

Article

Social Sustainability and Alexander’s Living Structure Through a New Kind of City Science

Tarina Levin ^{1,*}, Stefan Sjöberg ², Bin Jiang ³, and Stephan Barthel ^{1,4}

¹ Department of Building Engineering, Energy Systems and Sustainability Science, University of Gävle, Sweden

² Department of Social Work and Criminology, University of Gävle, Sweden

³ Thrust of Urban Governance and Design, The Hong Kong University of Science and Technology (Guangzhou), China

⁴ Stockholm Resilience Centre, Stockholm University, Sweden

* Corresponding author (tarina.levin@hig.se)

Submitted: 15 February 2023 | Accepted: 26 June 2023 | Published: 24 August 2023

Abstract

The disputed endorsement of inherited visceral and universal aesthetic preferences justifies the scientific validity of Alexander’s living structure. Apart from implying a resource-efficient way to promote well-being through urban design, the premise favors a collective approach to human self-perception and social justice. To better understand the contributions of Alexander, this article explores current knowledge about visceral and universal aesthetic preferences for living structure and if and how the new kind of city science, a mathematical model describing living structure, can be used for further testing. It also elaborates on the social impact of living structure, including its premise, and the potential of the new kind of city science to support social sustainability. A literature synthesis on living structure, the new kind of city science, and the premise showed a positive link between well-being and exposure to living structure. Limitations in research design nevertheless precluded conclusions about the associated visceral and universal aesthetic preferences. The new kind of city science was found appropriate for further research by holistically representing living structure. Moreover, like the hypothesized biological origin, social learning and sociocultural transmission were found to theoretically support the premise of universality and a collective approach to human identity and social justice, with further societal implications. For the concept of living structure to support social sustainability, it must be coupled with the promotion of empowerment and community mobilization. Hence, the operationalization of the new kind of city science should align with Alexander’s call for bottom-up approaches.

Keywords

Christopher Alexander; living structure; new kind of city science; social sustainability; urban design; urban planning

Issue

This article is part of the issue “Assessing the Complex Contributions of Christopher Alexander” edited by Michael W. Mehaffy (Sustasis Foundation) and Tigran Haas (KTH Royal Institute of Technology).

© 2023 by the author(s); licensee Cogitatio Press (Lisbon, Portugal). This article is licensed under a Creative Commons Attribution 4.0 International License (CC BY).

1. Introduction

Christopher Alexander’s (2002a) claim of having captured the essence of beauty and unveiled secrets of good art, architecture, and design is controversial since value and aesthetic appreciation are commonly considered subjective and learned (Dawes & Ostwald, 2017). The organic worldview theoretically enables the idea of objective beauty, acknowledging humans as part of

an interconnected whole inclusive of value and beauty (Alexander, 2004; Whitehead, 1929). In line with the biophilia hypothesis (Wilson, 1984), Alexander (2002a) assumes humans have a visceral and universal love for life, lifelike objects, and processes. By identifying and replicating the structural quality of living entities, i.e., “livingness,” objective beauty can be captured and enhanced. Alexander (2002a) terms such structures as “living structure.”

Despite identifying generic design principles, Alexander et al. (1977; see also Alexander, 2002a) think that holistic designs with high degrees of living structure can only emerge through a long-term process of inclusive, bottom-up agency (Alexander, 1979). Theoretically, this approach differs little from conventional planning and design since the assumption of subjective and learned design preferences is usually accompanied by an acknowledgment of the importance of participation and process (e.g., Dempsey et al., 2012). However, a purely subjective approach towards beauty aligns with a wear-and-tear society, continuously in need of renewal to provide for changing societal conditions. On the contrary, Alexander's claim of objective beauty implies that an aesthetically successful design is eternally good.

While pressure on urban space increases (Florida, 2017; UN-Habitat, 2016) along with increasing expectations of urban design to balance conflicting interests and ensure the maintenance of attractive, socially just, and health-promoting urban environments (Burton, 2000; Dempsey et al., 2012; Samuelsson et al., 2018; UN-Habitat, 2016), the assertion of living structure's permanence appears beneficial. Finding ways to imitate visceral and universal health-promoting qualities successfully would favor built investments in cities with long-term endurance and could increase urban dwellers' tolerance for densely built environments.

Densification and urbanization imply less space per capita and an increasing need for sharing. The importance of sharing is further stressed on a global scale by the breach of planetary boundaries along with increasing inequalities and risk of self-reinforcing feedback between the two (Millward-Hopkins, 2022; Rockström et al., 2009; United Nations Department of Economic and Social Affairs, 2020). Since taste in arts significantly takes part in identity formation (Fingerhut et al., 2021) and since ideas of "the self" are strongly linked to conceptions of social justice (Warren, 1990), a discursive displacement of beauty from "unique to the individual" to "inborn and universal" could have societal implications. The acknowledgment of objective beauty aligns with a collective approach to social justice based upon a strong link between identity and society, benefiting redistributive policies and sharing but potentially compromising individual autonomy, an essential protection against authoritarianism (Dawes & Ostwald, 2017; Heywood, 2021; Kymlicka, 2002).

The underlying assumptions of visceral and universal beauty are fundamental to assessing the contributions of Alexander. However, their validity is disputed both on a theoretical basis and due to the equivocal character of related empirical findings (Joye & De Block, 2011; Ulrich, 1993). The "new kind of city science" (NKCS), advocated by Jiang (2022a), proposes a mathematical model built on living structure and the organic view of space, facilitating the identification and assessment of a living structure. It comprises three fundamental issues about a city: how it looks, how it works, and what it ought to be. With the

NKCS, degrees of living structure can be identified in pictures and landscapes (Jiang & de Rijke, 2023), enabling novel research about the universal and visceral appreciation for living structure and about the biophilia hypothesis as a common model of explanation (e.g., Jiang, 2022b; Mehaffy & Salingaros, 2015).

Through a literature synthesis, this article aims to explore current knowledge about the premise of universal and visceral aesthetic preferences for living structure and if and how the NKCS can be used for further testing. Furthermore, the article aims to elaborate on the impact of living structure, including its premise, on social justice and social sustainability, and, finally, on the potential of the NKCS to support social sustainability. In so doing, the article brings new insights about the NKCS's potential to uncover Alexander's contributions and subsequent implications for some of the most critical issues of our time.

After describing the method, the remainder of the article first describes the living structure of Alexander and the NKCS and how the NKCS builds upon living structure and the organic worldview. After that, we account for the organic worldview, biophilia, and associated findings concerning visceral and universal aesthetic preferences for living structure. This is followed by elaborations on how the NKCS can further test the premise of visceral and universal preferences for living structure, the subsequent implications for social justice and social sustainability, and the potential of the NKCS to support such values. Finally, the conclusions are presented.

2. Method

The synthesis was carried out in three steps. We started by reviewing Alexander's living structure. The review was performed on Alexander's main work with a conceptual bearing on urban form and design, here considered to be the following: *A City Is Not a Tree* (1965), *A Pattern Language* (1977), *The Timeless Way of Building* (1979), and *The Nature of Order: An Essay on the Art of Building and the Nature of the Universe* (2002–2005). This was followed by a review of the NKCS, including articles by Jiang (2022a), who conceived the NKCS. The included literature describes the mathematical model of the NKCS, its purpose, and how it builds upon the living structure of Alexander and the underlying worldview. The premise of visceral and universal aesthetic preferences was identified as fundamental to justify living structure as science in addition to art. Due to the controversial nature of the premise, it became the point of departure for the rest of the study.

To further understand the premise, a third review was performed on the organic worldview and the biophilia hypothesis, serving as the foundational conceptual and scientific frameworks for living structure and the NKCS (e.g., Alexander, 2002a, 2004; Jiang, 2022a, 2022b; Salingaros, 2015). We began by accounting for the organic worldview and the biophilia hypothesis by drawing from its creators, Whitehead (1929), respectively,

Wilson (1984), and Kellert and Wilson (1993). To understand the biophilia hypothesis from the perspective of living structure, we also included literature from living structure advocates such as Alexander (2002a), Jiang (2022a), Mehaffy (2017), and Salingaros (2015). Thereafter, a review of the scientific support for the biophilia hypothesis and the underlying premise of visceral and universal aesthetic preferences for living structure was performed. It included articles presenting empirical research on human responses to nature and features relating to living structure, either in literature reviews or original research.

With that as a basis, conclusions were made on how the NKCS can be operationalized to progress the testing of the premise of visceral and universal aesthetic preferences for living structure. We also concluded the implication of present knowledge about living structure and its premise for social justice and social sustainability, and finally, on the potential of the NKCS to maintain and promote such values.

3. Living Structure and the New Kind of City Science

Alexander (2002a) describes a living structure as an evolving structure, inclusive of space and pervasive, departing from the surface of the earth as the expression of completeness, to which all else relates recursively. The world is perceived as complex and non-linear, and the living structure as the structure of complex adaptive systems (CAS; Alexander, 2003). Complexity and non-linearity, regarding both CAS and living structure, depend on the interdependence of a system's different components and subsequent emergent properties (Alexander, 2003; Jiang, 2015; Walker & Salt, 2006). Complexity is explained to be captured by the semilattice structure, described as the structure of living things (Alexander, 1965). A semilattice is similar to a treelike structure, but instead of having parts connected only through one common medium, a semilattice is a pronounced network with direct connections between nodes. Natural cities—i.e., cities that have emerged slowly over time instead of being planned—are often characterized by a semilattice structure, demonstrated by Alexander (1965) to provide the complexity needed to promote life through comprehensive interconnections. Planned and modernistic cities—for example, Brasília—are, on the contrary, often characterized by a treelike structure and considered incapable of supporting a living city.

Complexity recurs throughout the rest of Alexander's work. It is further emphasized in the presentation of 253 aesthetically beneficial design patterns identified by Alexander et al. (1977), suggested as tools to enhance the livingness of, for example, regions, towns, neighborhoods, buildings, rooms, and construction details. The patterns are explained to form a language with nearly endless possible combinations where a singular pattern, on the smallest level of scale, receives its meaning from the interactions between patterns over

and within each scale, hence from its context and “the whole.” When Alexander (2002a) later generalized the patterns into 15 properties of good design, understood as expressions of the underlying characteristics of life, complexity is continuously underlined (see, for instance, the first and 15th properties; Table 1). Complexity also reappears in Alexander's (1979, 2002b) elaborate promotion of a slow and stepwise emergent urban design, departing from what already exists, from the actions and interactions of the people living and engaging in their environment. On the contrary, large-scale and top-down processes are considered incapable of generating good design (Alexander et al., 1977).

Jiang (2022a, p. 31), through the NKCS, describes the living structure as “the recurring notion (or inherent hierarchy) of far more small substructures than large ones.” The NKCS captures the nonlinear thinking of CAS through a Paretian mindset, perceiving the world as unbalanced and heterogenous, contrasting the conventional Gaussian mindset and the perception of the world as predictable, linear, and simple (Jiang, 2015). The scaling law represents the Paretian mindset and endorses skewed distribution and an often-occurring absence of a well-defined mean (Jiang, 2015).

According to the scaling law, a living structure consists of a recursive hierarchy of a significantly higher number of small substructures than large substructures across all scales. The ratio between small and large substructures is closer to 80/20 in accordance with the Pareto distribution (Jiang, 2015, 2022a). Living structure is gradually valued, and the degree of living structure is to livingness what temperature is to warmth. The degree of living structure (L) is defined by the number of substructures (S) and their inherent hierarchy (H), that is, $L = S \times H$ (Jiang & de Rijke, 2023). More substructures and hierarchies, or a deeper recursiveness, imply more livingness. The scaling law describes a heavy-tailed distribution, i.e., a dataset with more data lower than the average (tail) than data higher than the average (head), caused by the interdependence of substructures. It captures the qualities of the semilattice (Jiang, 2015), physically manifest in the urban landscape as, for instance, high-connectivity streets in terms of the number of nodes connecting different spaces (Jiang, 2019).

Through the scaling law and the heavy-tailed distribution, it is possible to further understand the recursiveness of substructures (Jiang, 2022a). The divide between the head and the tail in the heavy-tailed distribution frames disparate substructures termed head/tail breaks (Jiang, 2013). The head of each break can be further divided into substructures if the substructure, i.e., the head, meets the conditions of a heavy tail distribution. The number of breaks represents the number of hierarchies and the recursiveness of the dataset. Many breaks are equal to a deep recursiveness.

Jiang (2022b) illustrates the hierarchical order of urban substructures in terms of street networks by comparing the city plans of London and Manhattan (Figure 1).

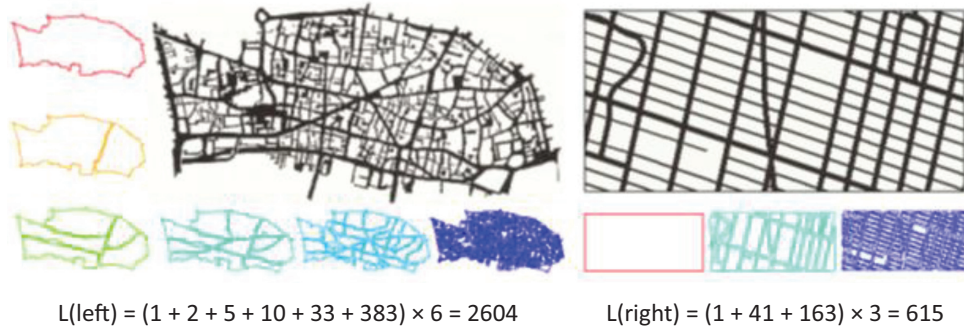


Figure 1. The city plans of London (left) and Manhattan (right) as examples of living structure. Source: Jiang (2022b, p. 39).

Instead of a conventional static view, the city plans are viewed as dynamically evolved from a whole. For example, the City of London is understood as a step-by-step evolution or transformation (like a cell division process) from one to two to five to 10 to 33 and 383 substructures over six hierarchical levels (Jiang & Huang, 2021). By comparing the two city plans, the degree of livingness of the City of London appears more than four times greater than New York’s, hence, the City of London has a higher degree of living structure than that of Manhattan (Jiang, 2022b).

Within the NKCS, the scaling law is considered dominant (Jiang, 2022a). However, the NKCS also encompasses Tobler’s (1970) law and the Gaussian mindset. Tobler’s law departs from a well-defined average with slight differences between substructures, acknowledging the interrelatedness of everything and the increasing interrelatedness with proximity. These two laws might seem contradictory, but with the scaling law working across scales, and Tobler’s law within scales, they complement each other (Jiang & de Rijke, 2023). Furthermore, Jiang (2022a) explains that living structure is favored by the approximate, and both laws are statistical rather than exact.

While the scaling law and Tobler’s (1970) law explain the appearance and function of cities and can be used to

assess existing structural states and dynamics, two corresponding principles concerning what a city ought to be meet each law (Jiang, 2022a). The scaling law is met by the principle of differentiation, aiming to create far more small substructures than large ones. It indicates recursiveness and applicability over scales. Tobler’s law is met by the principle of adaptation, intending to secure adaptation and relative similarity between substructures within the same level of scale.

The two fundamental laws (scaling law and Tobler’s law) and the two principles (differentiation and adaptation) of the NKCS are distillates of Alexander’s 15 properties of good design. According to Jiang (2019), by using both principles when designing a coherent whole is promoted, characterized by nested and recursively ordered substructures, well adapted to each other. The relationship between the 15 properties and the two principles (by extension, the two laws) of the NKCS is listed and explained below (Table 1).

4. The Organic World View and the Biophilia Hypothesis

The endorsement of the organic worldview, inclusive of the prevailing Cartesian and mechanical worldview, but

Table 1. Relationship between Alexander’s 15 properties and the laws and principles of the NKCS.

Property	Description of property (Alexander, 2002a)	The linkage between property and principles (Jiang, 2019)
Levels of Scale	Substructures of different sizes and hierarchical order enhance each other. However, the size difference between substructures should be balanced.	Levels of Scale and the scaling law mirror each other. The property is therefore linked to the principle of differentiation by promoting deep recursiveness and far more small substructures than large ones.
Strong Centers (i.e., substructures)	A substructure is strong when the surrounding substructures, and the contained and containing substructures, are strong.	Strong Centers is linked to both principles. Surrounding centers on the same level of scale meet the principle of adaptation, and the recurring centers across levels of scales meet the principle of differentiation.
Thick Boundaries	Distinct boundaries intensify substructures and connect as much as separate substructures and space.	Thick Boundaries meets the principle of differentiation and adaptation since the differentiation of substructures and space takes place within and over levels of scales.

Table 1. (Cont.) Relationship between Alexander’s 15 properties and the laws and principles of the NKCS.

Property	Description of property (Alexander, 2002a)	The linkage between property and principles (Jiang, 2019)
Alternating Repetition	Subtle variations enhance livingness by averting monotony. The structure becomes more living with only some minor alterations in each repetition.	Alternating Repetition meets the principle of adaptation because the alterations are usually similar in size.
Positive Space	Space is as essential as substructures. Substructures should expand outwards and include their surroundings, like corn kernels on a cob.	Positive Space applies within and across levels of scales and therefore meets the principle of differentiation and adaptation.
Good Shape	A good shape is a shape that recursively consists of other good shapes.	Good Shape meets the principle of differentiation since the property addresses substructures across levels of scales.
Local Symmetries	Symmetry on a local level benefits livingness but should not occur globally.	Local Symmetries meets the principle of adaptation. If symmetry occurs over levels of scales, the scaling law is contradicted.
Deep Interlock and Ambiguity	Substructures sometimes merge or consist of mutual substructures in a way that makes it difficult to distinguish substructure and space from each other.	Deep Interlock and Ambiguity meets the principle of adaptation because interlock tends to occur between similar substructures within the same level of scale.
Contrast	A distinction between substructures in terms of color, light, and structure can intensify aesthetic experiences.	Contrast meets the principle of adaptation because such distinction recurs between nearby and similar substructures.
Gradients	Variations should be gradual across space, imitating natural gradients that occur as responses to differences in the environment.	Gradients meets the principle of adaptation because of its field-like character, occurring between nearby substructures within the same level of scale.
Roughness	Like gradients, irregularities, for instance, in terms of texture, can occur in substructures as a cause of adaptation to surrounding irregularities.	Roughness meets both principles because it is related to fractals and occurs on the same level of scale and across levels of scales.
Echoes	Smaller substructures are similar to larger substructures, favoring coherence.	Echoes meets both principles because the property resembles the recursiveness of fractals across and within levels of scales.
The Void	A large and empty substructure can enhance the intensity of “the whole” and contribute to harmony and distinction.	The Void meets the principle of differentiation by taking place at the largest level of scale, surrounded by smaller substructures.
Simplicity and Inner Calm	This property occurs locally and represents a state of simplicity and calm by eliminating unnecessary substructures.	Simplicity and Inner Calm meets the principle of adaptation by only having local relevance. The application across levels of scales would result in minimalism.
Not-Separateness	Despite having individual characters, all substructures and space interact and must be holistically dealt with. The same applies to the 15 properties.	Not-Separateness has multiple meanings and can relate, for instance, to inseparable levels of scales or substructures of a whole.

not limited to it (Alexander, 2004; Whitehead, 1929), enables the existence of visceral and universal aesthetic preferences and, in extension, the justification of living structure and associated ideas as a science (Alexander, 2002a, 2004; Jiang, 2022a). According to Alexander (2004), the mechanical worldview, extended into modernist society, has until now hindered the appreciation and consideration of value and beauty in science since it perceives humans to be separate from the rest of the world, value to be subjective and arbitrary, and the quality of a system comprehensible through each systemic component separately. The organic worldview, conceived by Whitehead (1929), instead withholds humans and values as interdependent substructures of an organic, interconnected whole with emergent properties. The departure is scientifically approached through biophilic reasoning (Jiang, 2022b; Salingaros, 2015), sometimes with explicit references to complexity theory and CAS (Mehaffy, 2017; Mehaffy & Salingaros, 2015).

According to the biophilia hypothesis, humans are biologically predisposed to be attracted or repelled by certain environmental features through affective responses adapted to the environment where humans mainly evolved (Kellert & Wilson, 1993; Wilson, 1984). Salingaros (2015) describes two sources for biophilic instinct representing two parallel strands of conjecture. The first source relates to landscape characteristics of the savannah, encompassing the existence of, for instance, greenery, bodies of water, and a particular spatial organization. The second source, which Alexander and the NKCS relate to, regards the geometries of biology, i.e., living structure, which humans also have evolved to appreciate or detest depending on what has been functional. It concerns, for example, fractals, scaling, organized complexity, complex symmetries, and colors (Mehaffy & Salingaros, 2015; Salingaros, 2015). By identifying the seemingly beneficial quality in nature and living entities, the quality can be simulated and captured in non-living elements, such as paintings, artifacts, rooms, buildings, gardens, streets, and cities (Alexander, 2002a, 2005; Jiang & de Rijke, 2023).

Contemporary human habitats, industrialized and urbanized, are considered estranged from nature and devoid of living structure, thus, also inappropriate for human life (Kellert & Wilson, 1993; Wilson, 1984). This is particularly evident in modernist architecture and design adopting minimalistic ideals (Alexander, 1965, 2002b; Jiang, 2022b; Mehaffy, 2017). Worldwide use of living structure characteristics in architecture and art, seemingly over time until modern days, is used to argue for biophilia and the assumption of visceral and universal appreciation for living structure (Alexander, 2002a; Joye, 2007).

Reviews on biophilia confirm consistent reports of the aesthetic appreciation for nature and the health benefits of exposure to nature (Berto et al., 2023; Bratman et al., 2012; Gaekwad et al., 2022; Gullone, 2000). However, evidence of a predisposed aversion towards

some natural features (i.e., biophobia) is often considered to provide the most salient support for the hypothesis. Advocates think that if functional fear of specificities, for instance, snakes and spiders, can be transferred over generations, reasonably so can appreciation (Kellert & Wilson, 1993; Ulrich, 1993; Wilson, 1984). Nevertheless, all do not accept the assumed symmetry between positive and negative responses toward natural elements and entities (Joye & De Block, 2011; Ulrich, 1993). Joye and De Block (2011) argue that such assumptions are neither supported by evolutionary reasoning nor empirical findings.

A lack of cross-cultural studies and an overall geographical bias towards Western countries in the biophilic/biophobic body of literature furthermore hinders conclusions about the universality of such results (Gaekwad et al., 2022; Gullone, 2000; Ulrich, 1993) and about a potential biological origin (Gullone, 2000). However, Ulrich (1993) argues that while affirmative cross-cultural studies on biophilic responses do not disprove biological inheritance, they fail to provide evidence. Support for universal preferences cannot exclude possibilities of widespread acquired preferences through learning. Moreover, Ulrich (1993) thinks that both genetics and learning most likely have an impact, but to an uncertain extent, and suggests behavioral genetics as one way to investigate such distinctions further. In that case, Ulrich (1993) proposes, for instance, to first determine positive biophilic responses with high individual variability and then compare responses of a large sample of twins to the same biophilic stimuli.

Studies about exposure to nature and nature representations, like those mentioned above (e.g., Berto et al., 2023; Bratman et al., 2012), are used to argue for living structure since the significance of for instance, fractals, scaling, and organized complexity is based on their prominent existence in nature (Friedenberg et al., 2022; Salingaros, 2012, 2015). However, research on living structure is also isolated from nature representations. For example, Berto et al. (2023) conclude evidence of preferences for, and restorative qualities of, façades characterized by organized complexity. Preferences for patterns of organized complexity are also observed by Aks and Sprott (1996), and several studies focusing on artificial fractals conclude positive responses (Hagerhall et al., 2004; Spehar et al., 2003; Viengkham & Spehar, 2018). However, while demonstrating robustness in fractal preferences, Viengkham and Spehar (2018) found no support for universality, and Stamps (2002) concluded preferences for non-fractals in urban landscapes.

A positive and significant relationship between human activity and a high degree of semilattice structure is demonstrated by a study on human activity in relation to varying degrees of semilattice structure in urban districts (Huang et al., 2022). Likewise, a topological perspective is proven accurate in predicting human traffic flow (Hillier, 1996; Hillier & Iida, 2005; Penn, 2003), and high connectivity (as in a semilattice) promotes

movement and spatial integration (Legeby, 2018). This might be explained by Penn's (2003) suggestion that the perception of space depends on topology rather than geometry, an idea shared by Jiang (2019) and the NKCS since the topological perspective captures the physical manifestation of the scaling law.

Like research concerning exposure to nature and nature representations, research on human responses when exposed to a living structure, demonstrates positive results (Aks & Sprott, 1996; Hagerhall et al., 2004; Hillier & Iida, 2005; Huang et al., 2022; Spehar et al., 2003). However, the evidence is not enough to support universality or biological inheritance. Apart from a scant selection of empirical research, most studies depart from small samples and investigate self-reported preferences and aesthetic ratings of images (e.g., Aks & Sprott, 1996; Huang et al., 2022; Spehar et al., 2003; Viengkham & Spehar, 2018). Literature is geographically biased, and cross-cultural studies, like research investigating the relationship between biological and learned causes for affective and cognitive responses, appear to be scarce.

5. Discussion

The NKCS captures the essence of the organic worldview, the theoretical enabler of visceral and universal aesthetic preferences, and the departure of Alexander's work on living structure. The organic worldview and its incorporation of the mechanical worldview are represented by combining the Paretian mindset and the scaling law with the Gaussian mindset and Tobler's law. The organic interdependence of substructures and "the whole" is reflected by the Paretian distribution and the scaling law. In contrast, the mechanical order is reflected by the Gaussian distribution and Tobler's law (Jiang, 2022a). This gives a good account of the complexity prominent in the work of Alexander (e.g., 1965, 1979, 2002a, 2004), further manifested by the heavy-tailed distribution of the scaling law, the hierarchical graph of head-tail breaks, and the topological perspective of cities, indicative of the suitability of the NKCS to analyze cities as complex networks (Jiang, 2015).

The design principles of differentiation and adaptation distill Alexander's (2002a) 15 properties of good design (Jiang, 2019). By promoting the enhancement of far more small substructures than large ones, the principle of differentiation captures the feature of deep recursiveness, a defining characteristic of several of Alexander's (2002a) 15 properties, i.e., Levels of Scales, Strong Centers, Good Shape, and Echoes. The principle of adaptation instead emphasizes the feature of coherence in the same or nearby scales, particularly evident in the properties of Local Symmetries, Deep Interlock and Ambiguity, Gradients, and Simplicity and Inner Calm (Jiang, 2019; Jiang & de Rijke, 2023). Hence, we conclude that the NKCS provides a tool to make holistic accounts of a living structure instead of focusing on singular living structure characteristics, for instance, fractals. The NKCS

is therefore argued to be particularly appropriate to use in the continued research of living structure, for instance, regarding the underlying assumption of visceral and universal aesthetic preferences.

Empirical research supports a positive link between human well-being and nature and the characteristics of a living structure (e.g., Berto et al., 2023; Bratman et al., 2012; Gaekwad et al., 2022). However, empirical research testing the claims of universal and visceral aesthetic appreciation is scant, and evidence is inconclusive (Joye & De Block, 2011; Ulrich, 1993). Since the legitimacy of living structure as science, in addition to art, rests upon the existence of visceral and universal beauty, this knowledge gap is essential to understand the contribution of Alexander and how to proceed best when designing cities. However, it is a challenge to test these claims. Testing universal value demands extensive cross-cultural studies, and testing the biological inheritance of value demands a method capable of refuting learned responses (Gullone, 2000; Ulrich, 1993). Sometimes research showing physical responses is taken as evidence for heredity, but learned responses can also manifest physically, for instance, considering the placebo effect (Wager et al., 2004). Furthermore, the associated nature/nurture dichotomy is generally questioned for a more integrated approach (Creanza et al., 2017; Moore, 2002; Thompson et al., 2016). In agreement, Ulrich (1993) promotes biophilic research to recenter around the significance of biological factors in relation to learning rather than attempting to prove a binary existence. To argue for biophilic design on behalf of well-being, when conflicting with sociocultural norms and preferences, the genetic factor would have to prove dominant or at least of considerable significance for human well-being.

The NKCS cannot distinguish the origin of human responses by itself, but it can make holistic representations of a living structure devoid of other stimuli. It can also holistically account for the living structure in existing environments. As demonstrated by Giusti and Samuelsson (2023), new technologies such as smartwatches, tracking people's movements and health, can be used for large-scale, spatially explicit, public participatory research to collect people's self-reported experiences and spatially explicit data on heart rate variability, an important indicator for stress. The capacity of the NKCS to assess and map the living structure in urban landscapes, in combination with new opportunities for health-related data collection, enables cross-cultural and large-scale investigations of the relationship between degrees of living structure and well-being. It can help promote knowledge about the extent of conformity, perhaps universality, of aesthetic preferences for living structure. Another way to go forward with the same purpose could be to assess the degree of living structure in a large artwork sample from several divergent cultures. To research the biological influence on perceptions of beauty, the twin study suggested by Ulrich (1993) or

other suitable research designs could be performed with NKCS-generated representations of a living structure as biophilic stimuli.

Conclusive evidence for a significant biological component of aesthetic preferences would increase the scientific validity of living structure and associated ideas and make a strong case for human sameness and connectedness. However, so can conclusive evidence for the universality of preferences and even broad conformity explained by sociocultural evolution through social learning and a long-spun cultural transmission (Creanza et al., 2017; Thompson et al., 2016). Preferences acquired through rooted intercultural knowledge may not be fixed and eternal but suggest inertness (Thompson et al., 2016) and, therefore, also have the potential to legitimize living structure as a science. Moreover, while sociocultural evolution usually appears as a slow process of production and reproduction, some degree of plasticity enables sociocultural expressions deviant from learned and genetic bias, and sociocultural heterogeneity enables reform (Klüver, 2008; Thompson et al., 2016). The premise of living structure is controversial and exemplifies sociocultural heterogeneity. Despite so, it is possible that preferences for nature and living structure also represent a genetic bias. Continued scientific support for extensive preferences for living structure, regardless of preferential origin, could displace the discourse of beauty and reinforce the significance of a potential genetic bias. Moreover, it could increase the societal significance of Alexander's living structure and associated ideas, impacting urban design, resource use, well-being, and the sociocultural reform needed to manage increasing inequality and the breach of planetary boundaries.

The favoring of collective identity and conceptions of social justice is arguably justified to promote collaborative behavior and sharing. However, it stresses the importance of individual autonomy to maintain and promote democratic values and practices and avoid benefitting oppressive regimes. Alexander's (1979) promotion of inclusive, bottom-up agency to enhance living structure endorses individual uniqueness as necessary to build collective value. Moreover, theories on community work, particularly relevant within the context of urban social sustainability (Rothman, 1995; Sjöberg et al., 2015; Stepney & Popple, 2008), use collective identity to promote activation, inclusive participation, and democratic influence in decision-making processes (Adams, 2008; Popple, 2015). A long-term process promoting joint capacity, resource building, and collective empowerment encourages communities to mobilize and drive socially sustainable development themselves (Adams, 2008; Popple, 2015), for instance, through place-related planning since local construction projects engage people (Brusman & Turunen, 2018).

By enabling computer-generated design solutions with high living structure, the NKCS could challenge Alexander's (1979) faith in bottom-up agency for the emergence of holistic and aesthetically appreciated

design. However, it cannot replace the empowering lessons of participation and joint effort engagements in the local environment. Hence, we stress space, place, and design as means of democracy, social justice, and social sustainability and the importance of using techniques like the NKCS to facilitate and encourage inclusive, participatory processes to empower people and local communities. The NKCS could, for instance, be incorporated into a participatory digital tool, allowing people to design their proposals for local construction projects and promote participation in negotiations. However, while encompassing Alexander's 15 properties, the NKCS is presently more general. To concretize something abstract, a participatory tool departing from living structure and the NKCS might benefit from combining the principle of differentiation and adaptation with Alexander's 15 properties or even the 253 design patterns.

6. Conclusion

Research demonstrates the health benefits of exposure to nature and living structure characteristics. Nevertheless, further testing of the assumption of visceral and universal aesthetic preferences for living structure is necessary to learn more about the validity of living structure as science in addition to art and the contributions of Alexander. Research capable of distinguishing the origin of preferences appears challenging to design and perform, especially since universal preferences do not equate with visceral preferences. Universality could equally be explained by social learning and widespread cultural transmission. Therefore, a potential confirmation of universal preferences for living structure would still require a refutation of the impact of learning to confirm the hypothesized biological origin. However, we argue that it is unnecessary to prove a biological origin of aesthetic preferences to support the validity of the premise of living structure. Universal preferences, or even broad conformity, acquired through social learning and long-spun cultural transmission may not be fixed and eternal but indicate an inertness that grants similar conclusions.

Considering the increasing critique of the nature/nurture dichotomy, a genetic component of aesthetic preferences is likely. In agreement with Ulrich (1993), further research is suggested to recenter around the significance of biological factors in relation to learning rather than attempting to prove a binary existence. With that in mind, the positive link between well-being and exposure to nature and living structure could be an expression of genetic bias while, at the same time, through its controversy, also representing sociocultural heterogeneity. If continued research successfully confirms preferences for living structure, inherited or not, living structure and associated ideas could engage in a self-reinforcing process and increase their significance in urban design, resource use, well-being, and the sociocultural reform needed to manage increasing inequality and the breach of planetary boundaries.

Due to the unique capacity of the NKCS to holistically represent Alexander's living structure and the organic worldview, the mathematical model is considered appropriate for continued research on, for instance, the visceral and universal nature of living structure preferences. Apart from justifying living structure as science with design implications, conclusive evidence for universal aesthetic preferences, or at least widespread conformity, would likely favor a more collective approach to human self-identity and social justice. To benefit a socially just and health-promoting development within the planet's boundaries, individual autonomy, as a cornerstone of democracy and social justice, must be maintained and enhanced. We, therefore, stress the importance of space, place, and design as means of democracy. The NKCS should, in accordance with Alexander's call for bottom-up design processes, encourage and facilitate inclusive participation in the design and construction of local environments to empower and mobilize people and communities.

Acknowledgments

This work has been carried out under the auspices of the industrial post-graduate school Future Proof Cities (Grant No. 2019–0129), which is financed by the Knowledge Foundation (KK-stiftelsen) of Sweden. We kindly thank the funding body for their financial support. Moreover, we kindly thank Gävle Municipality for their support.

Conflict of Interests

The authors declare no conflict of interests.

References

- Adams, R. (2008). *Empowerment, participation and social work* (4th ed.). Palgrave Macmillan.
- Aks, D. J., & Sprott, J. C. (1996). Quantifying aesthetic preference for chaotic patterns. *Empirical Studies of the Arts*, 14(1), 1–16.
- Alexander, C. (1965). A city is not a tree. *Architectural Forum*, 122(1/2), 58–62.
- Alexander, C. (1979). *The timeless way of building*. Oxford University Press.
- Alexander, C. (2002a). *The nature of order: The phenomenon of life: An essay on the art of building and the nature of the universe* (Vol. 1). Center for Environmental Structure.
- Alexander, C. (2002b). *The nature of order: The process of creating life: An essay on the art of building and the nature of the universe* (Vol. 2). Center for Environmental Structure.
- Alexander, C. (2003). New concepts in complexity theory arising from studies in the field of architecture: A response by Christopher Alexander. *Katarxis*, 3, 1–24.
- Alexander, C. (2004). *The nature of order: The luminous ground: An essay on the art of building and the nature of the universe* (Vol. 4). Center for Environmental Structure.
- Alexander, C. (2005). *The nature of order: A vision of a living world: An essay on the art of building and the nature of the universe* (Vol. 3). Center for Environmental Structure.
- Alexander, C., Ishikawa, S., & Silverstein, M. (1977). *A pattern language: Towns, buildings, construction*. Oxford University Press.
- Berto, R., Barbiero, G., & Salingaros, N. A. (2023). Biophilic design of building façades from an evolutionary psychology framework: Visual attention software compared to perceived restorativeness. *Visions for Sustainability*, 2023(19), 91–124.
- Bratman, G. N., Hamilton, J. P., & Daily, G. C. (2012). The impacts of nature experience on human cognitive function and mental health: Nature experience, cognitive function, and mental health. *Annals of the New York Academy of Sciences*, 1249(1), 118–136.
- Brusman, M., & Turunen, P. (2018). Socialt hållbar samhällsplanering [Socially sustainable social planning]. In S. Sjöberg & P. Turunen (Eds.), *Samhällsarbete: Aktörer, arenor och perspektiv* [Community work: Actors, arenas and perspectives] (pp. 117–138). Studentlitteratur.
- Burton, E. (2000). The compact city: Just or just compact? A preliminary analysis. *Urban Studies*, 37(11), 1969–2006.
- Creanza, N., Kolodny, O., & Feldman, M. W. (2017). Cultural evolutionary theory: How culture evolves and why it matters. *Proceedings of the National Academy of Sciences*, 114(30), 7782–7789.
- Dawes, M. J., & Ostwald, M. J. (2017). Christopher Alexander's a pattern language: Analysing, mapping and classifying the critical response. *City, Territory and Architecture*, 4(1), Article 17.
- Dempsey, N., Brown, C., & Bramley, G. (2012). The key to sustainable urban development in UK cities? The influence of density on social sustainability. *Progress in Planning*, 77(3), 89–141.
- Fingerhut, J., Gomez-Lavin, J., Winklmayr, C., & Prinz, J. J. (2021). The aesthetic self: The importance of aesthetic taste in music and art for our perceived identity. *Frontiers in Psychology*, 11, Article 577703.
- Florida, R. (2017). *The new urban crisis*. Oneworld Publications.
- Friedenberg, J., Martin, P., Uy, N., & Kvapil, M. (2022). Judged beauty of fractal symmetries. *Empirical Studies of the Arts*, 40(1), 100–120.
- Gaekwad, J. S., Sal Moslehian, A., Roös, P. B., & Walker, A. (2022). A meta-analysis of emotional evidence for the biophilia hypothesis and implications for biophilic design. *Frontiers in Psychology*, 13, Article 750245.
- Giusti, M., & Samuelsson, K. (2023). Evaluation of a smartphone-based methodology that integrates

- long-term tracking of mobility, place experiences, heart rate variability, and subjective well-being. *Heliyon*, 9(5), Article e15751.
- Gullone, E. (2000). The biophilia hypothesis and life in the 21st century: Increasing mental health or increasing pathology? *Journal of Happiness Studies*, 1(3), 293–322.
- Hagerhall, C. M., Purcell, T., & Taylor, R. (2004). Fractal dimension of landscape silhouette outlines as a predictor of landscape preference. *Journal of Environmental Psychology*, 24(2), 247–255.
- Heywood, A. (2021). *Political ideologies: An introduction*. Bloomsbury Publishing.
- Hillier, B. (1996). *Space is the machine: A configurational theory of architecture*. Press Syndicate of the University of Cambridge.
- Hillier, B., & Iida, S. (2005). Network and psychological effects in urban movement. In A. G. Cohn & D. M. Mark (Eds.), *Spatial information theory: International conference, COSIT 2005, Ellicottville, NY, USA, September 14–18, 2005, Proceedings* (Vol. 3693, pp. 475–490). Springer.
- Huang, J., Cui, Y., Chang, H., Obracht-Prondzyńska, H., Kamrowska-Zaluska, D., & Li, L. (2022). A city is not a tree: A multi-city study on street network and urban life. *Landscape and Urban Planning*, 226, Article 104469.
- Jiang, B. (2013). Head/tail breaks: A new classification scheme for data with a heavy-tailed distribution. *The Professional Geographer*, 65(3), 482–494.
- Jiang, B. (2015). Geospatial analysis requires a different way of thinking: The problem of spatial heterogeneity. *GeoJournal*, 80(1), 1–13.
- Jiang, B. (2019). Alexander’s wholeness as the scientific foundation of sustainable urban design and planning. *New Design Ideas*, 3(2), 81–98.
- Jiang, B. (2022a). A new kind of city science built on living structure and on the third view of space. *Coordinates*, 18(2), 31–40.
- Jiang, B. (2022b). Geography as a science of the earth’s surface founded on the third view of space. *Annals of GIS*, 28(1), 31–43.
- Jiang, B., & de Rijke, C. (2023). Living images: A recursive approach to computing the structural beauty of images or the livingness of space. *Annals of the American Association of Geographers*, 113(6), 1329–1347. <https://doi.org/10.1080/24694452.2023.2178376>
- Jiang, B., & Huang, J.-T. (2021). A new approach to detecting and designing living structure of urban environments. *Computers, Environment and Urban Systems*, 88, Article 101646.
- Joye, Y. (2007). Fractal architecture could be good for you. *Nexus Network Journal*, 9(2), 311–320.
- Joye, Y., & De Block, A. (2011). “Nature and I are two”: A critical examination of the biophilia hypothesis. *Environmental Values*, 20(2), 189–215.
- Kellert, S., & Wilson, E. O. (1993). *The biophilia hypothesis*. Island Press.
- Klüver, J. (2008). The socio-cultural evolution of our species: The history and possible future of human societies and civilizations. *EMBO Reports*, 9(S1), S55–S58.
- Kymlicka, W. (2002). *Contemporary political philosophy: An introduction* (2nd ed.). Oxford University Press.
- Legeby, A. (2018). Everyday urban life at neighbourhood centers: Urban design and co-presence. In P. A. E. Toft & M. Rönn (Eds.), *The production of knowledge in architecture by PhD research in the Nordic countries* (pp. 73–100). Nordic Academic Press of Architectural Research.
- Mehaffy, M. (2017). *Cities alive: Jane Jacobs, Christopher Alexander and the roots of the new urban renaissance*. Sustasis Press.
- Mehaffy, M., & Salingaros, N. (2015). *Design for a living planet*. Sustasis Press.
- Millward-Hopkins, J. (2022). Why the impacts of climate change may make us less likely to reduce emissions. *Global Sustainability*, 5, Article e21.
- Moore, D. S. (2002). *The dependent gene: The fallacy of “nature vs. nurture”* (2nd ed.). Macmillan.
- Penn, A. (2003). Space syntax and spatial cognition: Or, why the axial line? *Environment and Behavior*, 35(1), 30–65.
- Popple, K. (2015). *Analysing community work: Theory and practice*. Open University Press.
- Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin, F. S., Lambin, E. F., Lenton, T. M., Scheffer, M., Folke, C., Schellnhuber, H. J., Nykvist, B., de Wit, C. A., Hughes, T., van der Leeuw, S., Rodhe, H., Sörlin, S., Snyder, P. K., Costanza, R., Svedin, U., . . . Foley, J. A. (2009). A safe operating space for humanity. *Nature*, 461(7263), 472–475.
- Rothman, J. (1995). Approaches to community intervention. In J. Rothman, J. L. Erlich, & J. E. Tropman (Eds.), *Strategies of community intervention* (pp. 26–63). F. E. Peacock Publishers.
- Salingaros, N. A. (2012). Fractal art and architecture reduce physiological stress. *Journal of Biourbanism*, 2(12), 11–27.
- Salingaros, N. A. (2015). *Biophilia and healing environments: Healthy principles for designing the built world*. Terrapin Bright Green.
- Samuelsson, K., Giusti, M., Peterson, G. D., Legeby, A., Brandt, S. A., & Barthel, S. (2018). Impact of environment on people’s everyday experiences in Stockholm. *Landscape and Urban Planning*, 171, 7–17.
- Sjöberg, S., Rambaree, K., & Jojo, B. (2015). Collective empowerment: A comparative study of community work in Mumbai and Stockholm. *International Journal of Social Welfare*, 24(4), 364–375.
- Spehar, B., Clifford, C. W. G., Newell, B. R., & Taylor, R. P. (2003). Universal aesthetic of fractals. *Computers & Graphics*, 27(5), 813–820.
- Stamps, A. E. (2002). Fractals, skylines, nature and beauty. *Landscape and Urban Planning*, 60(3), 163–184.
- Stepney, P., & Popple, K. (2008). *Social work and the*

- community: A critical context for practice*. Palgrave Macmillan.
- Thompson, B., Kirby, S., & Smith, K. (2016). Culture shapes the evolution of cognition. *Proceedings of the National Academy of Sciences*, 113(16), 4530–4535.
- Tobler, W. (1970). A computer movie simulating urban growth in the Detroit region. *Economic Geography*, 46(2), 234–240.
- Ulrich, R. S. (1993). Biophilia, biophobia, and natural Landscapes. In S. R. Kellert & E. O. Wilson (Eds.), *The biophilia hypothesis* (pp. 73–137). Island Press.
- UN-Habitat. (2016). *World cities report 2016—Urbanization and development: Emerging futures*. <https://unhabitat.org/sites/default/files/download-manager-files/WCR-2016-WEB.pdf>
- United Nations Department of Economic and Social Affairs. (2020). *Inequality in a rapidly changing world* (World Social Report No. ST/ESA/372). <https://www.un.org/development/desa/dspd/wp-content/uploads/sites/22/2020/02/World-Social-Report2020-FullReport.pdf>
- Viengkham, C., & Spehar, B. (2018). Preference for fractal-scaling properties across synthetic noise images and artworks. *Frontiers in Psychology*, 9, Article 1439.
- Wager, T. D., Rilling, J. K., Smith, E. E., Sokolik, A., Casey, K. L., Davidson, R. J., Kosslyn, S. M., Rose, R. M., & Cohen, J. D. (2004). Placebo-induced changes in fMRI in the anticipation and experience of pain. *Science*, 303(5661), 1162–1167.
- Walker, B. H., & Salt, D. (2006). *Resilience thinking: Sustaining ecosystems and people in a changing world*. Island Press.
- Warren, M. (1990). Ideology and the self. *Theory and Society*, 19(5), 599–634.
- Whitehead, A. N. (1929). *Process and reality: An essay in cosmology*. The Free Press.
- Wilson, E. O. (1984). *Biophilia*. Harvard University Press.

About the Authors



Tarina Levin is a PhD student in sustainability science at the University of Gävle, Sweden, within the industrial post-graduate school Future Proof Cities. The PhD project is co-created with the comprehensive planning department at the Municipality of Gävle, Sweden, and concerns social sustainability and urban form. She holds an MSc and BSc in landscape architecture from the Swedish University of Agricultural Science, Sweden.



Stefan Sjöberg is an associate professor in social work and a senior lecturer in sociology at the Department of Social Work and Criminology at the University of Gävle, Sweden. He also directs the research program Urban Commons under the strategic research area Urban Sustainability at the University of Gävle. He holds a PhD in sociology from Uppsala University, Sweden, and his main field of research concerns the Swedish welfare model, community work, and social mobilization.



Bin Jiang is a professor of urban informatics in the Urban Governance and Design Thrust at the Hong Kong University of Science and Technology (Guangzhou), China. He is also a professor in Geoinformatics at the University of Gävle, Sweden, and holds a PhD in Geoinformatics from Utrecht University, the Netherlands. His main field of research concerns georeferenced big data, geospatial analysis, AI/deep learning, urban livingness, and sustainability transformation.



Stephan Barthel is a professor in sustainability science at the University of Gävle, Sweden, and an associated researcher at the Stockholm Resilience Centre, Stockholm University, Sweden. He holds a PhD in natural resource management and an associate professor's degree in geospatial information science. His main field of research concerns urban sustainability, urban design and planning, and transdisciplinary co-creation for a fair climate transformation.