SOFTENING THE HABITATS
SUSTAINABLE INNOVATION IN MINIMAL MASS STRUCTURES AND LIGHTWEIGHT ARCHITECTURES

Proceedings of the TensiNet Symposium 2019
Softening the habitats | 3-5 June 2019, Politecnico di Milano, Milan, Italy
Alessandra Zanelli, Carol Monticelli, Marijke Mollaert, Bernd Stimpfle (Eds.)

Biomimicry for regenerative built environments: mapping design strategies for producing ecosystem services

Maibritt PEDERSEN ZARI*[a],Katharina HECHT[b]

*[a] School of Architecture, Victoria University of Wellington
PO Box 600, CBD, Wellington 6011, New Zealand
maibritt.pedersen@vuw.ac.nz

[b] Department of Biology, Utrecht University
Postbus 80.056, 3508 TB Utrecht, Netherlands
k.hecht@students.uu.nl

Abstract

Redesigning and retrofitting cities so they become complex systems that create ecological and societal health through the provision of ecosystem services is of critical importance. This is due to two key reasons. Firstly, it is well known that cities have a large negative ecological impact, and secondly, the human population is rapidly growing and is now mostly urbanised. As professionals of the built environment are required to solve more urgent and complex problems related to ongoing climate change, and biodiversity loss, it may be useful to examine examples of how the same problems have been solved by other living organisms or ecosystems. This can be termed biomimicry. Biomimicry that emulates whole ecosystems, particularly the function of ecosystems, has been identified as having more potential to positively shift the ecological performance of buildings and urban settings. In this regard the ecosystem services concept is useful. Although a small number of methodologies and frameworks for considering how to design urban environments so that they emulate and provide ecosystem services have been proposed, their use is not wide spread. A key barrier has been identified as a lack of translation of the concept of ecosystem services design into practical examples of design strategies, concepts, and technologies, and case study precedents illustrating the concepts. In response, this

DOI: 10.30448/ts2019.3245.54

paper presents research seeking to create a qualitative complex map in an online interactive format that relates the ecosystem services concept to design strategies and case studies in a comprehendible format for use by designers and built environment professionals. The paper concludes that buildings, and indeed whole cities should be expected to become active contributors to eco-sociological systems, rather than remaining unresponsive agents of ecosystem degeneration, and that the strategies and technologies to enable this already exist.

Keywords: Ecosystem services; biomimicry; urban design; urban ecology; data visualisation; sustainability; regenerative design.

1. Introduction

The way buildings and cities are designed will need to change rapidly and effectively to address converging drivers of change such as climate change and biodiversity loss. This must occur within the complex context of human population growth, increased per capita consumption, and global urbanisation (Grêt-Regamey et al. 2013). Although cities only occupy approximately 3 to 4% of global land area (van Vliet, Eitelberg, and Verburg 2017, Ruth and Coelho 2007), they are the sites of tremendous concentrations of energy use, water use, materials, greenhouse gas emissions, and other pollutants. Because of the built environment's increasing appropriation of the goods and services of ecosystems, vital ecological services for human society (and other species) such as climate regulation, soil formation, nutrient cycling, pollination, and waste assimilation are negatively affected (Vitousek et al. 1997). Modern cities are primarily sites for cultural expression and the facilitation of trade, rather than for the production of physical resources or the generation of services that produce tangible physical ecosystem or human health (Doughty and Hammond 2004). Despite this, urban environments must be considered in terms of their impact on climate and ecosystems and their potential role in facilitating regeneration of them.

Changes to the climate, and therefore related impacts on the built environment are expected to increase in intensity in the future. This suggests that re-evaluation of the built environment, and rapid expansion of policies and actions to mitigate greenhouse gas (GHG) emissions are urgently required (Masson-Delmotte et al. 2018). The built environment is responsible for approximately a third of global anthropogenic GHG emissions, leading to climate change (de la Rue du Can and Price 2008). The built environment will also have to adapt to climate change impacts, as the main site of human economic, social and cultural life. More than half of all humans now live in urban built environments. It is important therefore that built environment professionals are not only able to work towards mitigating the causes of climate change, but are also able to devise strategies to adapt to the impacts concurrently. In this regard nature inspired; lightweight; membrane; adaptive / intelligent façades; and kinetic technologies and materials with a focus on sustainability have proven to be important (Barozzi et al. 2016, De Vita et al.

2018, Loonen et al. 2013, Romano et al. 2018). Concurrently, biodiversity loss, and with it ecosystem degradation must be addressed. The degradation of ecosystems, along with the fact that there is a positively reinforcing feedback loop between biodiversity loss and climate change (Chapin et al. 2000, Pedersen Zari 2014), is why biodiversity loss is an urgent issue for humans to address (Rastandeh, Brown, and Pedersen Zari 2017), and why this must be considered in built environment design (Pedersen Zari 2018b).

Cities, and the buildings within them must become regenerative (Cole 2012). Regenerative design in this sense means design with an aim to produce quantifiable ecological and social health outcomes rather than design which aims to simply minimise energy or water use, or the emission of pollutants (Reed 2007). The question remains however, how can design professionals practically engage with such an agenda or set of goals? In this regard, there is an obvious and accessible example to investigate and then emulate; that is, the living biological world, and its complex systems. Ecosystems remain the best known example of sustainable organisation of life on this planet (Vincent et al. 2006). It is logical therefore to try to understand, and if possible, to mimic how organisms and ecosystems work and what they do in the creation of a regenerative human habitat.

1.2. Biomimicry for regenerative built environments

By looking to the living world, there may be organisms or systems that can be mimicked to create and maintain a resilient and adaptable built environment, and improve its capacity for regeneration of the health of ecosystems (Pedersen Zari, 2018a). This applies to urban scale interventions, through to the scale of building components and materials, and can be termed 'biomimicry' (Benyus 1997). Biomimicry is the emulation of strategies seen in the living world as a basis for design and innovation, and has potential to contribute to the creation of more sustainable architecture and urban environments (Pawlyn 2011). It is the mimicry of an organism, organism behaviour, or an entire ecosystem, in terms of its form, material, construction method, process strategies, or function (Pedersen Zari, 2007). Mimicking living organisms or ecosystems involves a process of translation into suitable solutions for the human context. Several noteworthy contemporary examples of biomimetic architecture or technologies that can assist the built environment in adapting to climate change or becoming an agent of ecological health are examined by (Pedersen Zari, 2018a) and (Pawlyn 2011). Additional historic examples of biomimicry are detailed by Vincent et al. (2006) and Vogel (1998). Biomimetic case studies examined by Pedersen Zari (2015a) suggest that ecosystem biomimicry, that is the emulation of how whole ecosystems function and the ways in which they work, may be the most effective kind of biomimicry to respond to climate change and biodiversity loss. This is because ecosystem biomimicry falls into a paradigm of whole systems thinking and change, rather than design of single components. Ecosystem biomimicry remains the least explored aspect of biomimicry in built form.

1.3 Systemic improvement of the built environment: ecosystem biomimicry

Ecosystems are typically resilient and many are able to move though infrequent abrupt changes while still supporting the survival of organisms (Gunderson and Holling 2002). The ability of ecosystems to adapt to the rapid changes that may come about due to climate change is difficult to predict (Walther et al. 2002). Despite this, mimicking ecosystems can offer insights into how the built environment could function more like a complex living system rather than as a set of unrelated, object-like buildings, and thus become better able to adjust to change.

1.3.1 Mimicking how Ecosystems Work: Process Strategies

Ecosystem processes inspired strategies for addressing climate change and ecological degradation challenge conventional architectural design and procurement thinking, particularly related to the typical boundaries of a building site and design time scales. By mimicking process strategies in ecosystems, designers may have successful models to follow in devising how systems in buildings or urban environments should be put together and how they should work. Typically, such systems mimic the process in ecosystems where waste becomes a resource for another component of the system, or where energy is shared ensuring the system eliminates or reduces duplication of effort. Well known examples of industrial ecology such as Denmark's Kalundborg industrial region illustrate how the process of cycling materials in ecosystems can be mimicked, even between diverse companies. In Kalundborg, this sharing of waste as resource results in a reduction of approximately 30 million m^3 of groundwater used, and a reduction in emission of 154 000 tonnes of CO_2 and 389 tonnes of mono-nitrogen oxides (NO_x). Five companies and one local municipality make up the industrial park where twenty different bi-product exchanges occur (Valentine 2016, Jacobsen 2006). The elimination of toxins and pollutants that lead to the degradation of ecosystems is also addressed with such an approach. Examining ecosystem processes other than just the cycling of wastes or sharing of energy, suggests additional strategies for the built environment to mimic.

A comparative analysis of knowledge in the disciplines of ecology, biology, industrial ecology, ecological design, and biomimicry was conducted with an aim of capturing cross disciplinary understandings of how ecosystems work. A group of ecosystem process strategies were formulated that can form the basis of built environment focused biomimetic design (figure 1). For methodology and research sources used to produce figure 1 see: Pedersen Zari (2015b).

1.3.2 Mimicking what ecosystems do: ecosystem services

Mimicking the functions of ecosystems (what they do) has also been investigated in a design context (Birkeland 2009, Pedersen Zari 2017a, Pedersen Zari 2017b). This is different from mimicking the processes of ecosystems (how they work). Mimicking ecosystem processes eventuates in buildings or neighbourhoods that may be biomimetic but not necessarily better than conventional designs in terms of ecological performance. Essentially the emulation of ecosystem remains at a metaphorical level. Analysing the urban built environment from the perspective of how ecosystems function, and then designing changes to cites, buildings, and building components so that they begin to quantifiably emulate the functions of ecosystems however, could work towards the creation of cities where positive integration with, and restoration of local ecosystem services could be realised (Pedersen Zari, 2018a).

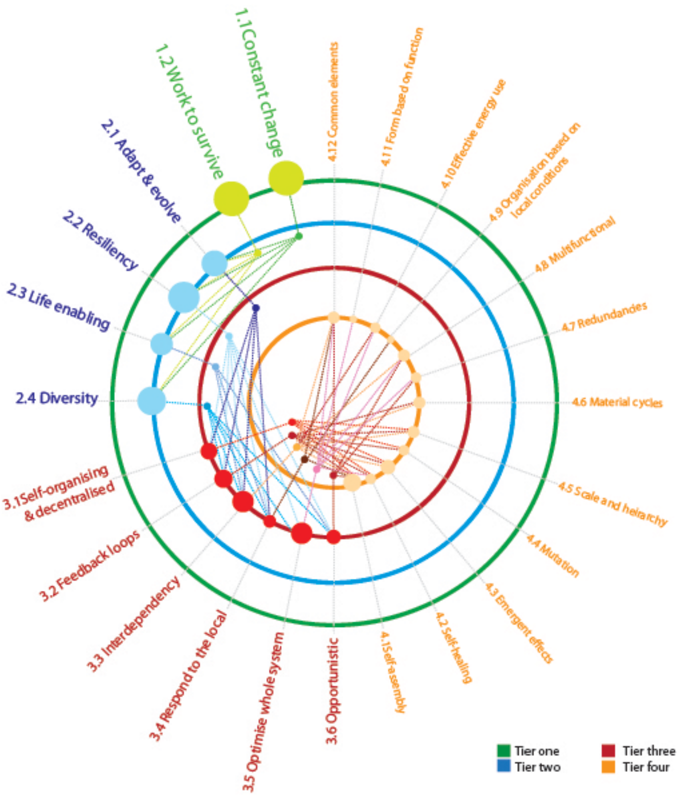

Figure 1: Ecosystem processes. Source: (Pedersen Zari 2015b).

The ecosystem services framework is one way to understand the complexity of ecosystem functions and human interactions with them. Ecosystem services are the benefits that humans (and all living organisms) derive, either directly or indirectly from the functions of ecosystems (Potschin and Haines-Young 2016). Ecosystem services are defined and listed in different ways (Millennium Ecosystem Assessment, 2005, Potschin et al., 2016), but typically are divided into: provisioning services such as food and medicines; regulation services such as pollination and climate regulation; supporting services such as soil formation and fixation of solar energy; and cultural services such as artistic inspiration and recreation. A focus on ecosystem services has been widely adopted among ecology and policy professionals (Martín-López et al. 2014), and was formalised by the United Nations' Millennium Ecosystem Assessment of Ecosystems and Human Wellbeing (Millennium Ecosystem Assessment, 2005).

One way to reduce the ongoing degradation of ecosystems is to create built environments that mimic or provide ecosystem services and therefore reduce pressure on ecosystems, as the urban environment grows and as the climate continues to change. In urban environments themselves, ecosystem services are less well understood (Gómez-Baggethun and Barton 2013), but are thought to occur at low rates except for cultural ecosystem services (Costanza et al. 2014). Despite this, several important urban ecosystem services have been identified and include: air purification; water flow regulation; micro climate regulation; and carbon sequestration (Gómez-Baggethun and Barton, 2013). Typically, these urban ecosystem services come from urban 'green spaces' such as forests and parks, or 'blue spaces' such as lakes and wetlands and represent important opportunities for novel design interventions, particularly related to increasing resilience to climate change (Elmqvist, Gomez-Baggethun, and Langemeyer 2016) and increasing human wellbeing (Foley and Kistemann 2015). Opportunities also exist for green or grey/green hybrid infrastructure and for buildings themselves to produce ecosystem services however (Escobedo et al. 2019, Birkeland 2009). Mimicking what ecosystems do (provide ecosystem services) can become the overall ecological performance goal generator for a development, while the specific methods or technologies to achieve the goals can be drawn from a wide range of existing design strategies, concepts, and technologies.

By emulating ecosystem services, a building or development could be designed for example to be part of a system that: produces food; produces renewable energy; produces raw materials for the future built environment; collects and purifies water; purifies air and soil; regulates climate through mitigating GHG emissions and the heat island effect; contributes to soil formation and fertility through careful cycling of bio-degradable wastes and recycling of non-biodegradable wastes; and deliberately provides habitat for species suitable for co-habitation with humans in urban built environments (Pedersen Zari, 2018a). New ecologically regenerative developments in turn could act as filters (mechanisms that purify air and water), producers (of food and materials) and generators (of energy) for the rest of the built environment which is still degrading ecosystems and is likely to persist for at least another 50 to 90 years (O'Connell and Hargreaves 2004). If these regenerative nodes became part of the built environment and start to perform even small aspects of ecosystem functions, it is possible that some causes of climate change and biodiversity loss attributed to the built environment would be mitigated, and at the same time the built environment could become more adaptable to climate change, while concurrently creating beneficial biodiversity outcomes.

Ecosystem services analysis (ESA), developed by (Pedersen Zari, 2018a), is a means by which the concept of ecosystem services is applied to built environment contexts, particularly in a context of regenerative design. The purpose of ESA is to measure past, current and future environmental performance of the built environment in terms of ecosystem services provision so that future spatial and temporal ecology derived performance goals can be devised.

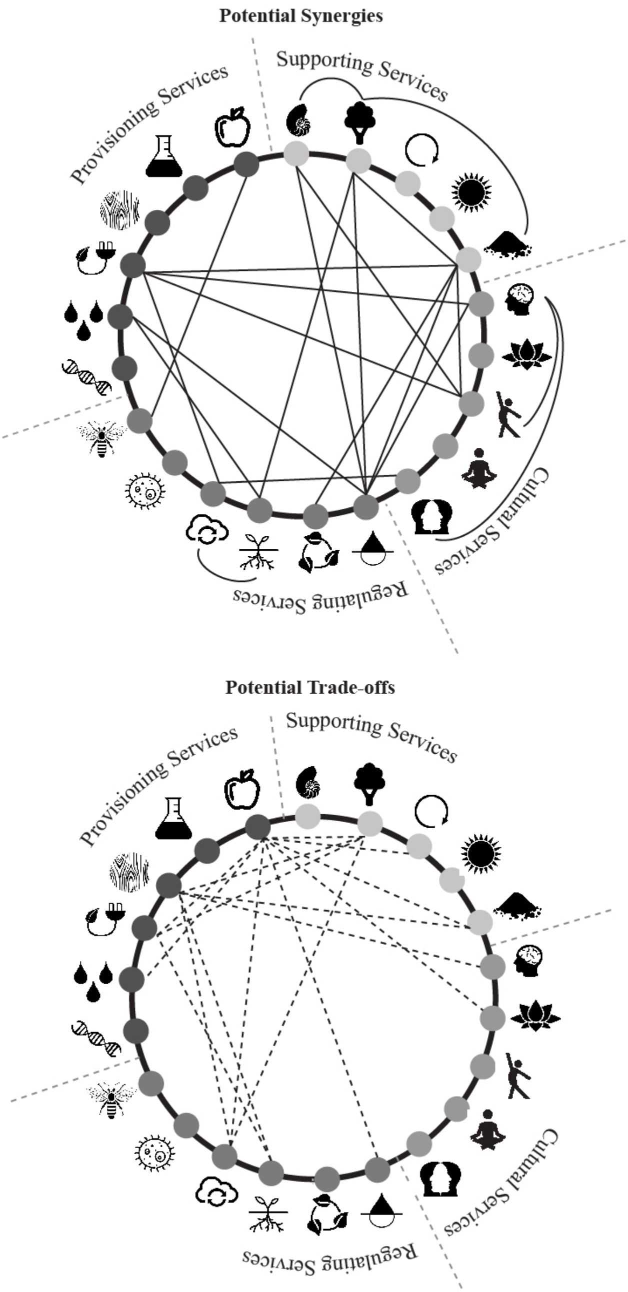

Figure 2: Potential synergies and trade-off relationships between ecosystem services. Source: (Pedersen Zari, 2019). See icon key next page.

If designers and policy makers are to effectively use the ecosystem services model in urban settings they must understand how these ecosystem services are related however (Bennett, Peterson, and Gordon 2009). This is so potential synergies between ecosystem services can be leveraged, but also so that potential trade-off relationships between certain ecosystem services can be avoided or addressed. Recent research by the author (Pedersen Zari 2019) has illustrated relationships between ecosystem services for a design audience based on quantifiable ecological research results devised by Lee and Lautenbach (2016). Further qualifying ecological and socio-economical associations between ecosystem services were provided by (Mouchet et al. 2014), (Howe et al. 2014), Bennett et al. (2009), and (Raudsepp-Hearne, Peterson, and Bennett 2010). See: figure 2.

2.0 The 'strategies for designing urban ecosystem services' map

In order to take the concept of emulating the functioning of ecosystem services (a form of ecosystem biomimicry) further, and to make it easier to implement, it is necessary to demonstrate how designers can practically implement ecosystem services focused design at both the architectural and the urban scale. The aims of this research then are twofold: 1/ Create a database of existing and developing strategies

Key to Figure 2: Ecosystem Services			
Supporting Services	**Habitat provision**	Cultural services	**Aesthetic & artistic inspiration** - Aesthetic value - Artistic inspiration
	Nutrient cycling - Retention of nutrients - Regulation of biogeochemical cycles		**Recreation and psychological wellbeing** - Sport - Outdoor activities - Tourism - Socialisation - Relaxation & psychological benefit
	Species Maintenance		**Sense of place and cultural diversity** - Celebration of cultural diversity/history - Sense of place
	Fixation of solar energy		**Spiritual and religious inspiration**
	Soil building - Soil formation - Renewal of soil fertility - Soil quality control - Soil retention		**Education and knowledge** - Educational - Inspiration & innovation - Cognitive development - Knowledge building
Regulation Services	**Disturbance prevention** - Noise - Wave - Erosion - Earthquake - Drought - Flood/Storm events - Wind	Provisioning Services	**Provision of fuel and energy** - Water energy - Wind energy - Active / passive solar energy - Human body heat - Hydrogen energy - Biomass energy - Geothermal energy
	Climate regulation - UV protection - Moderation of temperature - Climate adaptation strategies - GHG mitigation		**Provision of fresh water** - Drinking water - Sanitation - Irrigation - Industrial processes - Recreational
	Purification - Water purification - Soil purification - Air purification		**Provision of food** - Small to large scale urban agriculture
	Decomposition - Biodegradation - Material reuse/recycling - Consumption reduction		**Biochemicals** - Medicine - Natural chemicals
	Biological control - Control of invasive species - Disease/pest regulation		**Raw materials**
	Pollination		**Genetic resources**

and technologies that enable the creation of ecosystem services through the medium of buildings, built infrastructure and cities. 2/ map and illustrate this data so it is in an online interactive format comprehendible for designers or built environment researchers. The intention of the 'strategies for designing urban ecosystem services' map is that it becomes a tool for designers to use in investigating the practical application of design strategies that have been used to create ecosystem services, or aspects of them.

The online platform and interactive database of ecosystem services focused design methods, strategies, and case studies is the first one that is publicly accessible, interactive and thoroughly researched based. A complete, easily accessible and useful compilation of possible ecosystem services related design strategies will be valuable for people working in the architectural and urban design and planning fields.

3. Methodology

This research was design-led, rather than based on a more traditional science set of quantifiable experiments. Because of this, this methodology section outlines the steps in the research process. The reasoning behind each step and how these relate to the research aims is discussed concurrently, rather than being separated into discrete sections. The methodology used to produce the 'strategies for designing urban ecosystem services' map can be understood as follows:

3.1 Step one: literature and design precedent review

The theoretical framework for the map is based on the ecosystem services relationship diagrams and the urban ecosystem services categories described by (Pedersen Zari, 2018a). This work established the initial 22 ecosystem services and 49 subcategories of ecosystem services that were investigated and mapped (see: key to figure 2). A thorough critical literature and design precedent review of existing and developing strategies and technologies that enable the creation of ecosystem services through the medium of building components, buildings, built infrastructure, and cities was conducted. This was combined with and compared to international databases of urban nature-based solutions that focus on climate change adaptation (Keesstra et al. 2018, Pauleit et al. 2017, Raymond et al. 2017, Cohen-Shacham et al. 2016, Pedersen Zari et al. 2017) or climate change mitigation (Hawken 2017). For every strategy, concept or technology, identified, one or more illustrative international built case studies (114 in total) were investigated and summarised. Case studies include: architecture; landscape architecture; urban design; infrastructure design; building technologies / components / materials; and policies.

It should be noted that cultural ecosystem services are benefits that humans obtain from ecosystems related specifically to psychological, cultural, and societal wellbeing. This ecosystem services type has been well investigated in social sciences literature, and socio-ecological models that link cultural services with ecological functions already exist (Daniel et al. 2012). Due to the existence of such models, the 'strategies for designing urban ecosystem services' map currently focuses on design strategies, concepts and technologies for provisioning, regulating and supporting services. Architects and designers are trained to integrate cultural and aesthetic aspects into their design work already and typically are expert at this. This means mapping design strategies that produce cultural ecosystem services is both a large task, and crucially is less urgent in relation to improving the biological ecological performance of urban environments. Future work is planned that integrates and relates cultural services to existing elements in the 'strategies for designing urban ecosystem services' map.

3.2 Step two: relational database compilation

The results of step one were compiled as a database that identified relationships between design strategies, concepts, and technologies and specific ecosystem services. Case studies were also added to the database. The database was developed in the Microsoft Excel programme (Microsoft Office Professional Plus 2013). Relationships between 160 distinct design strategies, concepts and technologies that work towards ecosystem services generation were defined.

3.3 Step three: complex system visualisation

The final step was to design an interactive visualisation of the database that captured the ecosystem services and design strategies identified, as well as the relationships between them. In order to create a holistic understanding of complex systems, Suoheimo & Miettinen (2018) suggest employing complexity mapping as a tool. A qualitative visualization of complex systems shows interconnections, patterns, and dynamics of the participating elements (Liebovitch, 2014). In order to understand the relationships between each element in more depth, the complexity map was first drafted manually with sticky notes and hand drawn lines on a board (figure 3). This particular methodology is effective, and common in complex systems mapping (Suoheimo and Miettinen 2018).

Figure 3: Manual complexity mapping. Photo by K. Hecht

To ensure effective visualisation of the data several online qualitative complexity mapping web-based software and platforms were tested for suitability. The mapping tools investigated for their usability, and functionality included: bubbl.us (Stair 2013); MindMup (Adzic and Chatley 2017); 7Vortex (7Vortex 2018); and Kumu (Liebovitch 2014). Kumu was the platform selected due to its flexibility in structuring, connecting, and controlling the visualisation of the data. Kumu was created by J. and R. Mohr in 2011 and enables the mapping of relationships and the visualisation of complex systems and large datasets. An additional reason for the selection of Kumu was that the developed database spreadsheet (step two of the research process) could be transferred to the platform for automated updating.

Within the 'strategies for designing urban ecosystem services' map each discrete ecosystem service, or design strategy, or case study became a circle on the Kumu map and is termed an 'element'. In total there are 348 elements in the map, all of which have been manually linked with relationship lines (equating to 1421 individual relationship connections in the map).

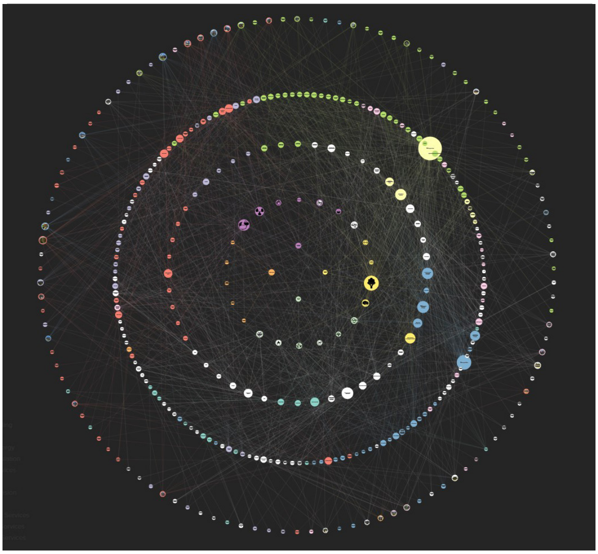

Figure 4: Screenshot of the strategies for designing urban ecosystem services map version 1.0.

The outermost circle are the case studies. The next circle in is the design strategies. The third circle is the ecosystem services subcategories. The second smallest circle is the ecosystem services categories and the innermost circle is the ecosystem services types (provisioning, regulating, supporting, and cultural).

Through an iterative design-led research process, it became clear that organising the elements into a series of concentric circles made the complexity map easier to use and meant that users could start from the middle of the map with the intention of designing for a specific ecosystem service, or they could start from the outermost circle from the case studies and work their way inwards to understand how multiple ecosystem services can be generated concurrently (figure 4). A link to version 1.0 of the map is available by contacting the authors.

Additional descriptions of each ecosystem service, ecosystem service subcategory, design strategy / technology / concept, and case study were completed and are accessible by clicking on the three grey dots on the left side in the map. References, links to additional material, and video clips where available and relevant, were added to the majority of the descriptions. The element colours were determined by affiliation to one of the seven most applicable ecosystem services to an urban context defined by Pedersen Zari (2018b). These categories are: provision of food; provision of fresh water; provision of fuel / energy; climate regulation; purification; nutrient cycling; and habitat provision. To facilitate the usability of the map, icons were used as background images for the ecosystem services categories and photos were used as element images for the case studies.

4. Results: understanding the 'strategies for designing urban ecosystem services' map

The size of each element in the 'strategies for designing urban ecosystem services' map was determined through the Kumu programme automatically by the amount of direct connections to it. This means the more relationship links an element has, the larger the element circle appears on the map. By analysing the sizes of the elements is it possible to see which ecosystem services have larger numbers of design strategies attached to them, and which ecosystem services have few existing design strategies associated with their creation in an urban setting. The map displays possible relationships between elements. These relationships can be direct or indirect which means that certain elements are connected via one or more other elements. For instance, the ecosystem service 'soil building' is indirectly related to the ecosystem service 'decomposition'. This can be explained due to the connection via the 'soil building' subcategory 'renewal of soil fertility' and the 'decomposition' subcategory 'biodegradation'.

Analysing the map based on numbers of connections to each element shows that provisioning services have the highest amount of connections (both direct and indirect), particularly the provision of fuel / energy ecosystem services (connection to 23 different design strategies), and the provision of fresh water ecosystem service (connection to 15 design strategies). This demonstrates that design strategies, concepts, or technologies that generate provisioning ecosystem services are among the most well-known, and developed and are already often integrated into sustainable built environment design. This is not surprising given that these ecosystems services are a familiar and integral part of traditional forms of human economic systems (Daily 1997). They are tangible, and easily understood.

Provisioning ecosystem services tend to be directly reliant on regulating and supporting ecosystem services (Pedersen Zari 2018a). It is important therefore that ecosystem services design does not ignore regulating or supporting services, although these are more difficult to quantify, and indeed to understand for many people (Daily, 1997). The type of ecosystem services with the least amount of connections (both direct and indirect) to known design strategies, concepts, and technologies in the map was supporting services. Supporting services include ecosystem services like 'soil building' or 'nutrient cycling' and directly support provisioning services. This suggests that future research and effort should be made to devise and test design strategies that produce or contribute to supporting and regulating ecosystem services more readily. The only exception to the low number of known design strategies that relate to supporting ecosystem services was 'habitat provision'. Habitat provision was actually the ecosystem service with the highest amount of direct connections to known ecosystem services related design strategies (connected to 40 design strategies). This can be explained because of the direct linkage to many design strategies, concepts, and technologies included in the map which are based on vegetation-related concepts such as green roofs, living walls, allotment gardens, and urban wildlife corridors for example.

Ecosystem services and sub categories with the least amount of known design strategies associated with them were: provision of genetic information; fixation of solar energy; and control of invasive species. This can be explained because the nature of these ecosystem services relies heavily on communities of living plants, meaning unless plants themselves are integrated into buildings or urban contexts it is difficult for buildings or grey infrastructure to produce these ecosystem services. Earlier research has shown that if the ecosystem service of habitat provision in urban settings is thought of as a bundle of ecosystem services including: provision of genetic information; biological control; species maintenance; fixation of solar energy; and soil building, these ecosystem services can be more readily integrated into urban contexts (Pedersen Zari, 2015b).

The ecosystem subcategories of greenhouse gas (GHG) mitigation, and climate adaptation, which both relate to the regulating ecosystem service of climate regulation, were among the largest categories in terms of associated design strategies. This may be a result of current effort in the building and urban design communities to devise strategies for design that addresses climate change (both the mitigation of and adaptation to it).

Among the design strategies, concepts, and technologies, ‘revegetation’ had the highest amount of connections to ecosystem services, suggesting that inclusion of green space and living infrastructure into cities will be an important part of achieving ecosystem services based ecological performance goals in urban settings. Applying just this one design strategy in an urban environment can, depending on the exact nature of the design, generate up to nine different ecosystem services including soil building, purification and provisioning of fuel and energy. Other design strategies with large numbers of connections, meaning the potential to contribute to more than one ecosystem service, included urban agriculture and carbon / GHG sequestration technologies.

In summary, the ‘strategies for designing urban ecosystem services’ map shows that there are existing design strategies that relate to the emulation, production, or support of every listed ecosystem service. This suggests that ecosystem biomimicry based on the idea of emulating ecosystem services does not have to rely on new, or un-tested technologies or design ideas. Rather, what is required is a re-imagining of the overall goals for ecological performance and effort to design building or urban spaces that produce multiple interconnected ecosystems.

5. Discussion

That a greater understanding of ecology and systems design is required on the part of design teams is implicit with an ecosystem services approach to architectural and urban design. Increased collaboration between fields that traditionally seldom work together such as architecture or urban design, and biology or ecology would also be required. The built environment varies greatly between different climatic, economic and cultural contexts, and systems that are appropriate to specific places will therefore also vary greatly. Although each differing geographic region will have to evolve its own unique system over time, knowledge of how to create or evolve such systems can be transferred, particularly through ecosystem services design visualisation tools such as the ‘strategies for designing urban ecosystem services’ map.

A whole-system ecosystem services generation approach to built environment design is a suitable solution for a longer-term response to climate change and biodiversity loss, because it addresses many of the underlying issues with current urban environments that are in need of re-evaluation (Grimm et al. 2008). The difference can be likened to a long-term treatment of the underlying cause of an illness in an individual, rather than a short-term treatment of symptoms which may in fact aggravate the underlying condition. In this case, this is the fact that the majority of human urban settlements are dependent on fossil fuels to heat, feed and transport people in a linear system which creates pollution leading in part to climate change. This system also causes the degradation of water ways, air quality, soil, and human health while at the same time consumes non-renewable resources in such a way that they cannot be re-used. A whole-systems approach to built environment design acknowledges that human developments and therefore humans are not in any way separate from the ecosystems they exist in.

5.1 The evolution of the ‘strategies for designing urban ecosystem services’ map

The ‘strategies for designing urban ecosystem services’ map as illustrated in figure 4 is currently at version 1.0. Version 1.1 will involve verifying the accuracy of existing relationships between map elements, and additional expansion of the text descriptions of each element. In order to better indicate and illustrate the nature of existing relationships, connection lines may need to be modified in terms of their direction / strength / colour etc. Version 1.1 will also require further collaboration with a graphic designer and / or software designer to improve some graphical and usability issues with the existing Kumu map. A revision of how elements are clustered (which currently is determined automatically by the Kumu algorithms) would also be useful. Beyond these minor improvements, it is important to integrate cultural ecosystem services more effectively into the map. The map will require continuous development to include new innovations in the area of design for urban ecosystem services.

The next major phase of the research will involve testing the developed online system practically in a pilot research project with designers, in order to evaluate the usability of the map and to then understand the range of further improvements that should be made. Work on phase 2 in the form of a pilot study using an app based ecosystem services site measurement tool (ESII Tool 2019) has begun with the intention of investigating how existing decision-support tools for ecosystem services measurement (see: Bagstad et al. 2013) can be more effectively translated into practical examples of design strategies using the medium of the ‘strategies for designing urban ecosystem services’ map.

6. Conclusions

Mimicking aspects of living organisms can produce innovations that address sustainability issues in some cases, but without an understanding of the ecological context of these organisms, such innovations can too easily become simple technological add-ons or substitution materials in conventional buildings. Such solutions also miss an opportunity to examine the possibility of systemic change in the built environment and to re-evaluate the nature of the relationship between people, their built environment the ecosystems they exist in.

Positive integration with ecosystems leading to a regenerative rather than damaging effect on them in urban contexts may contribute to maintaining biodiversity and the ecosystem services that humans are dependent upon for survival, particularly as the climate continues to change. Such a concept goes beyond encouraging a basic understanding of ecological processes over time. Instead it is the thorough integration of quantifiable biological ecological knowledge into architecture and urban design for the purpose of altering how buildings fundamentally function in relation to both ecosystems and to each other. Buildings, and indeed whole cities should be expected to become active contributors to ecosystems and social systems, rather than remaining unresponsive agents of ecosystem degeneration.

Acknowledgements
No external funding was received for this research.

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