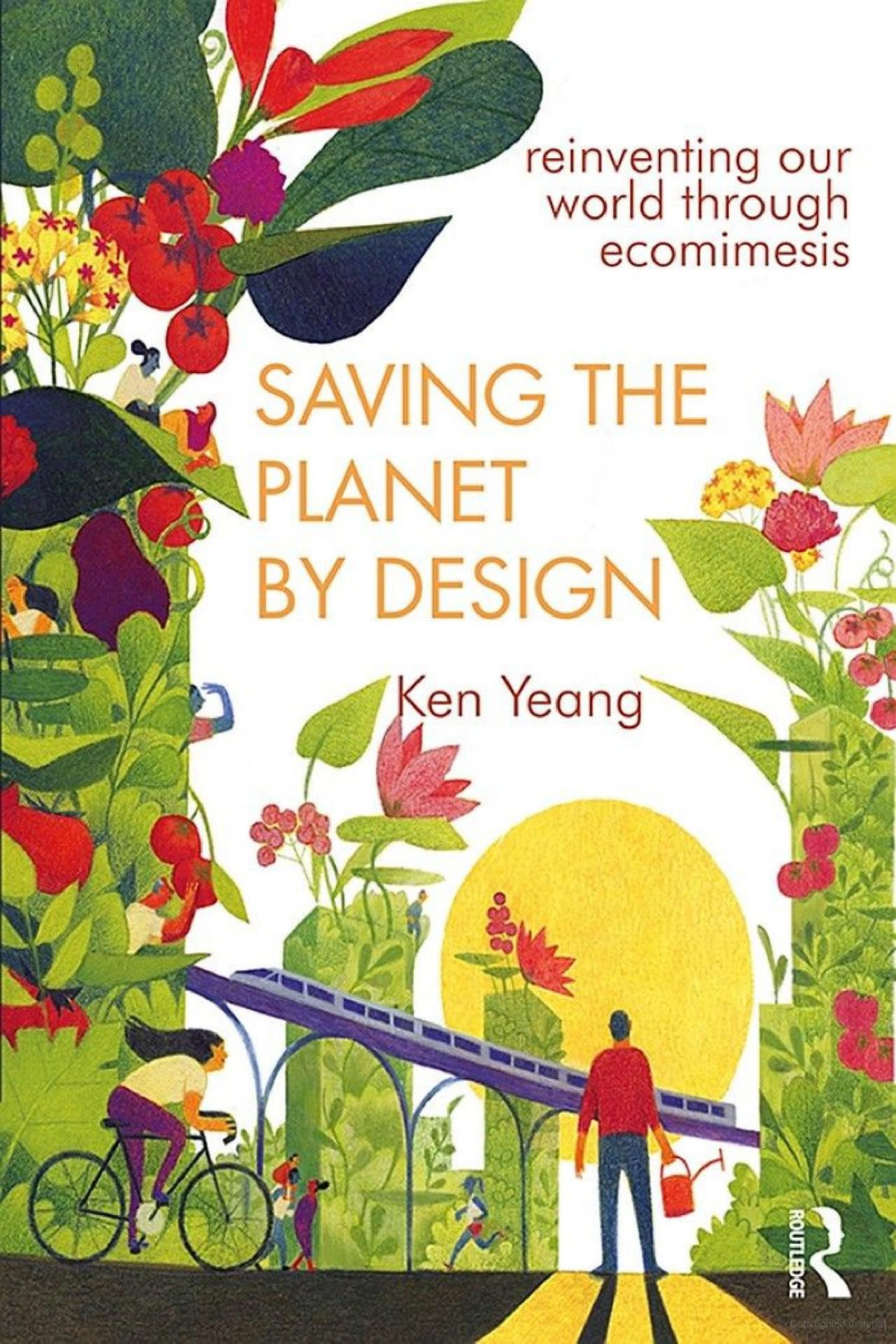

reinventing our
world through
ecomimesis

SAVING THE PLANET BY DESIGN

Ken Yeang

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FOREWORD

I started work on Ecological Design in the 1970s, carrying out research that culminated in my doctoral dissertation at Cambridge University, ‘A Theoretical Framework for the Ecological Design and Planning of the Built Environment’, which was published as *Designing with Nature: The Ecological Basis for Architectural Design* (McGraw-Hill, 1995). The ideas on the use of the ‘ecosystem’ concept as an analogy for design were published as ‘Bases for Ecosystem Design’ (*Architectural Design*, vol. 42, 1972, pp. 434–436) and as ‘Bionics – the Use of Biological Analogies in Design’ (*Architectural Association Quarterly*, vol. 4, 1974, pp. 48–57), which were further expanded in my *Ecodesign: Instruction Manual* (John Wiley & Sons, 2006, Chapter 1). What followed was a long hiatus when I became occupied with my architectural practice. I resumed research work on this treatise in 2016 concurrent with practice, leading to the completion and publication of this treatise.

PREFACE

This book is written as a set of instructive ideas and principles based on the science of ecology to provide the directives for an ecocentric approach for the making and remaking of our human-made world that includes its built environment and its various production and infrastructure systems. The book advances the earlier work (see below) on the idea of the emulation and replication of the attributes of the 'ecosystem' being ecology's model of Nature as the basis for Ecological Design, this is referred here as 'ecomimicry'. The work's relevance and usefulness are not for just those whose daily work impinges on the natural environment, such as architects, engineers, designers, real estate developers, builders and others, but crucially, for all who are seeking directives for action in enabling a resilient, durable and sustainable future for all of humanity.

My research and theoretical work started as a doctoral dissertation on Ecological Design and planning in 1971. In the intervening years, I had set up and operated a professional architect business in 1976. Implementing the theoretical work into practice required reinventing the design process itself and building prototypes in the interpreting and testing of the theoretical ideas as constructed built form. Practice, while enabling the earlier research and theoretical ideas to be tested, demanded further concurrent investigative research work to be done, and the lessons learnt are summarised in this treatise.

Environmental science makes evidently clear that humanity's endeavours to make and remake our human-made world are now no longer preventive of further environmental degradation, but have become in effect a 'race and rescue' mission. In implementing this mission lies the relevance of this treatise in providing the basis for action in seeking the resilience and sustainability for all lifeforms and their environments on the Planet.

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Reinventing the human-made world to address the sustainability equation

PROPOSITION

Can we save the Planet by design? – For a resilient, durable and sustainable future for human society, we need to repurpose, reinvent, redesign, remake and recover our human-made world so that our built environment is seamlessly biointegrated with Nature and functions synergistically with it. These are the multiple tasks that we must carry out and must be carried out imminently if there is to be a future for human society and all lifeforms and their environments on the Planet.

Why are these tasks critical? Addressing these is the most compelling question for all those whose daily work impinges on Nature, such as architects, engineers, landscape designers, urban planners, environmental policy makers, builders, real estate developers and others, but it is also a question that all of humanity needs to urgently address. Whereas addressing the issues of environmental impairment had in the immediate past been a question of preventive action to avert further impairments, the progressive state of environmental impairment has advanced such that repairing the existing degradation already done becomes a priority, besides averting further impairments that has now become a 'race and rescue' mission.

Virtually all aspects of the human-made world and its built environment need to be addressed in this way – beginning with humanity's synthetic and semi-synthetic artefacts and systems, including all urban conurbations from mega urban areas and cities to enclosures (such as buildings), as well as engineering structures and infrastructures for urban utilities, including transportation, movement and routing systems, energy production and transfer systems (sometimes referred to as 'grey infrastructure') and all of humanity's artefacts. The list extends to our biotic production systems for generating goods such as food, wood and medicines, among others. Of course, of high priority is our method of energy production from non-renewable sources and industrial systems for the design, fabrication and packaging of the multitude and variety of artefacts that serve both our commercial and our personal needs. The 'remaking' of the above requires that we transition the material flow of systems from the present day's throughput flow of 'take-make-dispose' linear economy to a circular economy of 'take-make-reuse-recycle-replenish-reintegrate (back into the natural environment)'.

How can we carry out the mission outlined above? Our response needs to be based on two key principles presented here – '**ecocentricity**', meaning to work guided by the science of ecology, and '**ecomimesis**', meaning working, designing and making the built environment, including all artefacts, to become Nature-like based on the emulation and replication of the attributes of the '**ecosystem**' as a concept.

What is the significance of these principles? The contention is that adopting these values profoundly changes the way *we design, make, manage and operate our built environment* to achieve our goal of saving and reclaiming the Planet for Nature.

ACHIEVING EFFECTIVE BIOINTEGRATION

The crux in carrying out this multiple set of directives successfully at all instances is effective '**biointegration'** – that is, the seamless and benign connecting and fusing of our human-made world and its technological systems, with its machines and its built environment, with Nature – that is, the natural environment upon which we are completely dependent for resources, from food, water, air and materials to energy. Moreover, this biointegration as reconnecting with Nature must be as seamless and as benign as possible, both physically and systemically.

Biointegration is defined as the state of being combined or the process of combining into a complete and harmonious whole of the physical and systemic connection between the abiotic and the biotic in Nature. An analogy of effective biointegration can be found, for instance, in the medical and dental practice of *orthopaedic* implanting that effectively combines human-made artificial components with the biological. However, we must aspire to do even better, as many of the current orthopaedic implants are made of unsustainable materials. The aim is to create implants that are harmless even after they disintegrate, which must similarly extend by analogy to our built environments, which are in effect implants in Nature, where the materials used must similarly become harmless even after they are dismantled or disintegrated.

This reintegration is crucial, as the current environmental impairment is due to our disconnection from Nature. This broken link needs to be replaced by a synergistic reintegration, which is the complete fusion of the human-made built environment, including not just its artificial but its semi-artificial components, systems and processes, with Nature, and particularly with the Planet's ecosystems, its constituents and its biogeochemical cycles.[1,2,3]

Biointegration can be both physical and systemic. Physical biointegration means minimising and reversing the physical displacement and fragmentation of natural and semi-natural habitats and populations of species by our urban and industrial and infrastructural developments. Systemic biointegration is where the flows and fluxes of energy,[4] materials, water and biota associated with the systems of manufacture, operation and recovery of both artefacts and the built environment are combined and fused together with Nature's ecosystems' and cycles' processes and flows. One of the key aims of effective biointegration must be to avoid the situation whereby we create a mostly inert human-made world and built environment, made from materials taken from various localities over the Planet that are reassembled to be distinctly and physically separated from its surrounding ecosystems and remain and accumulate in this inert state at the end of their used lives.

In effect, if we are able to effectively repurpose and achieve effective biointegration in everything that humans do, build and make in Nature on the Planet, including its built environment and all of its systems, then there will be no environmental problems. Successfully accomplishing this biointegration is then the fundamental challenge in our endeavour to save the Planet.

'SAVING THE PLANET' AS ECOLOGICAL DESIGN

The term ‘Ecological Design’ here refers to a broad strategic approach that is firstly guided by the science of ecology (see Chapter 2) and secondly affected by the process of ‘designing’, where the term ‘design’ is used not as the sole domain of designers, but as an efficient and systematic problem-solving process applicable to all related disciplines, as will be explained later.

What is the purpose of Ecological Design? Ecological Design is pivotal to our mission of saving the Planet. Its purpose and role are to address the issues caused by the millions of artefacts and structures, particularly the extensive urban structures humans design and construct, that make up our ‘built environment’. While other species in Nature can make new structures, such as termite mounds and coral reefs, no other species manufactures enduring artefacts from materials that cannot be broken down easily into organic constituents or will only biodegrade over extended timeframes. Many of the artefacts that are for humanity’s daily use, together with their packaging, after a short period of use or partial consumption become wastes that are in most instances thrown ‘away’ rather than being usefully and circularly absorbed back into the environment. In many instances, the packaging of single-use items lasts longer than the contents themselves. It has been estimated that some 80% of the artefacts we produce become problematic waste. The high degree of discarding of unwanted and unrecyclable artefacts and packaging, and the resulting emissions caused by their production, reflect not only the rapid development of human technology and society, but also the profligate and wasteful lifestyle of human society (see Chapter 8).

The waste we emit into the environment includes the voluminous emissions from the production of energy from fossil fuels, waste from the production of food in our animal agriculture and ineffective industrial agricultural systems, wastes from our manufacturing processes, and beyond. Essentially all activities of human society are conducted with total disregard of the consequences of their outputs on the Planet and its natural systems. The Planet, being a ‘closed system’, is being used as an environmental sink.[5] However, there is currently no other place that becomes the ‘away’ into which most of humanity’s wastes can be ‘thrown’. This misuse of the Planet as a sink for humanity’s unwanted solids, liquids and gases has reached a level at which this misuse has actually started to change global processes, particularly changing global climate as a result of the gases emanating from the burning of fuels to meet our energy needs, from industrial agricultural and food production from rearing animals, and other urban and semi-urban related activities.[6,7,8] We have similarly begun to affect through our own activities and technologies real changes to other global cycles such as the water cycle, carbon and nitrogen cycles.[9] The scale of these effects has led to the coining of the term ‘Anthropocene’ to refer to the current geological era in which Planetary processes are being dominated by the actions of humankind.

Human society may not be immediately be aware of the environmental impacts of these on the Planet, as many of the consequences of our actions are not immediately visible to the human eye. Many require a longer timescale to become visibly evident to humanity, and generally even longer to reach the point where humanity can collectively acknowledge that crucial restorative action needs to be imminently taken. This is because the Planet's ecosystems and biogeochemical systems have inherent limits in terms of capacity and speed of process. Being aware of this is a crucial aspect of Ecological Design

Trends are particularly clear in the world's oceans, where temperature increase is evident. Impacts include changing weather conditions, an increase in the intensity and frequency of storms and droughts, and rising sea levels.[10,11] With increasing and constant carbon emissions, Earth's atmosphere traps more heat. As polar ice caps melt, more water enters our oceans, causing rising sea levels. Increased carbon in the atmosphere also means increased carbon in the ocean, causing ocean acidification. Threats appear greatest in coastal areas where so many key human conurbations are located.

When a major climatic phenomenon such as a hurricane or an earthquake creates a 'high-level event' like a storm surge or a tsunami, the effects may be dramatically amplified by combination with background anthropogenic climate change. It is also undeniably evident that humanity is causing a huge acceleration in the loss of biodiversity, both in terms of the loss of tangible components of ecosystems such as habitats and species and in terms of ecosystem processes such as nutrient cycling and **ecological succession** (see Glossary). This is a trend that needs to be halted and reversed. The loss of species has been such as to lend the name of humankind to a mass extinction process – the 'Anthropocene Extinction' – equal in scale and significance to previous mass extinctions caused, for example, by tectonic shifts or meteorite strikes on Earth millions of years ago.

Our impact on the ecosystems is such as to push many ecosystem processes to the point of imminent collapse, threatening humanity's own survival in the process. The devastating events by Nature on human communities are not Nature's retaliation (as implied by some in the popular press). The rest of Nature is indifferent to humanity's motivation. These devastating events are just Nature's physical and chemical reactions to changes that affect the health, resilience and integrity of ecosystems and changes to biogeochemical cycles.[12,13,14,15,16]

Homo sapiens has shown great adaptability through history, adapting quickly to new circumstances when environmental catastrophe strikes and support systems disappear. We move to new areas and find new technological solutions, including substitutes for materials that may end up in short supply or become environmentally problematic. Nature too, given the chance, can be similarly adaptable.[17,18] Species that were in small number or in another area can move in, or whole new species can evolve to adapt to the new conditions. New societies and new Nature can then form new communities, interacting in new processes of succession and adaptation.[19,20]

However, for Nature, the recovery by succession to a new climax community may take hundreds or thousands of years, much longer than human generational timespans. Some species may not be able to keep up with the pace of environmental change. They may find their movements blocked or impeded by human-made barriers such as urban areas and infrastructure, a process referred as ‘ecological fragmentation’.[21] In halting and repairing such damage, ecological designers need to work across all scales to connect and protect our irreplaceable landscape across public and private lands, and from cities to the wildest places.

Current Earth sciences indicate that humanity has in effect crossed the critical thresholds of some of the resilience and carrying capacities of the systems operational in the **biosphere** (see Chapter 5 and the Glossary). Human society’s impacts on the natural environment have reached the point of no return. This means that even if human society takes imminent, extensive and concerted regenerative action to address and stem the negative consequences of humanity’s current actions and to avert future impacts, the effects of humanity’s past actions will still exert effects that will persist well into the future.

For example, not all the emitted greenhouse gases can be fully assimilated and sequestered into natural ecosystems, hence an excess remains in the atmosphere.[22] The impacts of these accumulated gases may extend into a future far longer than human history, with consequences for both the environment and humankind.

DESIGNING AND WORKING WITHIN NATURE’S LIMITS OF RESILIENCE

It needs to be emphasised that Ecological Design means working integrally **within the limits of Nature** as functioning within the **carrying capacities** of the Planet’s ecological systems and ability to produce natural resources. That means we must respect the limits of resilience and understand the thresholds beyond which ecological perturbation may lead to ecosystem collapse (see page 18).

Natural ecosystems to varying extents have the ability to withstand regular disturbances and disruptions or ‘shocks’ to their functioning from natural events or the interventions of man. A natural ecosystem generally adjusts to such disturbances so that it continues to support the ecosystem components and processes typically characteristic of it.[23,24] This feature of Nature is often referred to as its natural ‘resilience’.

Each organism within an ecosystem, such as a bacterium, protist, fungus, plant or animal (however large or small), plays some role in maintaining the stability of that community and the conditions of its habitat.[25] Theories vary as to how important that role is for each species, and experiments carried out (most at modest geographical scale) have shown direct correlations between biodiversity and the productivity, resilience and stability of different ecosystems. The same experiments indicate that some species do seem to be very much more important than others at a particular time (so-called **keystone species**, see Glossary). However, in a changed environmental condition, that balance can change, and without the wider species diversity, the system as a whole may not always be able to adapt. What is more, when trying to rate the importance of any given species to ecosystem function, it must be borne in mind that at one stage of its life-cycle a particular species may not be particularly important in the normal functioning of a given ecosystem, but at another stage it can be fundamental to that function.

If any of the ecosystem's constituents are diminished or removed by any disruption or disturbance, there may be a degree of substitution whereby a given component of the ecosystem takes up the function previously served by the component now missing. However, ecosystem resilience and adaptive ability are not infinite. With progressive loss of key species, fundamental change to an ecosystem can occur. A threshold is reached at which the ability of the ecosystem to find balance fundamentally changes.

The point at which, with a progressive increase in some environmental perturbation, a threshold of effect is reached at which resilience is exceeded, is generally non-linear. This nonlinearity results from complex web of interactions between ecosystem components and the cascade of secondary effects, for example when a species is lost that has a fundamental effect on nutrient cycling and biomass production. When sufficiently extensive, ecosystemic changes can start to affect biogeochemical cycles and alter atmospheric composition, for example.

After total collapse of an ecosystem, Nature may then recover and 'start over' by the process of ecological succession. However, depending on the extent of devastation, the recovery by succession may happen not over human generational time, but over much longer periods.

A key example of ecosystem limits is the potential ability of forest to absorb excess anthropogenic carbon dioxide emissions. Experiments involving manipulations of carbon dioxide levels have shown that young, rapidly growing forest can increase total net primary production by 25%.[26,27] This response may represent the upper limit for forest carbon sequestration.

A crucial aspect of designing with Nature-based infrastructure (in Chapter 5), then, is the need to work within the critical **limiting factors** of ecosystems. Working within these limiting factors is crucial not only for the ecological designing and making of the built environment, but in influencing the form, content, operation and the life-cycle logistics of all human-made designed systems, artefacts and the material used in them. They also affect approaches to the **recovery** and the eventual **biointegration** of all components of the human-made environment back into Nature (**replenishment**) where achievable. These thresholds further should help determine human efforts in **repairing, restoring and stabilising** the damage already inflicted on the natural environment and the **rejuvenation and regeneration** of the natural environment.

Working within the thresholds and limiting parameters of resilience and carrying capacities of Nature is a further factor underlying Ecological Design. But sadly, rather than working within the sorts of limits and thresholds just described, what we have been doing instead, and are ever more rapidly exacerbating, is to progressively diminish the ability of the biosphere to provide us with our life support system. We have done this by:

- **Directly destroying, displacing and fragmenting natural habitats** by the interventions we make in creating our urban areas, transport networks and food productions and material extraction and waste disposal systems.
- **Treating much of the biosphere as an environmental 'sink'** for non-biodegradable anthropogenic waste, and hence greatly altering many ecosystems and ecosystem processes.
- **Degrading the library of life –** biodiversity in all its forms from gene to habitat to process – often **irreversibly** through both of the above processes.[28]
- **Unsustainably exploiting non-renewable natural resources and unsustainably modifying hydrogeochemical cycles.**

Humanity may indeed have already **crossed the critical thresholds** of the resilience and carrying capacities of the biosphere in many respects. The Stockholm Resilience Centre has identified nine such biospheric thresholds with the limits of which we must operate to ensure a sustainable future both for humankind and that of all other species:[29]

- Available usable land.
- Global climate stability.
- Global hydrological cycle.
- Global nutrient cycles (nitrogen and phosphorus).
- Ocean chemical balance (especially pH).
- Stratospheric ozone layer integrity.
- Chemical toxic loading of organisms.
- Air quality (especially with respect to particulates).
- Biodiversity.

DESTRUCTION, DISPLACEMENT AND FRAGMENTATION OF NATURAL HABITATS

We might contend that humans, in comparison to other species, are 'good at