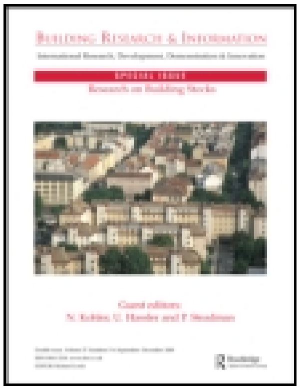

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Ecosystem services analysis for the design of regenerative built environments

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RESEARCH PAPER

Ecosystem services analysis for the design of regenerative built environments

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'Neutral' environmental outcomes in terms of energy use, carbon emissions, waste generation or water use are worthy but difficult targets in architectural and urban design. However, the built environment may need to go beyond efforts simply to limit negative environmental outcomes and instead aim for net positive environmental benefits. This implies that the built environment would need to contribute more than it consumes while simultaneously remediating past and current environmental damage. Such development could be termed 'regenerative'. The potential for understanding and then mimicking ecosystem services is explored for setting goals for regenerative developments, designing them and measuring their successes or failures as they evolve over time. Key leverage points are identified where the systems of the built environment may be changed in order to move towards a regenerative urban environment. Analysing the urban built environment from the perspective of how ecosystems function could be a significant step towards the creation of a built environment where positive integration with, and restoration of, local ecosystems may be realized.

Keywords: biomimicry, built environment, ecology, ecosystem services, environmental benefits, place, regenerative design, urban design

Des résultats environnementaux « neutres » en termes de consommation d'énergie, d'émissions de carbone, de production de déchets ou d'utilisation de l'eau, constituent des objectifs qui méritent d'être poursuivis, mais qui sont difficiles à atteindre dans le domaine de la conception architecturale et de l'aménagement urbain. Cependant, il peut être nécessaire que le cadre bâti aille au-delà des efforts cherchant simplement à limiter les résultats environnementaux négatifs et vise plutôt à obtenir des avantages environnementaux nets positifs. Ceci implique que le cadre bâti devrait contribuer plus qu'il ne consomme tout en corrigeant simultanément les dommages environnementaux passés et actuels. Un tel développement pourrait être qualifié de « régénérateur ». Les possibilités de compréhension, puis d'imitation des services écosystémiques, sont étudiées de façon à fixer des objectifs en matière de développements régénérateurs, à concevoir ceux-ci et à en mesurer la réussite ou l'échec au fur et à mesure de leur évolution au fil du temps. Les principaux points de levier sont identifiés là où les systèmes du cadre bâti peuvent être modifiés de manière à progresser vers un milieu urbain régénérateur. Analyser le cadre bâti urbain du point de vue de la manière dont les écosystèmes fonctionnent pourrait constituer un pas important dans le sens de la création d'un cadre bâti dans lequel il serait possible de réaliser une intégration positive avec les écosystèmes locaux, ainsi qu'une réhabilitation de ceux-ci.

Mots clés: **Mots clés:**, cadre bâti, écologie, services écosystémiques, avantages environnementaux, lieu, conception régénératrice, aménagement urbain

Introduction

Regenerative design aims to create developments that are capable of restoring health to both human communities and the ecosystems of which they are a part. While the philosophical basis of regenerative design would appear to be a logical goal for development given continued climate change and ongoing degradation of the planet's ecosystems (Intergovernmental Panel on Climate Change (IPCC), 2007; Carpenter *et al.*, 2009; Millennium Ecosystem Assessment,

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2005b), it is much more difficult to find successful built examples or guidance about how to begin and then work through the process of regenerative design. The aim of this paper is to describe a potential starting point for regenerative design in terms of ecological health and to discuss how this could be used in an urban environment. It begins by investigating ecosystem services in general and then identifies potential key ecosystem services that are applicable to a built environment context. It then examines how ecosystem services analysis might be applied to urban settings, and what benefits and difficulties are inherent in such an approach to design.

Regenerative design is holistic in nature. The social or community aspects of a project are entirely enmeshed with ecological health in terms of both physical and psychological well-being (for example, Kellert *et al.*, 2008; Eisenberg and Reed, 2003). The author acknowledges that for a development to become truly regenerative, the relationship between a restored ecosystem and human society needs to be understood and leveraged to ensure maximum well-being. This paper, however, focuses on the ecological aspect of regenerative design only. This is not because human well-being is thought to be less important or separate from the positive benefits of ecological regeneration, or because the need to understand and develop positive relationships between humans and ecosystems is not essential, but simply in order to narrow the scope of the research and to complement parallel investigations into other aspects of regenerative design (for example, see the papers in this special issue by Cole *et al.*; Mang and Reed; Plaut *et al.*; and Svec *et al.*).

Regenerative design seeks to address the continued degradation of ecosystem services by deliberately designing and developing the built environment in ways where ecosystem health is increased rather than diminished. Ecosystem services are not adequately protected in most cases due to an absence of sound regulation and policy and/or a lack of market-based solutions (such as mechanisms seeking to internalize the cost of incremental damage to ecosystems in development decisions, for example). This means that regenerative design relies primarily on the goodwill of developers, planners and designers. This reliance on goodwill, combined with the fact that it is difficult to understand the complexity of ecosystems, and the public goods nature of ecosystems (Costanza *et al.*, 1997), means it is currently difficult to achieve a level of protection of ecosystem services that would enable them to function at an optimal level. Despite this, and until such wider issues are addressed, the restoration of degraded ecosystems either to a level of basic operation or to improved health through design interventions is to be encouraged. Regenerative design implies that ecosystems should return or evolve to a state where they are thriving, so that no further human management is necessary. In discussing ecosystem health in the context of regenerative development, the question remains: what exactly are designers aiming to regenerate? And, how can moving towards this goal be evaluated? It is suggested here that mimicking or integrating with ecosystem services provides measurable and achievable goals for development that are based upon the physical reality of a specific place using the reference point of an ecosystem rather than other human activities or political trends.

Information about the negative environmental impact of the built environment is often relative to other human endeavours. For example, the United Nations Environment Program (UNEP) states that 40% of all energy and material resources are used to build and operate buildings globally (UNEP – Sustainable Buildings and Construction Initiative, 2007). Such a figure is useful in setting an agenda for future research and for establishing the urgency of the need to change urban environments and how they are used by their inhabitants, but it has no relationship to how much energy is available, what level of use would be sustainable, or what is the environmental impact of this use. A typical goal that fits into this way of thinking related to water consumption for a building, for example, might be 'to reduce water use by 10%.' This is based upon human-defined goals related perhaps to economic, political or convenience factors. It does not give information relative to an example of a successful and sustainable system however, nor does it relate to what could be physically possible at a given site. A common reaction to such information is to reduce, remove or stop certain behaviours or ways of constructing the built environment. Regenerative design aims to enable built environments to move beyond that and into the realm of creating health and well-being rather than simply reducing damage (Reed, 2007). A goal related again to water consumption but based on ecosystem services analysis might be to 'tailor water use within a given site to its annual rainfall budget.' This second kind of target is based upon the physical possibilities the site affords, can be clearly measured and enables a development to be understood in the wider context of the ecosystem of which it is a part. Ecosystem service-based targets suggest what action is needed to change behaviour as well as what the appropriate goals should be.

Understanding ecosystems as a basis for design

Ecosystems provide designers with examples of how life can function effectively in a given site and climate and offer insights into how the built environment could function more like a system than as a set of individual unrelated object-like buildings (Pedersen Zari, 2010). Various interrelated methods for incorporating an understanding of ecosystems into architectural or urban design have been advocated. For example, van der Ryn and Cowan (2007) and Todd and Todd (1993) examine various aspects of what they term 'ecological design'; while Graham (2003) discusses 'building ecology' and draws upon several ecological principles including laws of thermodynamics and the importance of understanding change. Lyle (1994) lists different strategies and technologies for regenerative design which draw upon a variety of ecological concepts. Gruber (2011), and Pedersen Zari and Storey (2007) examine mimicking the processes of ecosystems in an architectural context as part of a wider understanding of biomimicry (Benyus, 1997). McDonough and Braungart (2002) advocate the idea that 'waste equals food' as part of their 'cradle-to-cradle' vision, a concept derived from understanding how ecosystems work. Precedents and extensions of these ideas can be found within industrial and construction ecology research (for example, Kibert *et al.*, 2002; Hermansen, 2006). Ideas contained within research investigating permacuture (Mollison, 1988; Copeman, 2008), ecological engineering (Bergen *et al.*, 2001; Mitsch and Jørgensen, 2003), and green infrastructure (Benedict and McMahon, 2006) in relation to the design of the built environment also come from an understanding of ecosystems and have links with the concepts discussed above.

There is considerable value to be found within these ideas when considering how to begin a process of regenerative design. Kibert (2006) cites a number of these authors and criticizes many of these kinds of approaches to design due to the difficulty in understanding and modelling ecosystems. He asserts that:

> the mimicking of nature in human designs is one dimensional [and] non-complex ....

Mimicking ecosystem services as described in this paper differs, in that it suggests a design strategy based on a systematic transfer of scientific ecological knowledge into a built environment context, rather than design based on analogies or metaphors of ecosystems as defined by designers.

Some similarities exist between ecosystem services analysis described in this paper and ecological footprinting analysis (Wackernagel and Rees, 1996), particularly when considering the provisioning services. This is because these are related to human consumption. However, some key differences are apparent between the two approaches. Ecological footprinting relates individual, whole urban population, or national levels of human consumption of natural resources to the estimated annual regenerative capacity of the biosphere to renew those resources consumed, and to absorb the waste created. Often land and water productivity levels are used as the basis of these calculations. Ecological footprinting analysis often leads to the approximation of equitable shares of resource use for a given population, and can determine the percentage of 'overshoot' for which an individual or population is responsible (Venetoulis and Talberth, 2008).

By contrast, the kind of ecosystem services analysis described in this paper starts from the assumption that an ecosystem that has not been degraded by human activities is likely to be an example of highly effective organization of life in terms of environmental performance. Such an ecosystem, in a given location and climate, can therefore provide a model or a set of targets, for urban areas in the same location and climate to aspire to. The ecosystem used as the basis for the analysis may currently exist, or may have been damaged or removed already, implying that analysis must be of an ecosystem that existed in the past. Ecosystem services analysis is more site or climate specific than ecological footprinting and relates to an actual ecosystem (which could be any kind of terrestrial, riparian or marine ecosystem that is appropriate) rather than to generic land or biosphere capacity factors. The analysis of ecosystem services may be more time consuming initially but increases the potential for accuracy, particularly when considering the categories of supporting and regulating ecosystem services.

Ecosystem services for regenerative design

A focus on 'ecosystem services' has been widely adopted among ecology and policy professionals (Carpenter *et al.*, 2009), formalized by the United Nations' assessment of ecosystems and human well-being (Millennium Ecosystem Assessment, 2003, 2005a, 2005b). Several ecologists define and list ecosystem services (for example, Daily *et al.*, 2000; de Groot *et al.*, 2002; Millennium Ecosystem Assessment, 2005a; TEEB Foundations, 2010). The services that humans receive from ecosystems can be 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 and spiritual inspiration. Table 1 lists the main ecosystem services identified in a comparative survey of existing research. TEEB Foundations (2010) and TEEB (2011) provide insights, case examples and specific details of each ecosystem service.

Heal *et al.* (2005) note that certain ecosystem services were recognized when ecological knowledge increased, therefore it is likely that the list of known ecosystem services will evolve over time. Lists of ecosystem services could also change over time because they are determined not only by the functions of ecosystems themselves, but also by human ingenuity in deriving benefit from them.

Table 1 Ecosystem services

1. Provisioning Services	2. Regulating services (human time scale)	3. Supporting services (long time scale)	4. Cultural services
Food: Human (land/fresh water/marine) Forage	Pollination and seed dispersal	*Soil*: Formation Retention Renewal of fertility Quality control	Artistic inspiration
Biochemicals: Medicines Other	*Biological control*: Pest regulation Invasive species resistance Disease regulation	*Fixation of solar energy*: Primary production/plant growth (above ground, below ground, marine, fresh water)	Education and knowledge
Raw materials: Timber Fibre Stone Minerals	*Climate regulation*: Greenhouse gas (GHG) regulation Ultraviolet light (UV) protection Moderation of temperature	*Nutrient cycling*: Regulation of biogeochemical cycles Retention of nutrients	Aesthetic value
Fuel: Biomass Mineral Other	*Prevention of disturbance and the moderation of extremes*: Wind/wave force modification Mitigation of flood/drought Erosion control	*Habitat provision*: Refuguim Nursery function	Cultural diversity and history
Fresh water: Consumption Irrigation Industrial processes	*Decomposition*: Waste removal	*Species maintenance*: Biodiversity Natural selection Self-organization	Recreation and tourism
Ornamental resources	*Purification*: Water/air/soil		Spiritual and religious inspiration
Genetic information			Creation of a sense of place
			Relaxation and psychological well-being

Ecosystem services are fundamental to human survival (TEEB in Local Policy, 2011). In their seminal paper, Costanza *et al.* (1997) estimated, for example, that although humans would not be able to replace the ecosystem services they utilize with current technology, if these services had to be paid for in monetary terms, the cost would have been almost twice the entire global gross national product at the time of the research. It is commonly known that the built environment has a large negative effect on ecosystem services (Rees, 1999; Graham, 2003). One way to reduce or perhaps to reverse this is to create or re-design built environments so that they provide, integrate with, or support these services and therefore reduce pressure on ecosystems. This is particularly important as urbanization increases.

Disaggregating the functioning of ecosystems into discrete 'services' is philosophically as well as practically difficult. However, it is potentially useful as a tool to demonstrate the limits to regenerative design. Utilizing ecosystem services analysis enables ecological regeneration goals for a built environment context to be more readily devised and makes design interventions easier to measure. This is important to ensure that regenerative design has scientific credibility particularly as it becomes established, and does not simply become a vehicle for the creation of developments with high ideals but which nevertheless fail tangibly to improve the environmental performance of the built environment. A concentration on parts of ecosystems, rather than ecosystems as whole entities, could undermine the holism that is central to regenerative design. Therefore, ecosystem services analysis needs to be used in concert with other aspects of regenerative design that focus on the development of relationships between humans, the built environment and wider ecosystems.

Key leverage points for change

Ecological economists have sought to place value on ecosystem services in different ways as the ecosystem services concept has been applied to policy frameworks (Turner and Daily, 2008). Ultimately 'value' is still a human subjective measure and attempts to determine value weightings for ecosystem services often attract debate (Carpenter *et al.*, 2009; Rosemond and

Anderson, 2003). While all aspects of ecosystem functioning are important to the system as a whole, and it is not perhaps even possible to assign value to discrete parts of an ecosystem, this section investigates which ecosystem services are the most suitable to focus on in an urban built environment context. The urban built environment is defined here as the buildings, roads, infrastructure and surrounding human designed or domesticated landscapes, such as parks or sports grounds, for example, that make up an urban area.

Given that 26 distinct ecosystem services were initially identified (Table 1), it was necessary to determine which were the most appropriate for examination in the context of the built environment. This was assessed using three ranking criteria:

- services that are physically able to be mimicked by or integrated with the built environment
- services that have had the greatest impact on the maintenance of ecosystem health
- the relative negative impact that the urban environment has on the service in question and the scale this relates to in terms of a local, regional or global context

The results of this investigation are summarized in Table 2.

Integration of ecosystem services into the built environment

It was found that not all ecosystem services can be easily integrated with or mimicked in a built environment context such as pollination and regulation of species diversity, for example. Others are more conducive to integration with the built environment, such as the provision of energy or fuel (Bolund and Hunhammar, 1999). Following a methodology similar to that described by Shelton *et al.* (2001), three levels (low, medium and high) were used to rank the ease of addressing each ecosystem service by the built environment. Criteria used to determine an ecosystem service's applicability to the built environment included the ease of integrating an ecosystem service with a built structure and its surrounding context, and a consideration of existing technologies or design methods that already support or mimic the service. This allowed services to be prioritized and enabled an initial refinement of the list of ecosystem services suitable for developing regeneration oriented design goals in the built environment. This led to the formation of the following set of four services considered to have high applicability to the built environment: provision of fuel/energy, provision of fresh water, purification, and climate regulation. Two have medium applicability: nutrient cycling and provision of habitat (Table 2). These two services are thought to be of less significance because while the built environment can contribute to them, the regeneration of ecosystems that are not part of a built environment may be a more effective means of restoring these services. Services found to have low applicability to the built environment were not considered further in the ranking exercise.

A hierarchy of ecosystem services relative to overall impact

An attempt was made to examine the importance of each service in terms of an ecosystem service's physical, biological and chemical contribution to maintaining the functional health of global ecological systems (after the definition of ecological importance found in Costanza and Folke, 1997). Several authors discuss the need for ecological factors rather than just economic ones to be taken into account when valuing ecosystem services (Patterson, 2002; Heal *et al.*, 2005; ten Brink *et al.*, 2011). Despite this, a ranking of ecosystem services based on ecological importance has not been conducted to the author's knowledge. Such a ranking is problematic for a number of reasons. It is difficult because of gaps in knowledge about ecosystems, and also because of uncertainties and non-linear complexity found in ecosystems and in current ecosystem modelling (Peterson, 2002). This, combined with the fact that ecosystems provide both direct and indirect benefits, as well as tangible and more difficult to quantify benefits, over various temporal and spatial scales, makes it difficult to predict ecosystem dynamics and assign value to them (Chee, 2004; ten Brink *et al.*, 2011). Furthermore, although different categories of services can be listed individually, the interlinked and interdependent nature of ecosystem services makes it difficult practically to assign value to them as discreet, independent services (Chee, 2004; Patterson, 2002). Despite these difficulties, several authors do examine ways that value in terms of ecological importance could be assigned to ecosystem services (Costanza and Folke, 1997; Chee, 2004; Patterson, 2002).

Mulitcriteria evaluation (MCE), or multicriteria decision analysis (MDA), is a method where complex decision-making involving multiple criteria can be simplified (Proctor and Drechsler, 2006). It is useful in situations involving complex environmental issues and could potentially be useful in determining such a ranking of ecosystem services based on ecological value. Once an accurate ranking of ecosystem services in terms of ecological importance is provided, the list of services that the built environment can mimic or contribute to may change.

Although social and ecological systems are intimately linked (Young *et al.*, 2006; Folke, 2006; Azar *et al.*, 1996), and proponents of the biophilia hypothesis might argue that ecosystem health both affects and is

Table 2 Ecosystem services for the built environment

Ecosystem service	Ranking criteria			Examples of existing design methods that could be potentially be used	Positive environmental implications
	Applicability to the built environment	Ecological significance	Negative environmental impact caused by the built environment		
Supporting services					
1. Habitat provision (including: provision of genetic information; biological; fixation of solar energy; and species maintenance)	Medium	High	High at a local scale	Revegetation; preservation of existing flora and fauna; urban wildlife sanctuaries; living walls; urban forests; green roofs and facades; wildlife corridors; green belts	Increased biodiversity; reduction of the urban heat island effect; sequestration of carbon; increased air, water and soil quality; remediation of some forms of water, air and soil pollution; possible protection from wind or wave surges; more adaptable ecosystems as the climate changes; reduction of storm water peak flows
2. Nutrient cycling (including: decomposition; soil building; and the provision of raw materials)	Medium	High	High at a regional/global scale	Recycling and reuse techniques; cradle-to-cradle design; composting techniques; design for deconstruction; landfill mining; industrial ecology	Reduction of waste; reduced need for mining/growing/production/transportation of materials and energy leading to reduction in greenhouse gas (GHG) emissions, waste and ecosystem disturbance; decreased use of energy; increased health of ecosystems and humans
Regulation services					
3. Purification	High	High	High at a local/regional scale	Living machines; phyto-remediation and bio-remediation; filtration techniques; green roofs and facades; urban forests; constructed wetlands; composting techniques	Increased health of living organisms; increased terrestrial and marine productivity; reduction of air and water pollution; eutrophication reduction; remediation of polluted sites; reduced ozone damaging gas and GHG emissions
4. Climate regulation	High	High	High at a global scale	Storage of carbon in building structure; revegetation; design to enable behaviour change in energy use; renewable energy generation; passive solar design; non-high thermal mass infrastructure and landscaping; design to reduce reliance on fossil fuels	Mitigation of the causes of climate change; more adaptable communities; mitigation of the urban heat island effect; improved health of living organisms
Provisioning services					
5. Provision of fuel/energy for human consumption	High	Medium	High at a global scale	Design for renewable energy generation; cogeneration methods; design to enable behaviour change to reduce energy use; industrial/construction ecology	Reduced transport and energy generation-related GHG emissions; more self-reliant and therefore robust urban environments; reduction of air, water and soil pollution; reduction of mining and drilling impacts
6. Provision of fresh water	High	High	High at a regional scale	Rain water harvesting and storage; grey/black water recycling; design incorporating water saving equipment; porous paving surfaces; water efficient landscaping	Reduction of water pollution; increased health of riparian systems; reduction of the urban heat island effect; increased quality of water; increased health of living organisms

affected by human psychological health (for example, Kellert *et al.*, 2008; Storey and Pedersen Zari, 2006), for the purposes of this research cultural services are thought to have less direct or obvious links to improved ecosystem health than the other categories of ecosystem services. Also, many of these cultural services are not fulfilled by ecosystems exclusively. Artistic inspiration, for example, may be equally found in a city of character as it could be in a forest. For this reason the category of cultural services as well as the provisioning service of ornamental resources were not considered further in this context.

Shelton *et al.* (2001) found that all ecosystem services were ranked as having 'high' ecological importance because decline in one would impact on future production capabilities in another. The research in this paper follows a similar pattern. The exception is found in some of the provisioning services. These services, while of obvious importance to human well-being, tend to be related to human preferences only and so do not necessarily have high importance in terms of maintaining ecological health. This is why the provisioning service of fuel/energy is listed as being 'medium' in terms of ecological significance in Table 2. The provisioning service of fresh water is of great importance to humans, but also all flora and fauna, so it has a high rating.

The built environment's impact on ecosystem services

To determine which ecosystem services might be most appropriate to focus on in the context of the urban built environment, the environmental impact that the built environment has on each ecosystem service was considered. The underlying rationale was that if the built environment has a large negative effect on a particular service, then it would benefit that particular ecosystem service if the built environment could mitigate or reverse this negative impact by integrating with or working to restore the service. This provided a further and final set of criteria for ranking the ecosystem services. The basis of the rankings (of the impact that the built environment has on particular ecosystem services) was drawn from a number of sources such as Doughty and Hammond (2004), McDonald and Patterson (2004), Graham (2003), Newman (2006), Wilby and Perry (2006), and Kibert *et al.* (2002.

Six ecosystem services were identified that are most suitable for regenerative design in a built environment context, and are listed in Table 2. A comprehensive analysis of how each of these ecosystem services could specifically be supplemented by the built environment using existing technology or design methods is beyond the scope of this paper and is the subject of ongoing research. The last two columns of Table 2 are therefore not exhaustive but only indicative. The list of ecosystem services suggests that in a similar way to the functioning of an ecosystem, a building or development could be deliberately designed to be part of a system that:

- deliberately provides habitat for species other than humans
- contributes to soil formation and fertility through careful cycling of biodegradable wastes and recycling of non-biodegradable wastes
- purifies air, water and soil
- regulates the climate through mitigating greenhouse gas emissions or possibly sequestering carbon
- produces renewable energy
- collects water

In the absence of rankings provided by ecologists, the methods used to create the list shown in Table 2 have produced a more manageable set of ecosystem services to work with in a design context, while still capturing a wide range of ecological considerations. Such a list should be revisited as knowledge gaps are filled in the field of ecology.

Applying ecosystem services analysis to the built environment

The first step in applying ecosystem services analysis to regenerative design is to determine if there is an adequately healthy existing ecosystem in the locality that can be studied. If not, basing design targets on an ecosystem that existed prior to development on the site could be suitable as the focus of study. Measurable rates of ecosystem service provision that exist (or existed) on a site can then be determined. For example, specific figures such as annual rainfall and water retention in a particular place relate to the ecosystem service of provision of fresh water, and can be calculated with some accuracy. Although there are knowledge gaps in the field of ecology related to measuring ecosystem services (ten Brink *et al.*, 2011), each ecosystem service has aspects that can be measured and are useful in setting initial design targets for regeneration. These targets can then be used to determine the optimal environmental performance of the built environment that is now (or will be) on the same site as the ecosystem studied. For instance, the level of habitat provision to be provided in a new (or retrofitted) development should ideally be equal to the level of habitat provision in the original ecosystem. In examining climate regulation, one aspect that could form a design goal would be to determine how much carbon was contained and/or sequestered by the original ecosystem. This then would suggest what an optimum level to aim for in a new development would be. Although it may be difficult in some cases to determine with accuracy certain rates or figures related to ecosystem services, an approximate figure is still useful in determining site-specific regeneration goals.

The suggested methodology could be employed by teams of designers and ecologists as well as urban planners, policy-makers or ecological economists at regional levels. An incremental process that focuses on improving ecosystem services that currently exist in a specific place to an optimal level could be a tangible place to begin the process of regenerating ecosystem services in the urban built environment. The next stage would be to initiate measures to reintroduce ecosystem services that may be absent in urban areas due to the past degradation or removal of ecosystems. This suggests that a regenerative built environment will need to evolve over time rather than be expected to be fully functional after the initial realization of a design.

The built environment varies greatly according to different climatic, economic, political and cultural contexts, and systemic approaches that are appropriate to specific places will also vary greatly. Despite each locality needing to evolve its own unique regenerative built environment system, knowledge of how to create or begin such systems can be transferred. Ecosystem services analysis requires design teams to consider which ecosystem services are important or suitable to focus on for a particular site before any design of buildings or urban areas begins. Discussions with ecologists informed by local knowledge can define the hierarchy of importance of the ecosystem services and identify a specific focus. This suggests that wider disciplinary inputs into the process would be necessary than normally found in a traditional design context.

The closest example of ecosystem services analysis being applied to design that the author is aware is the Lloyd Crossing Project proposed for Portland, Oregon. The design team[1] investigated how the site's original ecosystem functioned before development in order to determine appropriate goals for the ecological performance of the project over a 50-year period. The stated goals of the project include: reducing environmental impact to predevelopment levels, achieving carbon balance, and living within the site's rainfall and solar budget (Portland Development Commission, 2004). At the time of writing the absence of regenerative developments that have been tested and measured for their ecological performance means their benefits or drawbacks have not been ascertained.

A case study of how ecosystem services analysis could be applied to a specific existing urban environment would demonstrate how targets could be created for the regeneration of ecosystems through built environment interventions. This would further clarify which ecosystem services would be most effective to target in an urban context. Beyond that, monitoring the impact that ecosystem services analysis had on a realized regenerative development project would illustrate (or disprove) the usefulness of ecosystem service analysis over time.

Benefits and difficulties of use

Aside from obvious ecological benefits of regenerative design in general, there are also significant social and economic benefits as discussed by Pedersen Zari and Jenkin (2009). Elaboration upon these benefits will not be repeated here, but there are several additional advantages when adding ecosystem services analysis to a regenerative design process that can be discussed. As mentioned, using ecosystem services analysis to evaluate existing built environments, or to devise design goals, enables the success or failure of developments to be gauged from a perspective of ecological reality. It avoids anthropocentric goals and unhelpful design metaphors that are difficult to quantify or that could ultimately amount to 'greenwash'. Ecosystem services analysis also enables tangible benchmarks to be devised over different time periods and lends itself to planning over the long term.

Using an understanding of ecosystem services is conducive to a regenerative approach, but enables a more specific targeted and measurable design response than simply aiming to 'regenerate ecosystems'. It could provide a practical way to move regenerative design from a mostly theoretical endeavour to the creation of measurable built examples. Understanding ecosystem services fits well into the philosophy of encouraging people to move beyond the typical 'reduce, recycle, efficiency' sustainability paradigm (Reed, 2007; McDonough and Braungart, 2002) and to grasp the potential of adopting a regenerative approach.

Although ecosystems are perhaps the best-known examples of effective organization of life in given locations (Benyus, 1997), the availability of a model to compare to or mimic may be lacking in some areas. For example in older urban environments, there may be little known about what ecosystems were like on a site before development, or there may be no similar ecosystems left to study. Uncertainty also exists about what the future effects of climate change will be on ecosystems (Walther *et al.*, 2002). This means that what had evolved at a particular place may cease to be a suitable model for integrating with or mimicking in the future. In some situations, it may be more appropriate to devise goals from predictions of future ecosystems or climatic conditions.

Encouraging greater interdependence and the sharing or exchange of resources between publicly and privately owned buildings and infrastructure also requires a different institutional regime (economic, legal and attitudinal framework) from that which is currently in place in many industrialized urban societies (Hunt, 2004).[2] Without changes in regulations or policies that govern decision making processes that effect ecosystem services, tangible progress towards improving ecosystem health may be difficult to achieve. Unless clear targets to improve ecosystem health are set, the highly economically competitive nature of built environment development and design, may mean that actions to regenerate ecosystems in this context remain voluntary and dependent upon the 'good will' of developers and designers. Such actions may therefore remain uncommon and not be truly effective beyond isolated cases at small scales.

Discussion and conclusions

There are several major findings from this research that can contribute to an understanding of ecosystem services analysis in the context of regenerative design:

- Ecological regeneration goals for developments can be provided by ecosystem services analysis of a particular place. Simultaneously, mimicking the complex interactions between living organisms comprising ecosystems is a readily available example from which to learn and draw upon to create built environments that integrate with the habitats of other species in a mutually beneficial way.

- Ecosystem services analysis appears to be a promising approach for a longer-term response to sustainability issues in general, and to climate change impacts specifically, because it addresses many of the underlying issues in urban environments that need re-evaluation. Ecosystem services analysis provides a starting point for creating regenerative design that is measurable. This is important for the establishment of the credibility of regenerative design.

- The application of ecosystem services analysis to regenerative design has significant philosophical implications because it asks design teams to judge their environmental performance goals in comparison with the best an ecosystem could do (or did do) on the same site and in the same climate. This entails rethinking how environmental performance is often currently measured. Practically, the use of ecosystem services analysis in the design process will mean working much more closely with ecologists and allowing time for conducting research on site-specific ecosystems.

- Employing ecosystem services analysis in the pursuit of regenerative built environments may require a rethinking of key performance indicators. Rather than a 'one-size-fits-all' approach, performance levels should be specific to a particular site, locality or region. Research is needed to ensure that ecosystem services selected for inclusion in a built environment design context are the correct ones. Failure to assess and amend, if necessary, the ecosystem services to be included in a specific design context could result in misplaced effort and resource.

- There is the need to determine to what extent a rural hinterland must be considered in tandem with an urban counterpart if regenerative goals are to be achieved across multiple ecosystem services. This implies a need to understand ecosystem services at a larger scale (city, region or ecosystem boundary) when devising goals and targets for individual buildings or small developments. Careful thought needs to be put into whether it is more appropriate to use human-defined urban boundaries or those related to ecosystems themselves, such as, for example, habitat-type demarcations, or water catchment zones when using ecosystem services analysis.

- The creation of regenerative built environments must be considered as a process continually evolving over time. This lends itself to the phasing of targets for the regeneration of ecosystem services, allowing planners, designers and decision-makers to focus on the 'low hanging fruit' (ecosystem services that are most easy to address) first and in the process learn about how to use ecosystem services analysis to the greatest effect.

- Examining in more depth how ecosystem services analysis fits in with the wider aspirations of regenerative design would ensure that potential synergies could be harnessed between the ecological benefits and social benefits of such an approach.

In conclusion, the built environment is increasingly held accountable for global environmental and social problems and it is becoming clear that substantial changes must be made in how the built environment is created and used in order to limit and potentially reverse damage to the climate and ecosystems. The needed change will not occur by experimenting with new technologies or rebuilding the entire current built environment, but it could be achieved perhaps through the adoption of new mindsets and goals for how built environments could be adapted to function in a way that is more conducive to the regeneration of ecosystems.

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Endnotes

[1]The design team included Mithūn Architects and GreenWorks Landscape Architecture Consultants.

[2]It is beyond the scope of this paper to explore in depth the effectiveness of economic price signals and incentives used to protect or restore ecosystem services (for case studies and analysis, see, for example, TEEB, 2011).