Frontiers in Social-Ecological Urbanism

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Abstract: This paper describes a new approach in urban ecological design, referred to as social–ecological urbanism (SEU). It draws from research in resilience thinking and space syntax in the analysis of relationships between urban processes and urban form at the microlevel of cities, where social and ecological services are directly experienced by urban dwellers. The paper elaborates on three types of media for urban designers to intervene in urban systems, including urban form, institutions, and discourse, that together function as a significant enabler of urban change. The paper ends by presenting four future research frontiers with a potential to advance the field of social–ecological urbanism: (1) urban density and critical biodiversity thresholds, (2) human and non-human movement in urban space, (3) the retrofitting of urban design, and (4) reversing the trend of urban ecological illiteracy through affordance designs that connect people with nature and with each other.

Keywords: social–ecological systems; urban design; climate-change adaptation; ecosystem services; cognitive resilience building

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1. Introduction

Social–ecological urbanism (SEU) is increasingly used by researchers to improve resilience in the urban built environment. The approach is positioned at the interface of urban ecology and urban design [1–3]. Its focus lies upon how urban form shapes and influences combined social and ecological services in the built environment.

While the SEU-approach is gaining interest, it is not well-known among urban scholars and practitioners. So far, two international symposiums on SEU have taken place. Both venues attracted a large number of scholars and urban professionals. The first, entitled 'Social-ecological urbanism: Perspectives on Urban Resilience and Sustainable Development', was held at the University of Gävle, Sweden in November 2016 [4]. The second symposium, entitled 'Balancing Dense and Green Urban Development', was held in June 2019 in the city of Gothenburg, Sweden, and it was organized by the Department of Architecture and Civil Engineering at the Chalmers University of Technology. The focus was on the balancing act needed to endorse different measures of density that embrace the advantages and counteract the disadvantages of building compact cities. The symposium clearly demonstrated that urban greening must be part of the equation of balancing between dense and livable cities (https://bit.ly/3kpO61S, accessed on 23 April 2022).

An early textbook on SEU has also been launched, describing how the approach can be used in building designs to improve social–ecological resilience [1]. The textbook is currently used at some university teaching- and training programs and urban design schools. In this paper, our aim is to present the SEU-approach to a wider audience of scholars and practitioners in urban planning, land-use, urban design, and landscape architecture.

Methodology and Article Outline

The main purpose behind this perspective paper is to lay down the foundations and outline for future research areas of a new approach for analyzing urban systems, referred to here as social–ecological urbanism. Taking into consideration the double crisis of climate change and biodiversity loss that humanity now faces, the SEU-approach stresses that urban research needs to narrow the gap between ecologists and designers when it comes to creating more sustainable cities, with collaboration focusing on the enhancement of social–ecological resilience [1]. Earlier attempts of bridging this gap have traditionally been dominated by relatively static design approaches, ignoring more non-linear and complex understandings of the interconnectedness of the social and ecological systems [3]. Urban designers have availed ecologists mainly as consultants and in the collection and classification of data in various design proposals and have traditionally incorporated ecological issues in the prescriptive and preventive aspects of projects. The more dynamic and non-linear understanding of the interconnectedness of urban ecology and urban design that the SEU-approach calls for is a shift in focus, where humans become resituated from being outside ecosystems to being integrated within them, or as stewards 'navigating' the system from within [3]. In the SEU-approach, humans become co-creators of nature through the integration and management of ecosystem services in tandem with social services in various urban design projects and by adopting social–ecological resilience thinking as a guiding design principle [1].

For the method applied in writing this perspective article, we use the inductive approach adopted by Barthel et al. [5], enabling multi-layered and cross-disciplinary collaboration and analysis from a diverse set of scientific disciplines represented by the authors' backgrounds in the natural, social, and humanistic sciences. The approach was initially developed by Conrad and Sinner [6] as a way to encourage scholars to work together to create interactivity with other researchers and professionals and to explore questions, generate knowledge, and express shared understandings of complex phenomena.

We begin by presenting the theoretical framework of the SEU-approach, including the three types of media for urban designers to intervene in urban systems. This is followed by an elaboration of the ways that the SEU-approach can be used for studying urban processes and their relation to urban form at the microlevel of cities, i.e., dealing with the aim to measure and experience the city at the eye-level-scale, where social and ecological services are directly experienced by urban dwellers. We next elaborate on the key role that institutions and property-rights arrangements hold for cities. While the SEU-approach could help to realize several Agenda 2030 targets in urban settings, we do not address them here due to limits in space. We instead end by highlighting four research frontiers with a real potential to strengthen collaboration among urban ecologists, urban designers, architects, and other practitioners involved in the shaping of sustainable and resilient cities.

2. Theoretical Framework of the SEU-Approach

The SEU-approach draws on studies of the resilience-building of interlinked social and ecological systems. Resilience science is the academic discourse that has most vigorously addressed and studied disruptions in complex adaptive systems, primarily ecosystems. While there exist a number of different definitions, the most dynamic interpretation is ecological resilience [7,8], signifying the magnitude of disturbance that can be absorbed before a system changes its structure by changing the variables and processes that control its behavior [9].

Berkes and Folke [10] originally used the term 'social–ecological system (SES)' to emphasize the concept of 'humans-in-nature', arguing that social and ecological systems are intertwined and that the delineation between the two is arbitrary. The SES discourse has grown rapidly over the last two decades, with well over 13,000 scientific publications devoted to social–ecological systems [11]. In this paper, we regard the 'built environment' as an urban social–ecological system, consisting of a set of critical natural, socioeconomic, and cultural resources (or capitals) whose flow and use are regulated by a combination of ecological and social systems [12], including technologies [13,14].

More specifically, the SEU-approach seeks synergies between social and ecological systems, where resilience implies absorbing disturbances without losing fundamental social–ecological functions [15]. The basic principles for enhancing resilience in the functions vital to urban systems are still tentative, especially with respect to couplings between infrastructure, biophysical processes, and the built environment [16]. However, there is a growing literature on ecological engineering, green and blue infrastructure, ecosystem services, and nature-based solutions exploring green contributions to urban resilience (e.g., Refs. [17–19]). The SEU-approach shares many similarities with other interrelated urban design approaches. Of particular interest are analytical frameworks and methodological approaches that can capture the complex interrelationships between urban social systems and ecological systems both within and beyond cities [20].

Although scholars have dealt with resilience in urban systems previously (e.g., Refs. [21,22]), and how resilience principles can be linked to urban design [23,24], few attempts have been made to link resilience to specific variables of urban form, thereby making it more instructive for undertaking interventions in urban governance, planning, and design. To bridge this gap, the SEU-approach sets the theoretical field of resilience science into communication with space syntax theory [25], which is a field particularly well-posed for studying urban dynamics at small-scale spaces that form urban space topologies [2]. While we are not able to elaborate on space syntax theory at any length in this paper, it represents an approach for increasing the understanding of the cognitive level of urban space by applying analytical measurements at this level. Space syntax can thereby support architectural and urban design with a richer set of descriptive socio-spatial analytical data [26].

While resilience theory and space syntax theory represent the theoretical bases in the SEU-approach, another theoretical departure concerns the development of knowledge that can inform intervention in social–ecological systems through urban planning and design (Figure 1). Such intervention is, however, never conducted directly on the natural and social processes that constitute urban systems but via particular media, such as 'urban form', 'institutions', and 'discourse' [2]. Urban form represents the morphology of the built environment and the biophysical landscape in which it is embedded, and it is the analytical medium for studying urban dynamics. Institutions represent the rules, regulations, and conventions of society that dictate what can and cannot be done in urban space; hence, institutions influence urban form both directly and indirectly in multiple ways. Institutions coordinate human interaction through both formal constraints (rules, laws, constitutions) and informal constraints (norms of behavior, conventions, attitudes, and self-imposed codes of conduct), and their enforcement characteristics [27]. Property-rights arrangements, including rights and obligations to land and its resources, represent key institutional mechanisms that frame human activities in cities, such as, for example, how to organize and manage ecosystem services or social services [28].

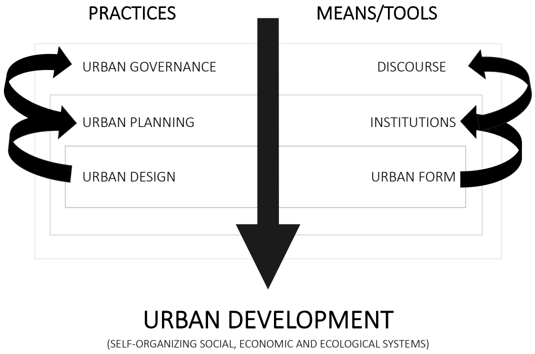

Figure 1. The media of interventions in urban governance, urban planning, and urban design.

While urban form conventionally belongs to the practice of urban design, institutions belong to urban governance and planning, which is why the negligence to treat them jointly in research and practice can be regarded as a key implementation deficit in urban governance. The implementation deficit is often manifested in urban systems through ongoing conflicts concerning land-use, issues of power, changes in property-rights regimes, social segregation, and a lack of understanding of what role ecosystems play for human well-being (e.g., Ref. [29]).

While urban form and institutions are key media for intervention in urban governance, planning, and design, both are affected by policy discourses in which arguments among competing knowledge claims ultimately determine what interventions can be made in urban systems. Policy discourses ultimately depend on existing power dynamics, as well as knowledge claims within and between competing discourses [30]. The scientific discourse on the detrimental effects of climate change and the loss of ecosystem services reveals that humanity is losing resilience at the planetary-scale [31]. Hence, without extensive reductions in greenhouse gas emissions, humanity will not be able to limit global warming by even 2 °C [32]. Hence, it is important that urban planners and policymakers help to prepare cities to buffer detrimental climate-change effects and also make sure that ecosystems are integrated into the design of urban systems not only for biodiversity conservation but to promote environmental learning in civic society through designs that promote human–nature connection [33].

Although urban interventions are part of a nested hierarchy of many forms of interventions that overlap, the SEU-approach limits analyses to the triad of interventions related to urban form, institutions, and discourse, keeping in mind that a handful of critical analytical variables is often enough to capture the key behavior of complex adaptive systems [34]. Hence, to obtain well-generalized representations of complex dynamics, it is advisable to avoid overfitting, which risks causing analytical frameworks to contain too many redundant and uninformative variables that drive a modelled system [35].

3. Cities as Social–Ecological Systems

In the following, we deal with four characteristics of the SEU-approach. We begin by presenting the analytical-scale of SEU, proceeding with how urban form shapes the accessibility to social services and how it can contribute to more resilient urban systems if adequately planned and configured. Next, we deal with the importance of planning and designing cities with consideration of ecological ramifications in order to boost climate-change proofing qualities and promote ecological learning in society. We end by elaborating on the key role that institutions play in the SEU-approach for the management of urban ecosystems and for shaping societal change in more sustainable directions.

3.1. The 'Eye-Level' Experience of the City

Implicit in the analytical SEU-framework is that the media interventions determine what type of social and ecological services can be generated in a city (Figure 2). Although we realize how tightly interwoven social and ecological systems are, there is a distinction made in the SEU-approach between social services and ecosystem services. While they are treated at par with each other, the purpose of this distinction is to gain precision in spatial analyses and to understand how we may best support both through urban design.

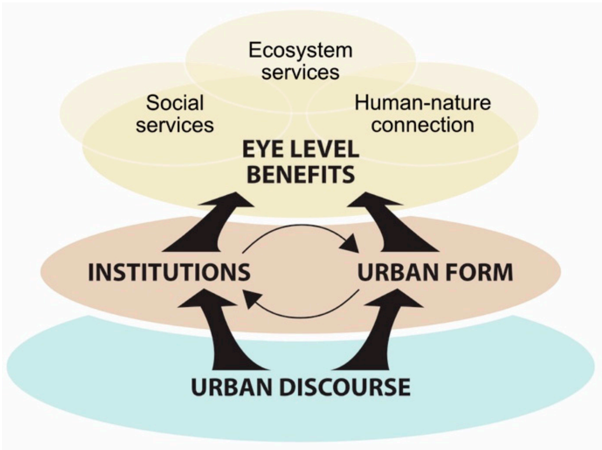

Figure 2. A conceptual outline of SEU. On the SEU view, institutions and urban form, both shaped by urban discourse, interplay to create the conditions for social–ecological outcomes. Spatial and social processes in cities are not separate, and urban form should thus be seen as a socio-spatial system. SEU highlights the eye-level benefits, such as social services, ecosystem services, and cognitive resilience building, but also stresses that these eye-level benefits are embedded in a larger systemic context.

Samuelsson et al. [36] refer to the analytical-scale of SEU as the 'eye-level scale', that is, the cognitive level where "people in the street" experience the city [2] and where urbanism in its original sense was meant to be enacted [37]. Thanks to the recent decades of technology-driven developments, it is now possible to develop new knowledge at the eye-level-scale of cities that has completely revolutionized the research fields dealing with the urban environment. In urban ecology, for instance, sweeping characterizations of cities by way of urban–rural gradients have largely been replaced by studies differentiating between environments at finer scales [38]. Developments of geographic information systems (e.g., Ref. [39]), more advanced forms of spatial modeling, e.g., cellular automata, agent-based modeling, and network analysis (e.g., Ref. [40]), and the application of deep learning models in combination with high-resolution satellite imagery (e.g., Ref. [41]) are all examples of advancements that have led to detailed and sophisticated descriptions of urban form being able to span entire urban systems.

Despite the recent advancement in higher resolution technologies, knowledge is still lacking regarding how urban form relates to urban processes at the perceptive and cognitive levels of urban space. This knowledge gap was independently pointed out decades ago by many researchers, such as urban geographers [42], spatial analysts [43], and urban morphologists [26], but more recently also in urban ecology studies [38], space syntax theory and urban morphology studies [44,45], and studies of urban subjective well-being [36,46]. The SEU-approach aims to close this knowledge gap by focusing on how the triad of media interventions referred to earlier can reveal new insights on how a city could become a more resilient social–ecological system.

3.2. Social Services

Even though it is important to recognize that social services on the local-scale depend on systemic characteristics at larger scales, it is at the local-scale that urban residents interact with and experience the city [36,47]. Hence, in this way, the SEU-approach represents a subset of Louis Wirth's idea of urbanism, signifying how individuals in a city interact with one another and experience a city's different facets [37]. For example, urban form, as captured by street network centrality (i.e., the relative position in the network) and built density, has a strong impact on pedestrian flows [48–50], which, in turn, influence socio-economic processes. Studies by Hillier et al. [50], Bernow and Ståhle [51], and Scoppa [52] show that streets that are highly integrated in a street system attract a great deal of movement and, therefore, also represent prominent locations for retail and exchange of people from different parts of the city. Moreover, Legeby [53] describes how urban form could be spatially configured to facilitate co-presence in public spaces between social groups and, in extension, mitigate social segregation. Co-presence is important for the nurturing of desirable societal processes in a city as the sharing of space makes people gain information and knowledge from fellow citizens and participate in processes that negotiate social structures, identities, and acceptable behaviors. Thus, and importantly, even though spatial and social factors are intertwined in cities, the spatial system provides a structure for social processes. This has great similarities with how ecological systems are understood and may thus provide a basis for a shared framework centered around spatial processes [1,44].

Related to spatial structure and social processes is the issue of urban inhabitants' well-being. An urban form designed with social services in mind can invite walking and biking [54], which promote health and well-being [55,56], as well as richer interactions with the environment that build social connectedness [57]. Urban form configurations that provide opportunities to use one's neighborhood as a rich spatial resource counteract spatial segregation [53], with benefits for subjective well-being through diversity of experiences in day-to-day life [36,58] and for local economies [59]. This is not to say that human interaction should be maximized everywhere. Crowding often causes stress [60], and, in some cities, the central areas contain many negative experiences related to stress [36]. To achieve sustainable urban form for social services and well-being is thus a balancing act of stimulating local activity without inducing crowding [61].

Some previous work addresses how urban form can contribute to more resilient urban systems. For example, Marcus and Colding [2] elaborate on how the morphological properties of resilience can be expressed by urban form, discussing, for example, how resilience principles can be used to analyze systemic relationships of street networks and how people move in the urban landscape. Such an analysis can disclose urban form structures that are socially maladaptive and unable to provide essential social services, such as access to good public transport or access to job markets. Marcus and Colding [2] found that, the more closed and homogenous the structure of urban form is at the local level, i.e., reducing interactions with other urban form structures in the urban socio-spatial system, the less flexible it is to survive economic and social disruptions. In contrast, urban systems that facilitate access to diversity possess a better chance to survive different types of socioeconomic crises than closed/homogenous systems.

To promote social resilience in urban systems, Marcus and Colding [2] found that institutional diversity, in the form of fine-grained land divisions, increases the ability for people to self-organize in cities and survive periods of crises. Hence, increased knowledge on how urban form interacts with institutions and other properties that confer resilience holds real potential to counteract unsustainable development trajectories.

Conceptual development for linking the larger-scale to the eye-level-scale also draws on the dual advancements in high-resolution descriptions of urban form and methods for tracking people's day-to-day movement, experiences, and well-being (see, e.g., Refs. [58,62,63]). In this vein, Samuelsson [61] refers to the ability of neighborhood-scale urban form to function as a resource supporting subjective well-being in diverse ways as 'topodiversity'. Topodiversity is a systemic property of urban form emerging from street networks, the distribution of buildings, and presence of urban nature. More specifically, topodiversity emerges when there is neighborhood-scale diversity in place-scale street network integration, building density, and the presence of nature while, at the same time, the extremes of sprawl, which does not support walking and biking, and high densities that induce crowding are avoided [61]. Topodiversity supports eye-level resilience by endowing inhabitants with the ability to escape a busy street and seek refuge in a park or go down to the local square to run errands while nurturing a sense of connection with the local community.

3.3. Ecosystem Services

For a long time, ecologists shunned the studying of urban environments based on the belief that the built environment offered little value for biodiversity [64]. For example, a mere 0.4 percent of all the published papers in the nine leading ecological journals dealt with cities just two decades ago [65]. Today, the field of urban ecology has grown tremendously, emphasizing the view that ecology is intimately linked to well-functioning social systems [63,66,67]. However, and despite the advancement of more sophisticated tools and methods in urban analytical research, it is still common to plan and design cities without consideration of ecological ramifications (see, e.g., Ref. [20]), such as how cities can promote climate-change mitigation as well as adapt to climate-change effects and counteract the massive loss of global biodiversity [68–70]. Suffice it to say, many city designs lack the ecological part of the urbanism that planners aim for in order to improve urban quality of life [71]. Moreover, the integrated analysis and assessment of cities linked to human health, resource use, and ecosystem integrity can provide a fuller understanding of the current environmental and health impacts of urbanism and provide options for future designs of cities [20]. For one thing, multi-species designs are poorly manifested in contemporary urban design and architecture, reflecting a clear distinction between socio-economic and ecological values instead of manifesting such linkages concretely in urban form through deliberate designs [44]. Moreover, we lack well-formulated and more targeted management and conservation policies that seek to better maintain and preserve ecological habitat structures in urban landscapes [72]. To support ecosystem services, the land-use has to be planned from a landscape perspective [73] in recognition of the fact that different animal and plant species utilize a number of different habitats in the overall urban landscape [74]. Hence, multi-species designs that include humans are particularly important to develop for cities so they can support and deliver both social and ecological services at par with each other [75].

Explicitly integrating ecosystems into urban design opens up a new window of opportunity for adding ecological values to cities since urban design has traditionally been mostly concerned with shaping the physical landscape to support socio-economic functions. As demonstrated in earlier studies, the integrated analysis and assessment of cities linked to human health, resource use, and ecosystem integrity can provide a fuller understanding of the current environmental and health impacts of urbanism and can also provide options for future designs of cities [20]. However, and as emphasized in the SEU-approach, it is at the eye-level-scale that people not only enjoy the benefits of social services but also of ecosystem services. It is a known fact that trees and other plants absorb pollutants and regulate light and wind conditions, that wetlands purify water, and that flowers promote pollination, which, in turn, contributes both to biodiversity and to food production [76,77]. Experiencing nature is also a powerful antidote to stress in urban life [78] and can critically support well-being during crisis times, such as the COVID-19 pandemic [79]. Integrating ecosystems into urban design is thus a key strategy for enhancing topodiversity [61] and building eye-level resilience [36].

To bring urban nature into cities is, furthermore, important for ecological learning to occur in civic society. The presence of nature plays a pivotal role in shaping peoples' attitudes toward the environment and environmental protection far beyond city borders [80–82]. A criterion for this, though, is that urban residents have the possibility to experience nature in their immediate environments [83]. There has lately been an increase in research on the topic of human–nature connection (HNC) (e.g., Refs. [14,84,85]) and its close relationship with pro-environmental attitudes [86]. HNC comprises an individual's affective and experiential connection to nature [87] (p. 504). A deep-seated HNC is most readily acquired during childhood [14,88–90], which seems to persist largely unchanged through adulthood [91] and may then promote pro-environmental behaviors, such as responsible energy consumption, recycling, or biological conservation (e.g., Refs. [85,91,92]). Hence, to experience nature at the eye-level is fundamental for sustainability transformations [93]. To quote Miller [94] (p. 431): "[if] people no longer value nature or see it as relevant to their lives, will they be willing to invest in its protection?” Urbanization and city densification (in combination with increased daily screen time) could potentially trigger baseline shifts in collective environmental attitudes [80]. Telling examples include Japanese children’s time spent in nature environments having decreased substantially over a ten-year period, as well as that 12% of English children had not visited a nature environment in the previous 12-month period [95]. Providing eye-level interaction with nature for urban inhabitants, not the least of which children, is paramount for reversing these trends. Hence, availing human–nature connections is a basic tenet of the SEU-approach (Figure 2).

3.4. Institutions and the Urban Policy Discourse

While institutions are non-material and invisible forms of governance tools, they frame urban form in a multitude of ways, such as through legally binding development plans, building codes, property-rights, land-use restrictions, as well as national and international conventions, treaties, and targets. Moreover, models for urban design, such as the smart-growth model and the biotope area factor (BAF), represent powerful normative and informal types of institutional design frameworks that influence how cities are built and configured. In this way, institutions are mediators of public norms, policies, and discourse, and they need, therefore, to be flexible, inclusive, and be able to respond and adjust to new social and environmental conditions and circumstances [2]. Central here is for the urban policy discourses to inform the design of both institutions and urban form in such a way that they support each other rather than, as is often the case today, contradict each other.

It is a common mistake to think that urban designers represent the shapers of cities; however, and as Elrahman and Asaad [96] argue, the power balance of a city’s institutional framework does not support this assumption. On the contrary, urban planners are the ones that have the power to make decisions about the city due to the fact that “their profession operates on the higher levels of policy formulation” [96] (p. 1163). In turn, the political majority, as well as fiscal budgets, influence the decisions that planners can make, which can lead to institutional inertia and an inability to adapt to changing circumstances, such as to more actively address climate change [33]. As has long been recognized in resilience science, institutions represent key mechanisms for responding to climate change and for shaping societal change in desirable directions [2,97].

The fact that ecosystems, as with any type of infrastructure, need continuous management implies also that there must exist locally adapted institutions that allow for and determine what types of ecological management inputs are warranted at a particular site or location in a city [10,98]. It should be recognized that many types of ecological design elements (e.g., freshwater ponds, eco-roofs, urban gardening sites) depend on their continuous management over time in order to function appropriately. Hence, institutional components that include property-rights rules, social networks, and local norms are regarded as crucial parts of the design process in SEU. The braiding of institutional and spatial components serves to simultaneously support ecological and social services. Erixon Aalto et al. [3] used this idea in the design of a new university campus in Stockholm, Sweden that involved a transdisciplinary design process, comprising both professionals and researchers from the fields of ecology, urban design, and architecture, as well as local interest groups, planners, and developers. The group organized and performed a series of workshops and meetings with civil society groups that had a stake in the new campus area and worked out a design template consisting of key social and ecological services that the new campus should support. The spatial design components included so-called ’green arteries’ that promote the migration of biological species, including humans, and actively managed green spaces that serve as active grounds, of which several are managed by staff and students. Moreover, the campus buildings themselves serve as green facades and green roofs to fulfill ecological functions. Together with institutional components, the design template facilitated a closer braiding of social services and ecosystem services (Figure 3).

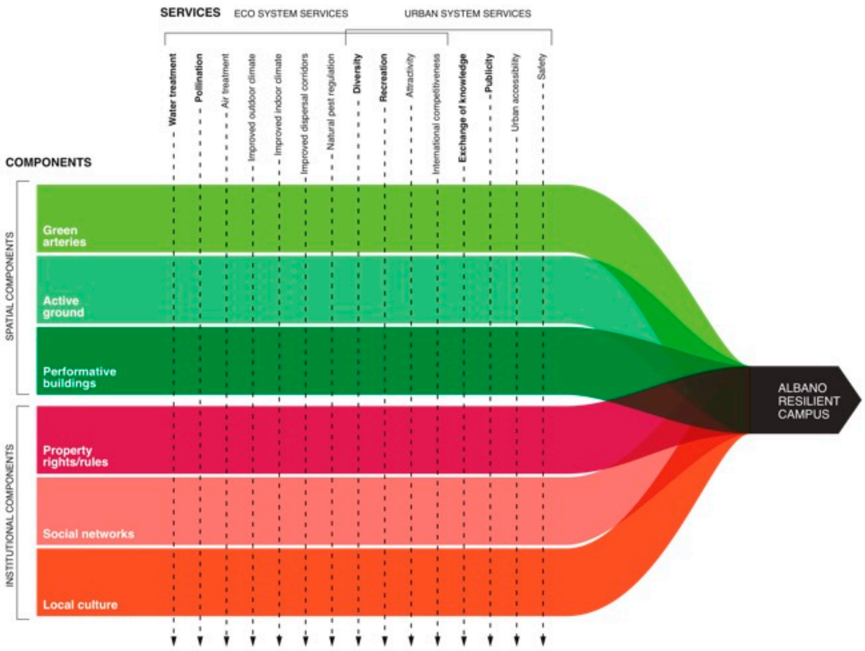

Figure 3. The SEU-approach is striving toward a closer braiding of social and ecological services in the design of cities. This entails that institutional components, such as property-rights and culture-specific social norms, are treated at par with ecological design components to simultaneously promote social and ecological services at the micro-scale of cities. Source: Barthel et al. [1].

Due to the global trend of the privatization of urban public space, policymakers and planners need to more meticulously address property-rights to halt the incremental demise of public greenspaces with the subsequent loss of ecosystem services. Maintaining a well-balanced diversity and mixture of property-rights regimes could be a wise planning policy in order to increase the chances for civic participation in ecosystem management [99]. Hence, the SEU-approach strives for broadened opportunity for public participation, or what Healy [100] refers to as collaborative planning and design, with the potential to mobilize collective action of civil society groups to achieve strategic urban governance targets [101–103]. The incorporation of civic interest groups in ecosystem management has been shown to provide several advantages, including economic benefits [104] and wider ecological learning among urban residents [105,106]. A good example of property-rights arrangements that support public participation, co-creation, and co-management are urban commons [99]. These may be synonymous with public property, but the public becomes a 'commons' only when the citizens have real influence over public resources. Hess [107] describes a whole range of new commons that range from cultural commons to knowledge commons to neighborhood commons to health commons. Colding et al. [99] have described how 'urban green commons', 'coworking spaces', and 'community climate commons' can boost civic environmental learning.

4. Frontiers in Social–Ecological Urbanism

We are but at the beginning of disclosing more detailed information at the eye-level of cities. Hence, the SEU-approach and similar analytical frameworks have an important role to play in contributing to the advancement of urban theory. In the following, we list four future research areas that could be pursued by the SEU-approach. These include studies of (1) urban density and critical biodiversity thresholds, (2) human and non-human movement in urban space, (3) the retrofitting of urban design, and (4) reversing the trend of urban ecological illiteracy through affordance designs that connect people with nature and with each other.

4.1. Urban Density and Critical Thresholds

The SEU-approach is helpful for illuminating and gaining knowledge around how a multitude of sometimes conflicting social and environmental sustainability goals relate to urban density. This relates to an ongoing debate in the urban discourse between compact built form and a more dispersed urban settlement pattern [108]. Much of the urban design literature rather uncritically favors city compaction with more connected street networks and higher residential densities to support social contact and to promote physical exercise through walking and cycling [109]. The compact city approach, thus, represents a powerful normative informal planning institution by being portrayed as positive for innovations and economic growth, as well as reducing greenhouse gas emissions [110].

Recent scientific reports, however, have highlighted knowledge gaps surrounding the compact city, related to both environmental claims and human well-being [110–112]. While reducing urban greenhouse gas emissions is paramount, the value of city compaction cannot be judged solely based on its benefits at larger levels (i.e., at the regional- or global-scale) but should also be judged based on its effect at local scales where everyday life plays out. For example, there is ample evidence of the negative well-being impacts of crowding, noise, and air pollution in dense city parts [113–116]. Moreover, by refuting opportunities for people to experience nature in everyday life in densely built cities, people become increasingly environmentally illiterate, leading to environmental generational amnesia [81]. Hence, rather than assuming that people simply can adapt to increasing urban density without also considering the negative consequences for human well-being and connection to the biosphere, we propose that urban designers and ecologists cooperate around creating local neighborhoods that are 'dense enough' without compromising the vital green elements that could make such areas environmentally benign.

Hampering the pursuit of the above stated objective, current studies of city compaction suffer from a lack of coherent measurements of both density and its associated environmental benefits [111]. For example, three substantially different conceptualizations of urban density exist in the literature: population density, building density, and growth boundaries, each measured in different ways and at different spatial scales. This means that comparison between studies and a cumulative development of proof are difficult to attain. Furthermore, urban form can take on various shapes using the same building density [117], and a combination of various density measures is needed to distinguish different urban form types. The differences in the composite of density measures make a great deal of difference for what social and ecological services urban form can provide (Figure 4).

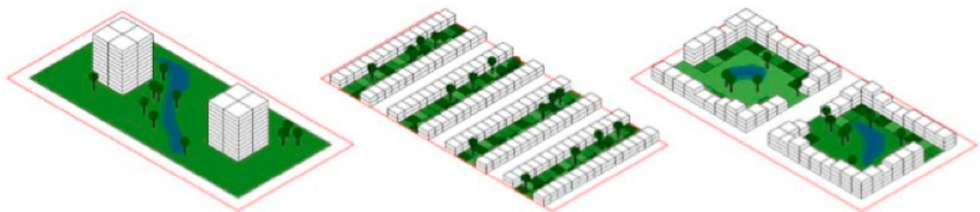

Figure 4. Three urban types (point, street, and perimeter block) with the same density (floor space index = 0.75) display differences in other density measures, as revealed in spacematrix analysis (e.g., ground space index, building height, open space ratio), as well as differences in green space ratio and parcel density (i.e., institutional configuration).

Suffice it to say, further SEU studies need to build more knowledge on the relationship among, on the one hand, density and urban form and, on the other hand, social and ecological services. In this context, it will be particularly useful to identify densification thresholds for biodiversity and ecosystem services at the micro- and meso-scales of cities. Such thresholds that determine how much built-up density certain biological organisms can tolerate to adapt to cities have been determined at wider city-scales [110,118–121] but should also be determined at finer scales [38]. Another approach would be to identify more general urban patterns that combine density and greenery in such a way that provides benefits on the local-scale (human wellbeing and health-related benefits) while not jeopardizing regional environmental challenges.

4.2. Human and Non-Human Movement in Urban Space

In addition to density, the spatial configuration of the built environment plays a major role for shaping both social and ecological processes. A key research gap that the SEU-approach could contribute to bridging is to increase understanding regarding how urban form can be configured to support social and ecological services by structuring how organisms move and orient themselves in the urban landscape. For a long time, architects and urban designers have been aware that designs can support or impede certain human uses and activities. For example, a long series of space syntax studies have found strong correlations between the configuration of the built environment and various social services, mediated by human pedestrian movement (e.g., Refs. [50,53]). How urban form is shaped and distributed in space determines, for example, the spatial segregation (isolation) of neighborhoods, accessibility to urban services and resources, locations for retail, as well as job opportunities [2,59]. On the block-scale, smaller outdoor spaces, such as enclosed gardens, parks, and plazas, often create a feeling of security [109]. Moreover, the morphological dimensions of building and block structures facilitate a wide array of functions depending on their spatial configuration, even using the same density (Figure 5).

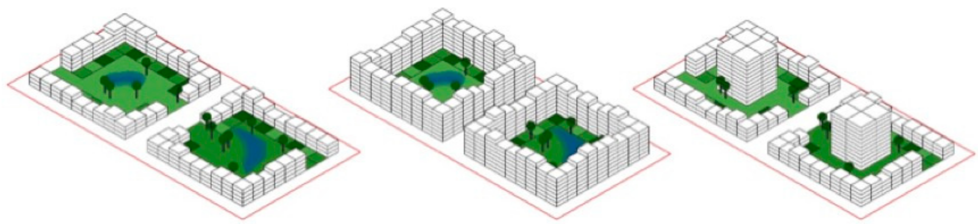

Figure 5. Different court building types have different influence on biodiversity and ecosystem services (BES). To what extent and in what ways represent a future research frontier in SEU.

While knowledge has improved regarding how people navigate and how the configuration of urban form influences movement in cities, we have considerably less knowledge regarding how non-human species move at the eye-level-scale of cities (see, e.g., Ref. [122]) and how it influences biodiversity and ecosystem services (BES). Closing this knowledge gap involves research on how both the horizontal and vertical shapes of buildings affect certain key organism groups, such as pollinator species and seed dispersers, that are key for sustaining biodiversity and for making urban food production feasible. An attempt at finding out how urban form influences biodiversity was conducted by Andersson and Colding [123] by studying breeding birds in three types of housing development (i.e., detached houses with small groves, detached houses next to woodlands, and apartment buildings with extensive tree commons) with approximately the same amount of tree cover. While no significant differences in terms of bird communities were found between the housing developments during any of the seasonal survey periods, a difference in the functional composition of the bird communities between developments was found as the season progressed. Since the three types of housing typologies investigated only cover a narrow spectrum of the types of housing that exists in urban settings, the results suggest that urban form may indeed influence BES. Similar results were found in a study on pollinators in 16 sites in Stockholm, demonstrating that the spatial distribution of green areas and buildings is important to consider when managing pollinator diversity [124]. Further SEU studies of housing alignments could potentially reveal information that planners and designers could use to more optimally configure building- and landscape designs that promote both human movement and species migration.

4.3. Retrofitting of Urban Design

An important part of building the cities of tomorrow is to find ways to retrofit present neighborhoods at the local level so that they become more climate-resilient since it is at the local level of cities that climate-change effects will be experienced by most residents. As incremental changes can add up to significant modifications in built form over time, there is a real potential to make densely built areas greener [125]. Demuzere et al. [126] have explored the existing evidence for the contribution of green infrastructure to climate-change mitigation and adaptation services, indicating that a whole range of benefits could be noticed at the micro- and meso-scales of cities by adding green infrastructure. Such retrofitting may involve quite small adaptations, such as the planting of trees to increase shading and reduce the temperature associated with urban heat island effects. Areas covered by trees can lower the temperature by 2 to 4 °C in comparison to areas without tree cover [127].

Urban infrastructure will require transformative changes to also adapt to changing disturbance patterns. Hybrid infrastructure, i.e., built environments coupled with landscape-scale biophysical structures and processes, offer different layers of resilience critical for dealing with increased variation in the frequency, magnitude, and different phases of climate-related disturbances [16].

The application of green facades, i.e., 'greenskins', can provide multiple environmental benefits on both new and existing buildings, e.g., in terms of energy savings, nutrients and water needed, and efficient preservation of edifices [128]. However, the ecological benefits from greenskins vary depending on geographic settings and biophysical conditions, such as the hardiness zone. When the local knowledge and local conditions are satisfactory, vertical greening systems can improve biodiversity in dense urban areas as they create habitats for microorganisms and for smaller animals (bees, bats, birds, etc.). At the same time, greenskins can provide economic and social benefits, e.g., the greater permanency and durability of buildings and increased well-being of residents [128].

Although the empirical evidence is conflicting [126], green roofs have been shown to improve air quality and reduce pollution through a reduction in fine dust levels ([129] from [128]). The air quality improvement due to vegetation is related to the absorption of fine dust particles and the uptake of gaseous pollutants, such as CO_2, NO_2, and SO_2.

Urban greening can also reduce noise, although the type of substrate plays a key role in settings with low vegetation, i.e., grass or low plants [130]. An improved acoustic performance of the substrate for use on façades or roofs can be achieved for material properties with a low flow resistivity and large porosity [130]. For belts of trees alongside roads, the tree stems may play an equally strong role for noise reduction as the soft forest floor type of ground [131].

After decades of being expelled from residential areas, water is now becoming an increasingly significant feature in urban design [132]. Installing ponds and open, domestic rainwater systems are important layout elements in retrofitting urban design both for climate-change purposes and for the creation of oases of tranquility. A good example of this constitutes Augustenborg in Malmö, Sweden, which experienced numerous social and technical problems in the 1990s due to basement flooding from increased precipitation. The construction of open storm water channels and man-made ponds (including green roofs) helped to solve these problems and contributed to a 50% biodiversity increase at the neighborhood level.

Retrofitting urban environments for adapting to climate change and in a manner that simultaneously benefits both humans and non-human organisms is a key research frontier in SEU. This requires, however, the existence and support of locally adapted institutions and property-rights arrangements that can back up such a transition. Institutional arrangements can have an impact not just on retrofitting investments but on providing management rights to a greater set of urban residents [5,33], something that the Intergovernmental Panel on Climate Change (IPCC) has deemed high on the agenda for climate-change adaptation and mitigation [32]. It should, however, be recognized that the retrofitting of urban form at the micro-scale of cities may not always be desirable. For example, the implementation of green infrastructure in vulnerable communities is fraught with many challenges due to a lack of economic resources and political will [133]. Some communities may have developed informal institutions for infrastructure provisions that are already sustainable. Without sufficient consideration of the local knowledge, social context, and ecological and biophysical conditions, the retrofitting of urban form in such communities may be problematic [133]. Hence, retrofitting should draw on co-creation and co-management with the people residing in a particular area to promote inclusion and fairness in urban design.

4.4. Reversing the Trend of Ecological Illiteracy through Urban-Design-Affordances

In the SEU-approach, urban form needs not only to be designed to improve resilience to withstand and cope with climate change but also to promote cognitive resilience building, defined here as "the mental processes of human perception, memory and reasoning that people acquire from interacting frequently with local ecosystems, shaping peoples' experiences, world views, and values towards local ecosystems and ultimately towards the biosphere" [134] (p. 162). Underlying this proposition is the fact that knowledge of the psychological benefits of nature experience can support efforts to integrate nature into architecture, infrastructure, and public spaces in urban areas [81]. Due to the fact that cognitive resilience building primarily occurs at the eye-level of everyday sensory experiences, a highly useful research frontier in the years to come will be to examine the possibility for designing urban form so that the built environment can promote cognitive resilience building more or less automatically.

Of particular significance in this regard is psychologist James Gibson's argument on how the structure and shape of the physical environment create what can be referred to as affordances [135] (pp. 127–143), i.e., how a given environment presents potentials for certain human behavior [13]. Organizing cities so that the morning walk to school or work promotes cognitive resilience building is a challenging future SEU research task in order to create more sustainable cities [47,82]. Mapping topodiversity in neighborhoods across cities [61] could serve this purpose by identifying key places for intervention in the spatial system where ecological retrofitting and redesign provide the greatest leverage for mitigating further ecological illiteracy among urban residents.

5. Conclusions

The aim of this paper has been to present the SEU-approach to a wider audience of urban scholars and practitioners, and to elaborate on the theoretical framework of the approach, including the three types of media for urban designers to intervene in urban systems. As discussed herein, the SEU-approach has its roots in the resilience thinking of social–ecological systems and space syntax research, and it is especially useful as an analytical framework for studying urban processes and their relation to urban form at the eye-level-scale of cities, where social and ecological services are directly experienced by urban dwellers. Institutions and property-rights arrangements are key enablers of urban intervention designs; thus, to build resilience of urban social–ecological systems require a policy discourse that is sensitive to climate change, the ongoing global loss of biological diversity, as well as the social potentials that urban form can provide if and when rightly planned and designed. As emphasized herein, urban discourse shapes the interplay between institutions and urban form that ultimately creates conditions for more interlinked forms of social–ecological outcomes. As suggested herein, the future challenges of SEU research involve studies of densification thresholds for biodiversity at the micro- and meso-scales of cities, new ways of retrofitting urban form for promoting climate-resilience, increasing our understanding regarding species movement in the built environment, and designing city neighborhoods with an ability to afford pro-environmental human behavior and promote cognitive resilience building.

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