A-UEI-23-3.

**Data Availability Statement:** The raw data supporting the conclusions of this article will be made available by the authors on request.

**Conflicts of Interest:** The authors declare no conflicts of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

## Appendix A. The Results of Space Syntax Visual Graph Modeling

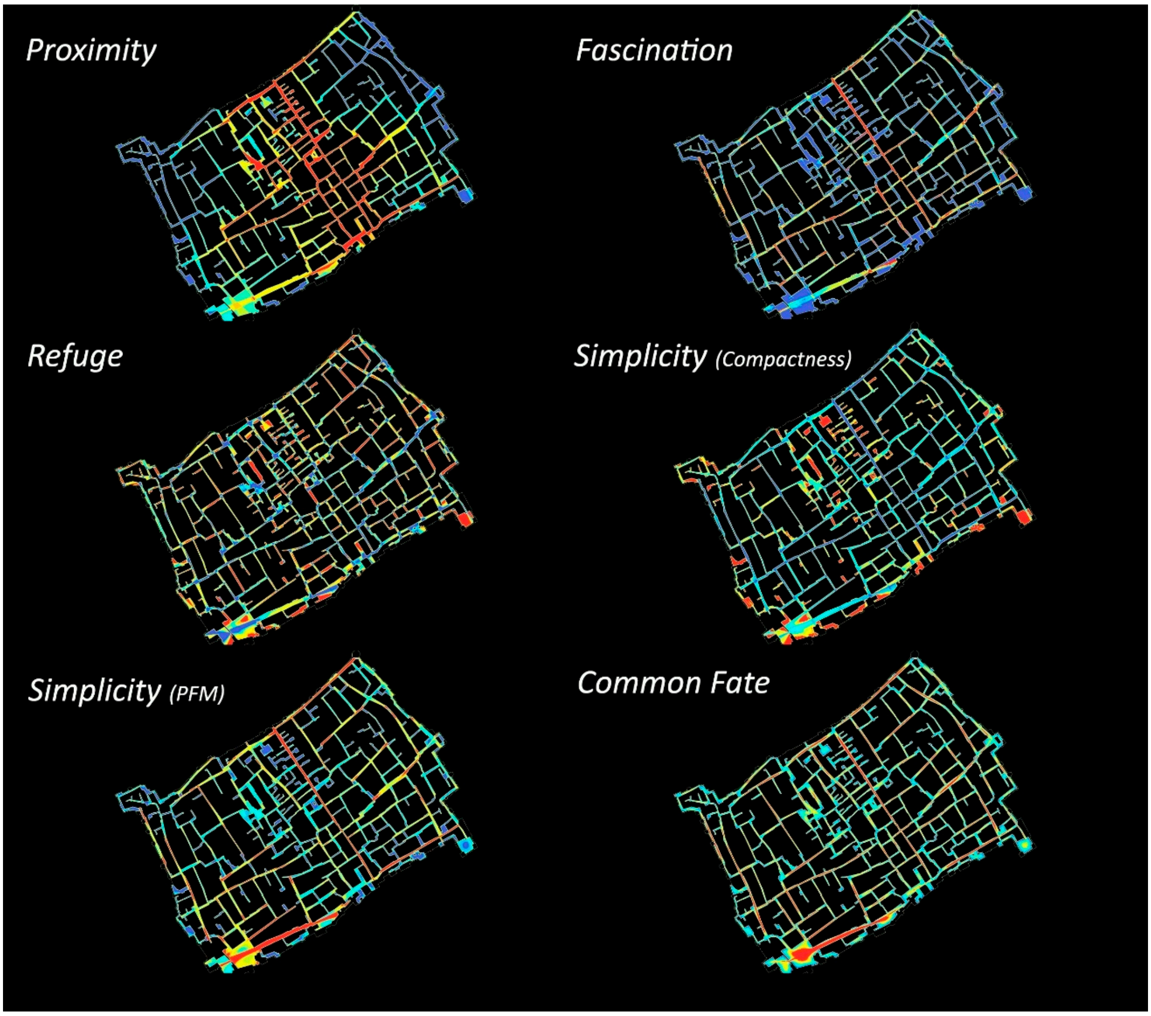


**Figure A1.** Results of the space syntax modeling of Sfax urban structure. Red color marks values equal and bigger than 1 standard deviation and blue marks minus 1 standard deviation, thus pointing out accordingly 15.9 percent of the highest and the lowest values.

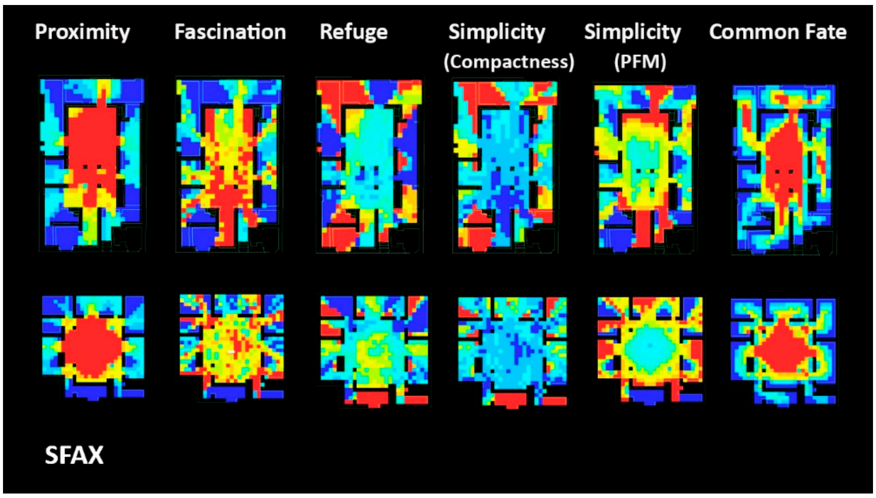


**Figure A2.** Results of the space syntax modeling of Sfax buildings (building 1 at top line). Red color marks values equal and bigger than 1 standard deviation and blue marks minus 1 standard deviation, thus pointing out accordingly 15.9 percent of the highest and the lowest values.

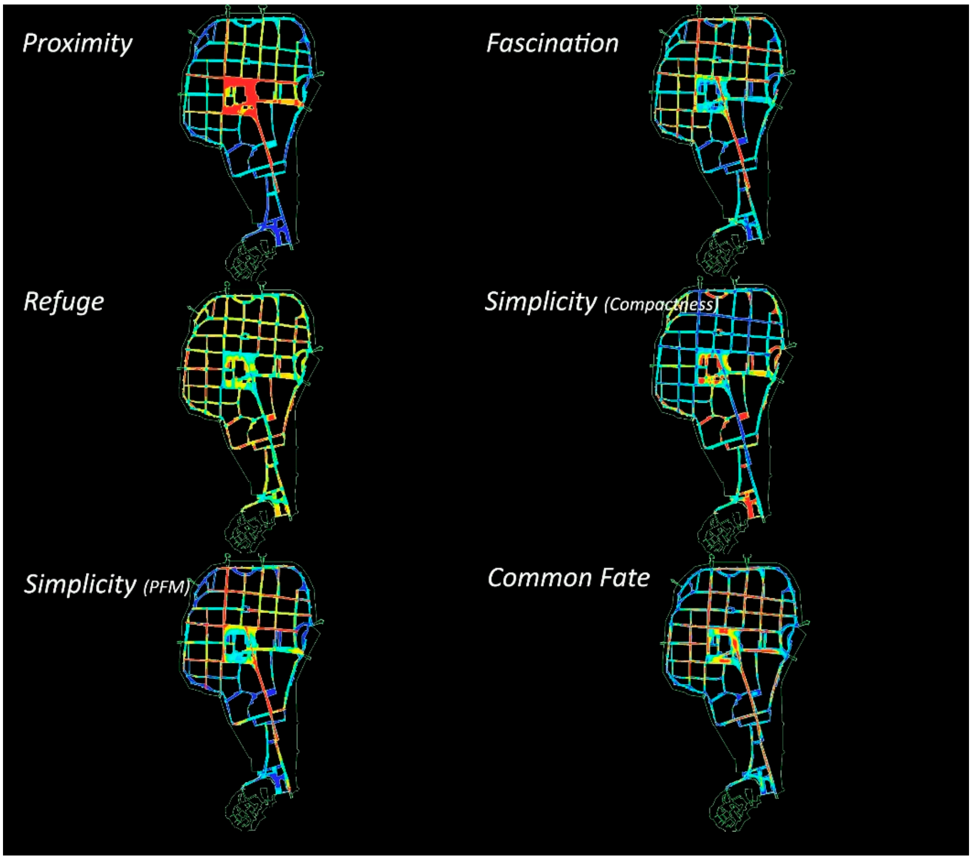


**Figure A3.** Results of the space syntax modeling of Cracow urban structure. Red color marks values equal and bigger than 1 standard deviation and blue marks minus 1 standard deviation, thus pointing out accordingly 15.9 percent of the highest and the lowest values.

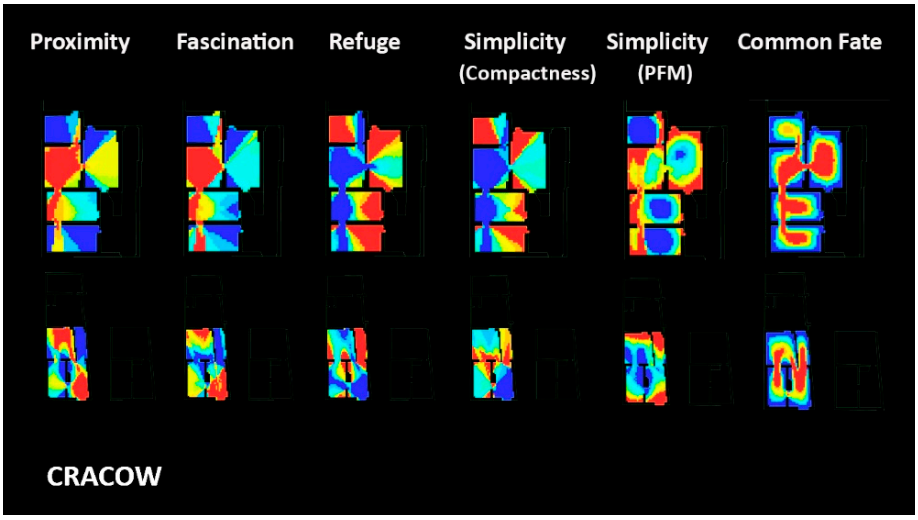


**Figure A4.** Results of the space syntax modeling of Cracow buildings (building 1 at top line). Red color marks values equal and bigger than 1 standard deviation and blue marks minus 1 standard deviation, thus pointing out accordingly 15.9 percent of the highest and the lowest values.

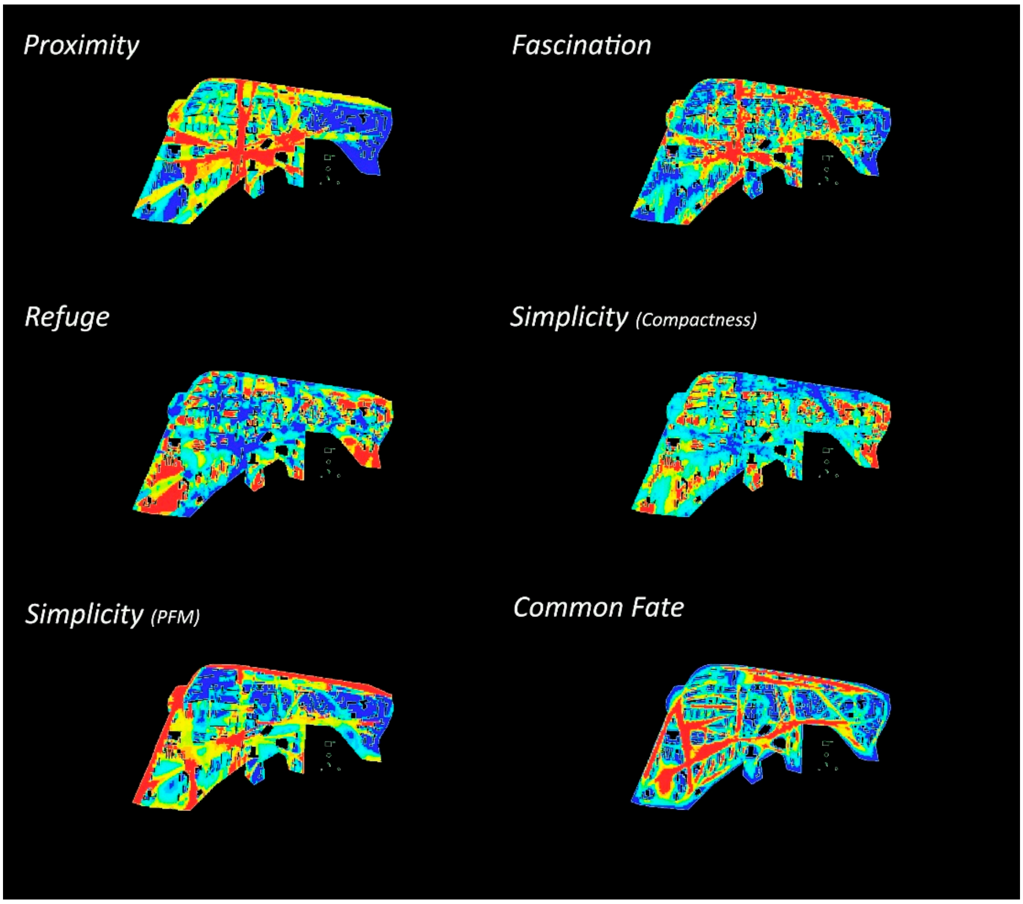


**Figure A5.** Results of the space syntax modeling of Elektrėnai urban structure. Red color marks values equal and bigger than 1 standard deviation and blue marks minus 1 standard deviation, thus pointing out accordingly 15.9 percent of the highest and the lowest values.

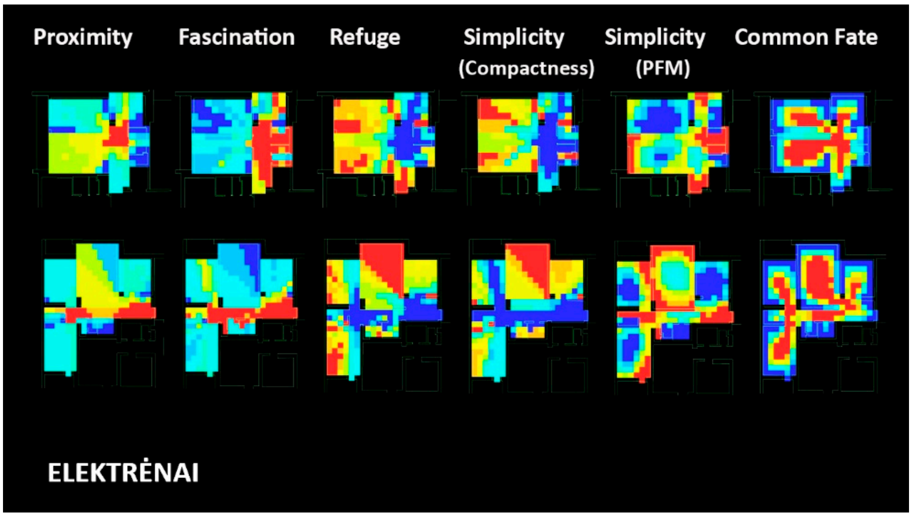


**Figure A6.** Results of the space syntax modeling of Elektrėnai flats (buildings) (building 1 at top line). Red color marks values equal and bigger than 1 standard deviation and blue marks minus 1 standard deviation, thus pointing out accordingly 15.9 percent of the highest and the lowest values.

## Appendix B. The Results of Space Syntax Axial Graph Modeling

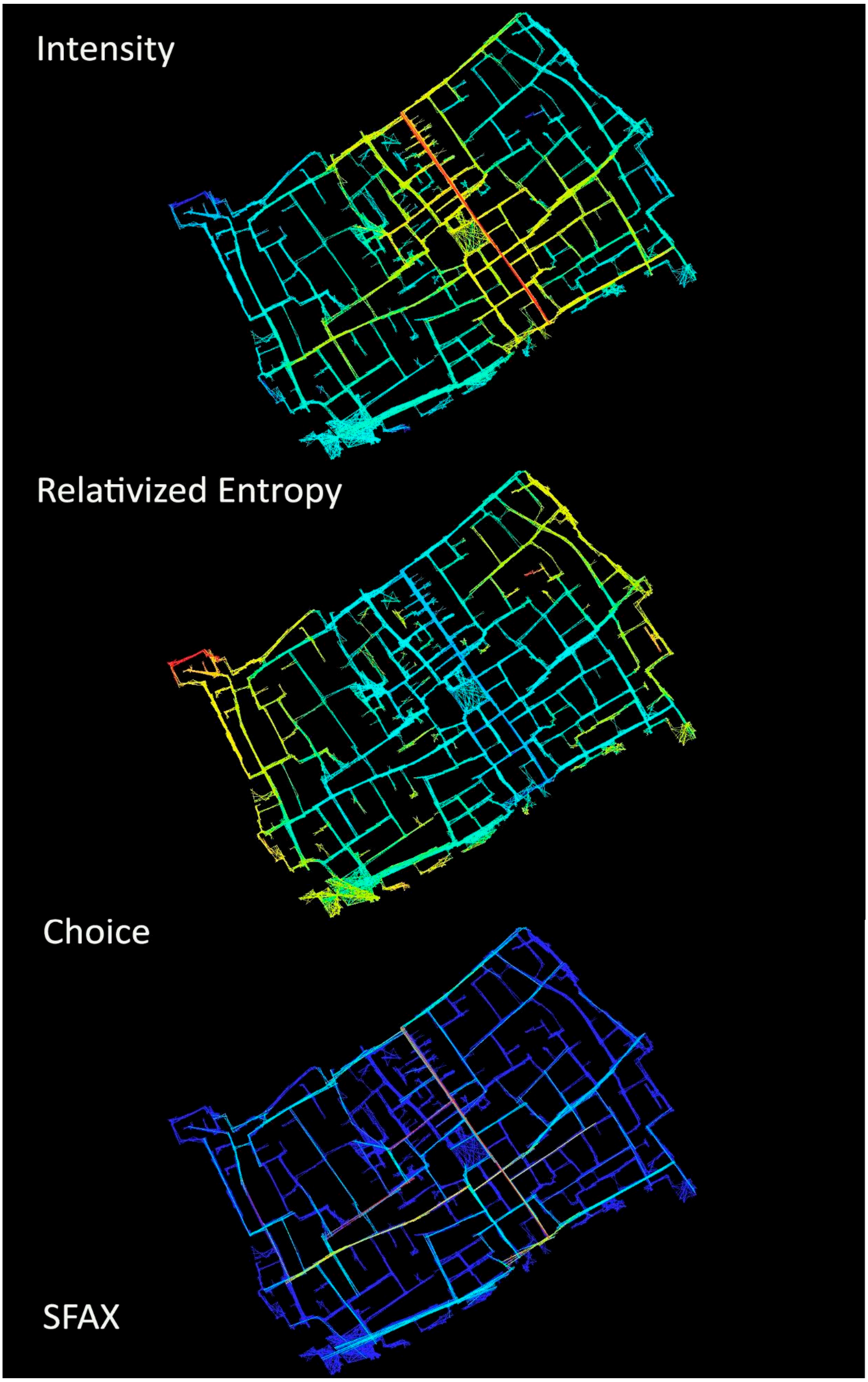


**Figure A7.** Intensity, Relativized Entropy, and Choice within radius n for Sfax axial graph. Red colors show high and blue colors show low numerical values.

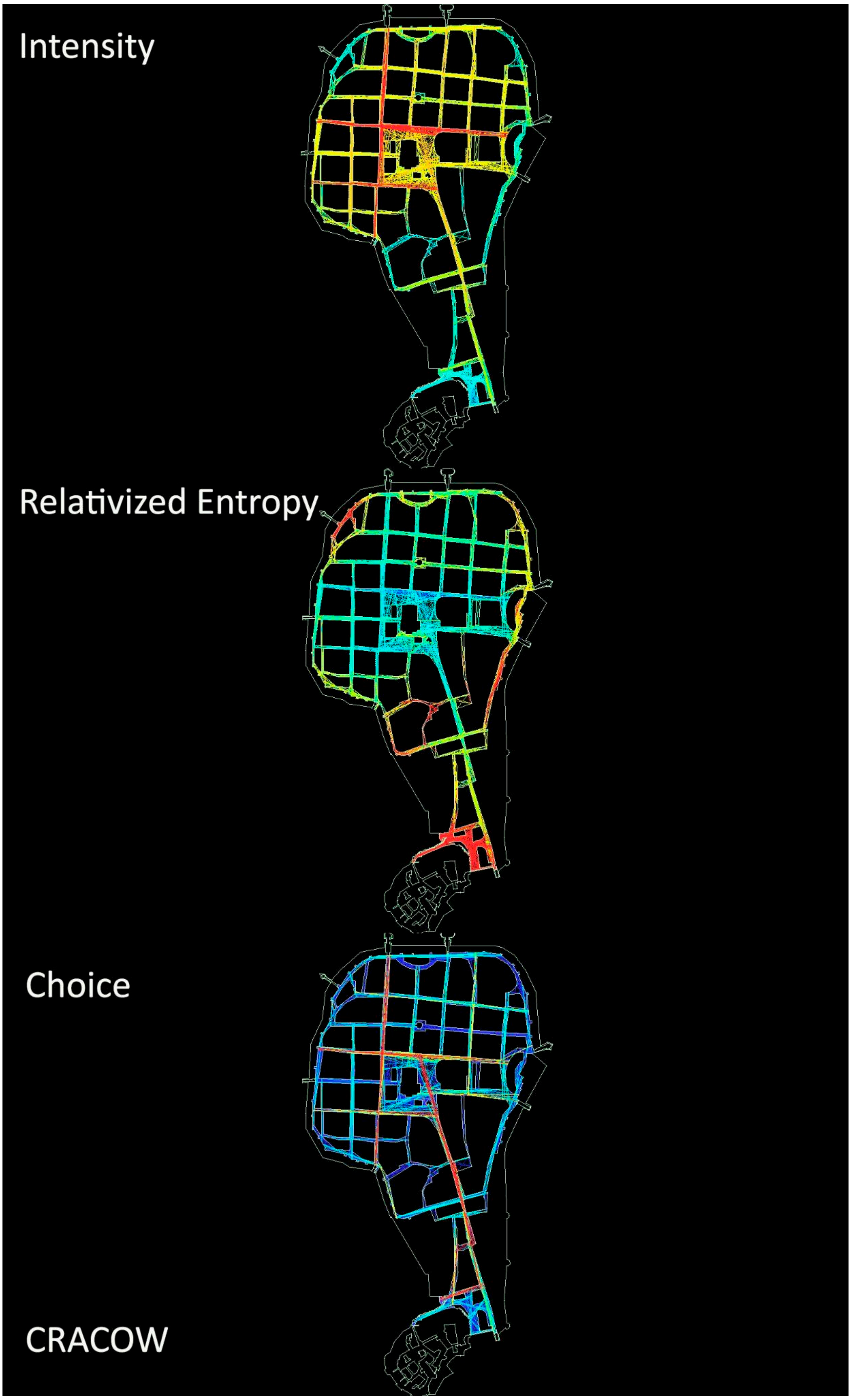


**Figure A8.** Intensity, Relativized Entropy, and Choice within radius n for Cracow axial graph. Red colors show high and blue colors show low numerical values.

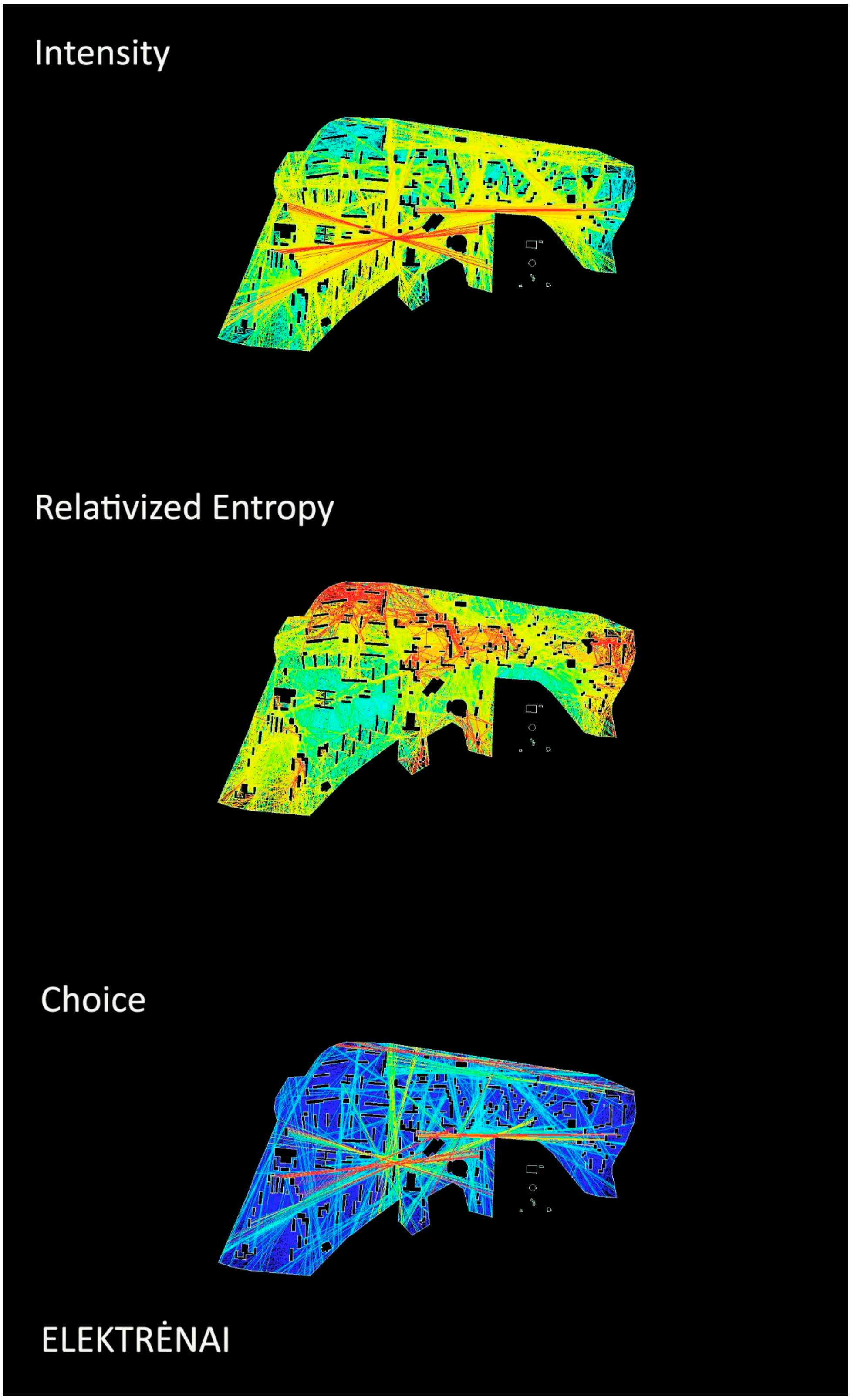


**Figure A9.** Intensity, Relativized Entropy, and Choice within radius n for Elektrėnai axial graph. Red colors show high and blue colors show low numerical values.

## References


1. Gertik, A.; Karaman, A. The fractal approach in the biomimetic urban design: Le Corbusier and Patrick Schumacher. *Sustainability* **2023**, *15*, 7682. [CrossRef]
2. Zaleckis, K.; Gražulevičiūtė-Vileniškė, I.; Viliūnas, G. Mathematical Graph Based Urban Simulations as a Tool for Biomimicry Urbanism? *Evol. Stud. Imaginative Cult.* **2024**, *8*, 153–183. [CrossRef]
3. Gehl, J. *Cities for People*; Island Press: Washington, DC, USA, 2010.
4. Environmental Protection Agency (EPA). *Heat Island Compendium*; U.S. Environmental Protection Agency: Washington, DC, USA, 2020.
5. Beatley, T. *Handbook of Biophilic City Planning & Design*; Island Press: Washington, DC, USA, 2016.
6. United Nations Human Settlements Programme (UN-Habitat). *Urban Resilience Reports*; UN-Habitat: Nairobi, Kenya, 2017.
7. Montgomery, C. *Happy City: Transforming Our Lives Through Urban Design*; Farrar, Straus and Giroux: New York, NY, USA, 2013.
8. Bristol, K.G. The Pruitt-Igoe Myth. *J. Archit. Educ.* **1991**, *44*, 163–171. [CrossRef]
9. World Bank. *Dhaka Megacity Development Review*; The World Bank: Washington, DC, USA, 2018.
10. Basu, A.; Duvall, J.; Kaplan, R. Attention restoration theory: Exploring the role of soft fascination and mental bandwidth. *Environ. Behav.* **2019**, *51*, 1055–1081. [CrossRef]
11. Landscape Theory. *Scenic Solutions, 2017*. Available online: https://scenicsolutions.world/theory-of-landscape-aesthetics/ (accessed on 18 November 2024).
12. Ulrich, R.S.; Simons, R.F.; Losito, B.D.; Fiorito, E.; Miles, M.A.; Zelson, M. Stress recovery during exposure to natural and urban environments. *J. Environ. Psychol.* **1991**, *11*, 201–230. [CrossRef]
13. Van den Berg, A.E. Restorative effects of nature: Towards a neurobiological approach. In Proceedings of the 9th International Congress of Physiological Anthropology, Delft, The Netherlands, 22–26 August 2008; pp. 132–138.
14. Wilson, E.O. *Biophilia*; Harvard University Press: Cambridge, MA, USA, 1986.
15. Wagemans, J.; Feldman, J.; Gepshtein, S.; Kimchi, R.; Pomerantz, J.R.; van der Helm, P.A.; van Leeuwen, C. A Century of Gestalt Psychology in Visual Perception: II. Conceptual and Theoretical Foundations. *Psychol. Bull.* **2012**, *138*, 1218–1252. [CrossRef]
16. Pettersson, R. Gestalt principles. In *Information Design*; Routledge: Abingdon, UK, 2017; pp. 441–450.
17. Todorovic, D. Gestalt principles. *Scholarpedia* **2008**, *3*, 5345. [CrossRef]
18. Tveit, M.; Ode, Å.; Fry, G. Key concepts in a framework for analysing visual landscape character. *Landsc. Res.* **2006**, *31*, 229–255. [CrossRef]
19. Zaleskienė, E.; Gražulevičiūtė-Vileniškė, I. Landscape aesthetics theories in modeling the image of the rurban landscape. *J. Sustain. Archit. Civ. Eng.* **2014**, *7*, 10–21. [CrossRef]
20. Green, J. Back to Nature for Good: Using Biophilic Design and Attention Restoration Theory to Improve Well-Being and Focus in the Workplace. Master's Thesis, University of Minnesota, Minneapolis, MN, USA, 2012.
21. Ohly, H.; White, M.P.; Wheeler, B.W.; Bethel, A.; Ukoumunne, O.C.; Nikolaou, V.; Garside, R. Attention Restoration Theory: A systematic review of the attention restoration potential of exposure to natural environments. *J. Toxicol. Environ. Health Part B* **2016**, *19*, 305–343. [CrossRef]
22. Appleton, J. *The Experience of Landscape*; John Wiley: Chichester, UK, 1975.
23. Kaplan, R.; Kaplan, S.; Brown, T. Environment preference: A comparison of four domains of predictors. *Environ. Behav.* **1989**, *21*, 509–530. [CrossRef]
24. Benyus, J.M. *Biomimicry: Innovation Inspired by Nature*; Harper Perennial: New York, NY, USA, 1997.
25. Uchiyama, Y.; Blanco, E.; Kohsaka, R. Application of biomimetics to architectural and urban design: A review across scales. *Sustainability* **2020**, *12*, 9813. [CrossRef]
26. Kellert, S.R. *Nature by Design: The Practice of Biophilic Design*; Yale University Press: New Haven, CT, USA, 2018.
27. Haupt, P. Integrated urban landscape: Nature as an element of transition space composition. In *Back to the Sense of the City: International Monograph Book*; Centre de Política de Sòl i Valoracions: Barcelona, Spain, 2016; pp. 73–83.
28. Salingaros, N.A. The biophilic healing index predicts effects of the built environment on our well-being. *J. Biourbanism* **2019**, *8*, 13–34.
29. Hayes, S.; Toner, J.; Desha, C.; Gibbs, M. Enabling biomimetic place-based design at scale. *Biomimetics* **2020**, *5*, 21. [CrossRef]
30. Ma, M.; Zhou, N.; Feng, W.; Yan, J. Challenges and opportunities in the global net-zero building sector. *Cell Rep. Sustain.* **2024**, *1*, 100154. [CrossRef]
31. Zhang, S.; Ma, M.; Zhou, N.; Yan, J.; Feng, W.; Yan, R.; Ke, J. Estimation of Global Building Stocks by 2070: Unlocking Renovation Potential. *Nexus* **2024**, *1*, 100019. [CrossRef]
32. Salingaros, N.A. Fractal Art and Architecture Reduce Physiological Stress. *J. Biourbanism* **2012**, *2*, 11–28.
33. Biomimicry Institute. What Is Biomimicry? 2021. Available online: https://biomimicry.org (accessed on 18 February 2025).

34. Dicks, H.; Bertrand-Krajewski, J.L.; Ménézo, C.; Rahbé, Y.; Pierron, J.P.; Harpet, C. Applying biomimicry to cities: The forest as a model for urban planning and design. In *Technology and the City: Towards a Philosophy of Urban Technologies*; Springer: Berlin/Heidelberg, Germany, 2021; pp. 271–288.
35. Zaleckis, K.; Gražulevičiūtė-Vileniškė, I.; Viliūnas, G. Invisible Inheritable Urban Biomimicry and How to Re-discover and Evaluate It. *In press. Unpublished manuscript*.
36. Hillier, B.; Hanson, J. *The Social Logic of Space*; Cambridge University Press: Cambridge, UK, 1989.
37. Hillier, B. *Space Is the Machine: A Configurational Theory of Architecture*; Space Syntax: London, UK, 2007.
38. Dutt, B.B. *Town Planning in Ancient India*; Isha Books: Delhi, India, 2009; 412p.
39. Schinz, A. *The Magic Square: Cities in Ancient China*; Edition Axel Menges: Stuttgart, Germany, 1996; 428p.
40. Mumford, L. *The City in History: Its Origins, Its Transformations, and Its Prospects*; Houghton Mifflin Harcourt: Boston, MA, USA, 1961; Volume 67.
41. Bullmore, E.; Bassett, D. Brain Graphs: Graphical Models of the Human Brain Connectome. *Annu. Rev. Clin. Psychol.* **2010**, *7*, 113–140. [CrossRef]
42. Hillier, B.; Leaman, A.; Stansall, P.; Bedford, M. Space Syntax. *Environ. Plan. B* **1976**, *3*, 147–185. [CrossRef]
43. Turner, A.; Doxa, M.; O'Sullivan, D.; Penn, A. From Isovists to Visibility Graphs: A Methodology for the Analysis of Architectural Space. *Environ. Plan. B* **2001**, *28*, 103–121. [CrossRef]
44. Gibson, J.J. *The Senses Considered as Perceptual Systems*; Cornell University Press: Ithaca, NY, USA, 1968; pp. 221–222.
45. Benedikt, M. To Take Hold of Space: Isovists and Isovist Fields. *Environ. Plan. B* **1979**, *6*, 47–65. [CrossRef]
46. Wiener, J.M.; Franz, G. Isovists as a Means to Predict Spatial Experience and Behavior. In *Spatial Cognition IV: Reasoning, Action, Interaction*; Freksa, C., Knauff, M., Krieg-Brückner, B., Nebel, B., Barkowsky, T., Eds.; Springer: Berlin/Heidelberg, Germany, 2005; Volume 3343, pp. 103–121.
47. Psathiti, C.; Sailer, K. A Prospect-Refuge Approach to Seat Preference: Environmental Psychology and Spatial Layout. In Proceedings of the UCL Symposium, London, UK, 7 February 2017; p. 16. Available online: http://discovery.ucl.ac.uk/1568213/ (accessed on 18 November 2024).
48. Koutsolampros, P.; Sailer, K.; Varoudis, T.; Haslem, R. Dissecting Visibility Graph Analysis: The metrics and their role in understanding workplace human behavior. In Proceedings of the 12th International Space Syntax Symposium, Beijing, China, 8–13 July 2019.
49. Li, D.; Yan, X.; Yu, Y. The Analysis of Pingyao Ancient Town Street Spaces and View Spots Reachability by Space Syntax. *J. Data Anal. Inf. Process.* **2016**, *4*, 177–186. [CrossRef]
50. Alexander, C.; Ishikawa, S.; Silverstein, M. *A Pattern Language: Towns, Buildings, Construction*; Oxford University Press: New York, NY, USA, 1977; pp. 248–352.
51. Lynch, K. *The Image of the City*; The MIT Press: Cambridge, MA, USA, 1960; 194p.
52. Salingaros, N.A. The Laws of Architecture from a Physicist's Perspective. *Phys. Essays* **1995**, *8*, 638–643. [CrossRef]
53. Hakim, B.S. *Urban Rules and Processes: Historic Lessons from Practice*; Emergent City Press: Washington, DC, USA, 2019; pp. 87–93.
54. Van Der Meerschen, M. La Medina de Sfax. *Unesco-Icomos Doc. Cent.* **1972**, *8*, 1–28. Available online: https://www.icomos.org/public/monumentum/vol8/vol8_1.pdf (accessed on 18 November 2024).
55. Plan Krakowskich Bram i Baszt wg Klemensa Bąkowskiego. Available online: http://www.starykrakow.com.pl/dawne-mapy,plany/mapy.htm (accessed on 18 November 2024).
56. Drėmaitė, M.; Janušauskaitė, V.; Kiznis, N.; Šiupšinskas, M. *Jūs Gaunate Butą: Gyvenamoji Architektūra Lietuvoje 1940–1990 Metais*; Lapabs: Vilnius, Lithuania, 2024; p. 325.
57. Turner, A. Depthmap: A Program to Perform Visibility Graph Analysis. In Proceedings of the 3rd International Symposium on Space Syntax, Atlanta, GA, USA, 7–11 May 2001; pp. 31.1–31.9.
58. Hillier, B.; Burdett, R.; Peponis, J.; Penn, A. Creating Life: Or, Does Architecture Determine Anything? *Archit. Behav.* **1987**, *3*, 233–250.
59. Park, H. Before Integration: A Critical Review of Integration Measure in Space Syntax. In Proceedings of the 5th Space Syntax Symposium, Delft, The Netherlands, 13–17 June 2005; pp. 555–572.
60. Salingaros, N.A.; Mehaffy, M.W. *A Theory of Architecture*; Umbau-Verlag: Solingen, Germany, 2006.
61. Salingaros, N.A.; van Bilsen, A. *Principles of Urban Structure*; Technepress: Amsterdam, The Netherlands, 2005.
62. Salingaros, N.A. *Algorithmic Sustainable Design: The Future of Architectural Theory*; Umbau-Verlag: Solingen, Germany, 2010.
63. Salingaros, N.A.; Alexander, C. *Anti-Architecture and Deconstruction*; Umbau-Verlag: Solingen, Germany, 2008.
64. Cullen, G. *Concise Townscape*; Routledge: London, UK, 2012.
65. What is Positive Stress? Advekit blog. Available online: https://www.advekit.com/blogs/what-is-positive-stress (accessed on 18 November 2024).
66. Batty, M. Exploring Isovist Fields: Space and Shape in Architectural and Urban Morphology. *Environ. Plan. B Plan. Des.* **2001**, *28*, 123–150. [CrossRef]

67. Ostwald, M.; Dawes, M. Using Isovists to Analyse Prospect-Refuge Theory: An Examination of the Usefulness of Potential Spatio-Visual Measures. *Int. J. Constr. Environ.* **2013**, *3*, 25–40.
68. Peponis, J. Building Layouts as Cognitive Data: Purview and Purview Interface. *Cogn. Crit.* **2012**, *6*, 11–52.
69. Ode Sang, Å.; Tveit, M.; Fry, G. Capturing Landscape Visual Character Using Indicators: Touching Base with Landscape Aesthetic Theory. *Landsc. Res.* **2008**, *33*, 89–117.
70. Batty, M.; Longley, M. *Fractal Cities: A Geometry of Form and Function*; Academic Press: London, UK, 1994.
71. Salingaros, N.A. Applications of the Golden Mean to Architecture. *Meand. Through Math.* **2012**, *4*, 15–36.
72. Burry, M.; Burry, J. *The New Mathematics of Architecture*; Thames & Hudson: London, UK, 2016.
73. Aksamija, A. *Sustainable Facades: Design Methods for High-Performance Building Envelopes*; Wiley: Hoboken, NJ, USA, 2013.
74. Taylor, R.P. Reduction of Physiological Stress Using Fractal Art and Architecture. *Leonardo* **2006**, *39*, 245–251. [CrossRef]
75. Bauman, Z. *Globalization: The Human Consequences*; Columbia University Press: New York, NY, USA, 1998.