

# DESIGN FOR A LIVING PLANET



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*Opposite: A portion of the Great Barrier Reef from space. Parts of the structure resemble a tree or plant, and that is not a coincidence. Both are complex adaptive systems, and both exhibit fractal geometric properties, as well as other properties that offer important lessons for modern designers. Image: NASA*

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*Cover art: A computer-generated image of a coral reef exhibits an intricate fractal structure.  
Image by Alexis Monnerot-Dumaine, Wikimedia Commons.*

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The Appendix to Chapter 3 is a revised version of an article that appeared on ArchDaily in 2013. Thanks to editor Vanessa Quirk for her courtesy.

The Spanish version of Jorge Luis Borges' one-paragraph essay "On Exactitude in Science" is reproduced from the public domain. It was first published under the pseudonym B. Lynch Davis in the March 1946 edition of *Los Anales de Buenos Aires*, Año 1, No. 3 as part of a piece called "Museo". It was subsequently included in the collection of essays entitled *El Hacedor* (Alianza Editores, Buenos Aires, Argentina, 1960). English translation by one of the authors (N.A.S.) was especially prepared for this book.

Colophons drawn by Nikos A. Salingaros.

Finally, our thanks to editor Susan Szenasy and Metropolis Magazine, who published serialized chapters from this book, where they found a wide readership.



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## Preface

The reader finds collected here a series of essays on twenty related topics that we wrote to introduce designers and design students to new developments in the sciences underlying modern design, with a focus on the design of human settlement. The series was written as a book project with serialized chapters in the web magazine *Metropolis POV*, and then refined for this collection. We were gratified by the relatively wide readership they enjoyed there, and the feedback we received. Our thanks to Metropolis publisher Susan Szenasy and the magazine for running the series, and for helping to raise awareness and interest of the architecture and design communities in such developments.

These topics outline, in a brief and introductory way, the early stages of a remarkable transformation in the science and art of design. It is fueled by insights from many fields, including the sciences of complex adaptive systems, relatively new topics in mathematics such as fractals and networks, biological and medical sciences, the cognitive and psychological sciences, and the rapidly maturing discipline of design science itself. All of this is notably propelled by new developments in software design. At the heart of this development lies a mode of understanding design as more than a specification of assembled parts — and certainly more than a willful artistic expression of favored ideas — but rather, as a transformational operation on self-organizing systems. As we will discuss, this shift in thinking has profound implications.

The craft of such a transformation does have an artistic component, which is complementary to its scientific dimensions. But design in the sense meant here engages with a comprehensible structure, aiming to achieve another state of comprehensible structure that is preferred by the designers and their clients (to echo Herbert Simon's famous definition of design). Such a process is not mysterious, and not subject to the paralyses that seem to grip many design professions today. These self-organizing processes offer us a concrete basis to deal with the great challenges of our time — but only if we first understand the kinds of design problems they pose, and the kinds of tools and approaches that can operate effectively upon them. That is the central lesson that this book documents.



The computer software community is already aware of the use of patterns in design, and many other fields have put into practice many aspects of the other ideas discussed herein. Indeed, there are early signs of a renaissance under way, fueled by new insights about the structures and processes of living systems. However, the architecture and planning communities are unfortunately lagging far behind — stuck in a remarkably obsolete set of theories, fashions, ideologies, and habits of hero-worship, occasionally excused with lip service toward contrary or ironic ideas. This outmoded and irresponsible approach helps to perpetuate a new generation of non-adaptive designs, at a time our species can ill afford them.

It is therefore our hope that these essays will spark a more genuine interest in the wonderful new developments that are supported by science, and informed by various different academic disciplines. The aim is to educate designers working in all applications but with a focus on the built environment — letting readers know of the existence of these new approaches to design, and alerting them to the possibilities of new methodologies for their craft.

Those who are trained as architects will inevitably find here some criticism, on occasion trenchant. We apologize in advance, yet this is unavoidable. At present, orthodox architectural practice is still severely constrained by the outmoded design theories and form languages inherited from the early 20th Century. Where this persistent orthodoxy contradicts scientific findings — or worse, uses such findings merely to generate alluring new packaging around the same failing practices — we are compelled to point this out. This series of essays is not, however, primarily intended as criticism of current practice; rather, it is meant to open genuine new possibilities, at a time when that seems most needed.



## Introduction

# DESIGN FOR A TECHNOLOGY OF LIFE

*“People used to say that just as the 20th century had been the century of physics, the 21<sup>st</sup> century would be the century of biology... We would gradually move into a world whose prevailing paradigm was one of complexity, and whose techniques sought the co-adapted harmony of hundreds or thousands of variables. This would, inevitably, involve new technique, new vision, new models of thought, and new models of action. I believe that such a transformation is starting to occur... To be well, we must set our sights on such a future.”*

— Christopher Alexander, *The Nature of Order*.

As we write this in 2014, the world’s major economies seem to be emerging finally from the historic recession and global financial crisis beginning in 2008. There is a prevailing sense that we have “dodged a bullet” and — with a few tweaks to financial regulations and the like — we can now resume life as before. Operationally, we have resumed all our previous assumptions that human occupation of the planet is perfectly fine in the broader sense.

Yet there are clear warning signs that not enough has changed, and that, if we do not learn the lessons of the recent past and reform our ways, we may soon enough be in for a repeat, or much worse. Indeed, the near-catastrophic events of 2008 now appear as a kind of “warning shot across the bow”, demonstrating, to those who care to notice, that deeper systemic reforms are needed.

We are not speaking only of changes in financial regulations, or changes in economic policy. The Ponzi-like structure of our current economics has its roots in a deeper reality: the Ponzi-like structure of our consumption, depletion, and degradation of the planet’s resources, and the set of resulting catastrophes that mounting evidence now shows are ever more likely.

We must face the fact that today we are still far from a sustainable basis for our economics, for our technologies, and ultimately, for our

way of life: the way we go about settling and living on the planet, and using its resources. In spite of our aspirations, we are far from anything like “sustainable design”.

Even for those who understand this reality, however, there is little agreement about how we should go about making the changes needed. Indeed, intense debate about the very nature and extent of the challenge we face is taking place. Is it merely a matter of adding new sustainability technologies here and there, and perhaps a few more new rules about debt and finance, to our existing systems? Or is our challenge more fundamental? Will we have to make more pivotal changes to the “operating system” by which we acquire and transform resources — and if so, how can that be done without causing profound disruption?

This book examines the growing body of evidence, developed by a growing chorus of well-informed people, suggesting that the transformation must necessarily be a broad one. According to this argument, we must somehow deeply transform the failing technology that we have been using to structure our world (including our economic technology). We need to re-evaluate in order to change, and re-form, our knowledge of making, our *techne + logos* — what is, at heart, our technology, and especially, our design technology.

More than that, we must fundamentally re-assess how we think about the process of design — particularly as it relates currently (and pathologically) to the other failing systems of culture and nature around us. This book explores some of the key topics surrounding that central idea. Only then, having analyzed the design process, can we begin to explore how to make changes that are as gentle and minimally disruptive as possible.

There is good news to share, in spite of our planet-scale worries: we do have powerful alternatives at our disposal. They come from the inherent resources of natural and biological processes, and the astonishing and very promising lessons they offer to us today. Indeed, there is real promise of an imminent revolution — one capable of delivering a richer, better-adapted, healthier world. The challenge is to understand these processes, and make use of them in a new revitalized process of design.

In fact, the core conclusion of the findings reported in this book is revolutionary: *sustainability depends upon the geometry of design*. When the new tools presented here are internalized, the creative output — innovative design — better fits into the continuity of life on Earth, rather than opposing and threatening it.

This is a startling reversal of conventional thinking. Most people suppose the geometric design of a toaster or a car has no real effect on the future of society. But these elements are embedded in a larger geometrical system, created by a prevailing design philosophy. When the same design philosophy is unconsciously applied to design a city, it produces dangerously unnatural objects on a global scale.

Nevertheless, beneath the surface of continuing “business as usual”, remarkable progress is actually being made. But we must look for it, and actively encourage and apply it.

\* \* \*

In a sense this book is about science in the broadest definition of the word: the effort to gain useful and reliable knowledge about the world, and our possible actions within it. We are not discussing — except in passing — “technocratic” science: the application of research to making ever more things, or merely to reduce the world to ever-smaller seemingly-mechanical parts. (As a careful and specific tool, such reductionism has its place, as long as it doesn’t dominate and replace systems thinking). We speak instead of science as a useful lens on nature, and our place within that nature as active agents of its structuring. In that sense this is a book about “design science”, and about the philosophy of design.

To that end we explore promising new design technologies, and hopeful transformations of old ones. We examine emerging fields like biophilia and evidence-based design, new understanding of phenomena like networks and fractals, and concrete examples of new processes, and new techniques to employ very old processes, to take on our disastrous problems. Our civilization is at last beginning to tease out the useful structural lessons offered by natural systems.

These new insights and approaches guide us in developing new strategies that can transform the current egregiously failing technologies of design, and begin the necessary transition. Our goal is a technology that is not overly reliant upon an abstract (and dangerously unrealistic) ideal of endless consumption and depletion, but is equally able to produce a world of regeneration. That is to say, we can design for ourselves an economics that does not merely exploit resources, but also replenishes them.

We must change, therefore, from a *depletion economics* to a *repletion economics*.

In that context, we will examine the concept of *economies*, including the familiar economies of *scale* and *standardization*. These have been the powerful agents of modernity, creating the world we know today. But as discussed herein, humanity has neglected two other fundamental economies, the economies of *place* and *differentiation*. By this critical omission we have set in motion catastrophic malfunctions in the adaptivity of structures in our world. That has led directly to a runaway depletion cycle — and it is this runaway cycle that we must now repair.

Related to this, we must redesign critical elements of our economic systems, particularly those that value (or fail to value) externalities, like damage to the resources on which all economics (and all life) ultimately depends. Though the full discussion of the needed economic transition is beyond the scope of this book, we can begin appropriately with the new understanding of design, and design science.

Extremely promising lessons come from the emerging new understanding of how natural systems generate form. They do so in a way that is quite distinct from the ways that we humans typically generate form, especially when it comes to today's "modern" technology. This distinction does not arise simply because human beings are different from nature, by virtue of having culture, technology, and so on. It arises because we have adopted — very recently, in historic terms — certain models of structure that are very productive in limited ways, but are very dangerous in other ways. We must now revise them, before they fail catastrophically,

and destroy our world as we know it. As a species, we must *learn* — growing out of an industrial adolescence into a more mature adulthood.

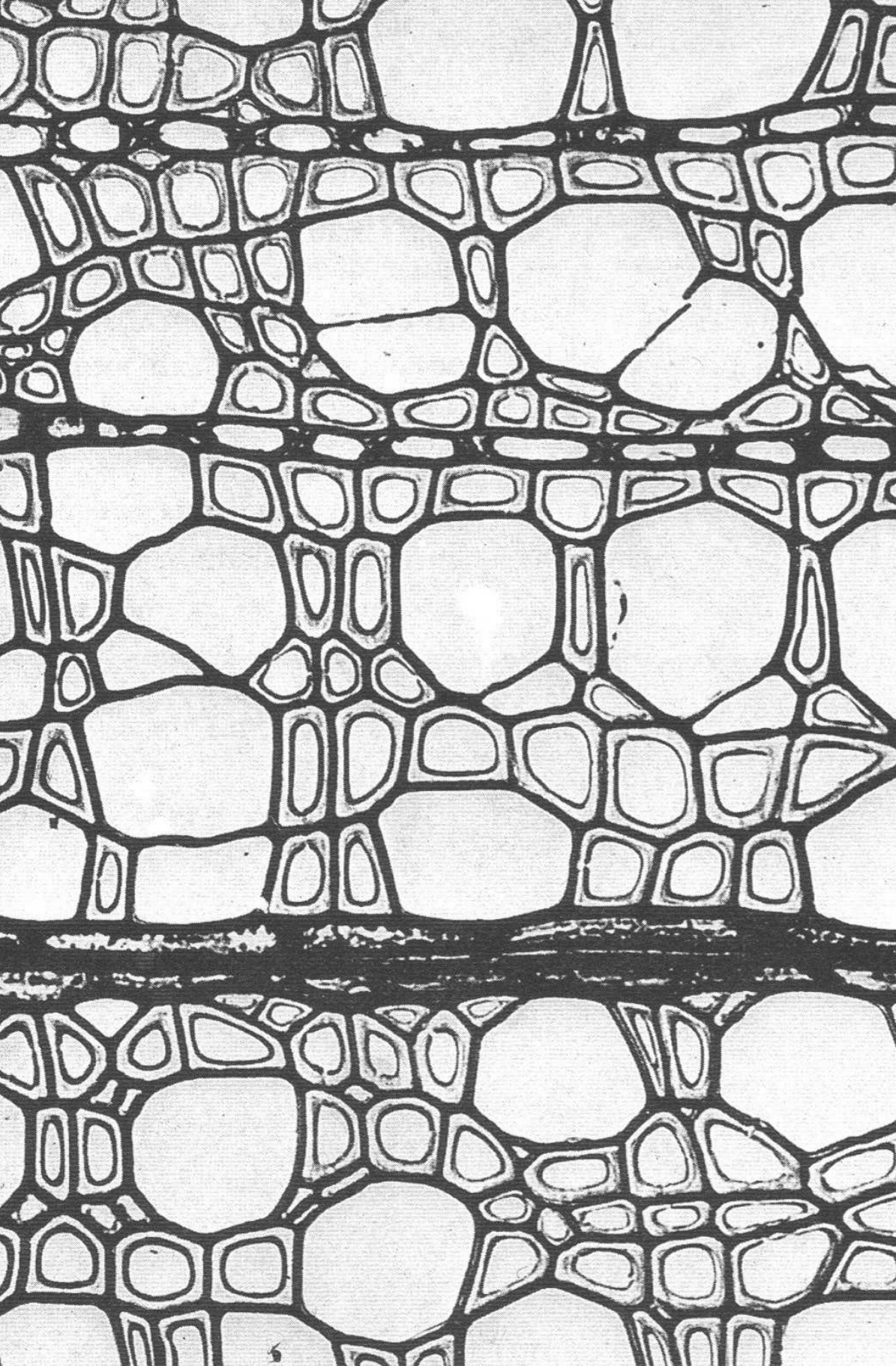
Another related theme that we will discuss was described by the philosopher and mathematician Alfred North Whitehead as “a right adjustment of the process of abstraction”. We use abstractions very effectively to create economies of scale and standardization — but there are dangers. In a real sense, an abstraction is an idea that has been standardized, and it can in turn be used to generate large-scale copies. But if it is not adapted to place and to its nuances (a process that creates differentiation) then the structure will very likely generate mistakes, errors, and damage. Viewed narrowly, such a structure is pleasing, entertaining, and sometimes even valuable. Viewed broadly, however, it can be seen to produce slow but catastrophic damage to the life around it.

We will discuss a number of insights about the process of design, and the implications of scientific work over the last half-century or so, which point us in hopeful new directions. As a case in point we will discuss in detail the work of Christopher Alexander, who has illustrated and taken forward the implications of these findings, more clearly and directly than anyone else we know.

Alexander’s work amounts to a kind of technological critique, revolving around the observation that we’re doing something fundamentally wrong in the way we *make things*. We’re substituting an oversimplified model of structure-making — one more closely related to our peculiar hierarchically limited way of conceiving abstract relationships — in place of the kinds of transformations that occur regularly in the Universe and on the Earth, and especially in biological systems. More specifically, our present-day design paradigm is a much more limited, fragmentary, dangerous form of this larger kind of transformation. This is what is generating a slowly unfolding planetary disaster.

That’s where this discussion touches upon so many interrelated aspects of what’s happening in our world today — economically, ecologically, and culturally. But it returns, inevitably, to the question of *design* — of how we as humans can transform, as Herbert Simon put it, “existing states into preferred ones”. That’s the exhilarating revolution that we’ll explore in this volume.







# PART I: TOWARD RESILIENT ARCHITECTURES

*This section explores the problem of “resilience” in our time, and how we can actually achieve it in our designs, by learning from the resilience of natural systems.*

## **1. Biology Lessons**

*Lessons from comparisons between human form-generating systems and non-human ones. Biological systems offer lessons for design strategies towards adapting to an age of climate change and resource depletion.*

## **2. Why Green Often Isn't**

*An instructive problem with human form-generating systems, and how they fail to achieve sustainability, in spite of stated intentions.*

## **3. How Modernism Got Square**

*More specifics of the current predicament, and the history of how we got here. Those who are trained as architects will inevitably find here some criticism, on occasion trenchant, of their favorite idols.*

## **4. The Geometry of Resilience**

*What we will have to do to achieve resilience in the design of forms for the future.*

## **5. Agile Design**

*Lessons on the process of generating resilient forms, using the “agile” methods identified by the software community.*

*Opposite: The resilient structure of wood is revealed under a microscopic photo. Because wood is a living structure, it is capable of self-organization and self-repair. The structure we see here is an evolutionary adaptive response to the chaotic forces that trees and other plants must endure. We have much to learn from such processes, and the structures they produce. Image courtesy of the Center for Environmental Structure.*

# Chapter 1

## BIOLOGY LESSONS

The word “resilience” is bandied about these days among environmental designers. In some quarters, it’s threatening to displace another popular word, “sustainability”. This is partly a reflection of newsworthy events like Hurricane Sandy, adding to a growing list of other disruptive events like tsunamis, droughts, and heat waves.

We know that we can’t design for all such unpredictable events, but we could make sure our buildings and cities are better able to weather these disruptions and bounce back afterwards. At a larger scale, we need to be able to weather the shocks of climate change, resource destruction and depletion, and a host of other growing challenges to human wellbeing.

We need more resilient design, not as a fashionable buzzword, but out of necessity for our long-term survival.

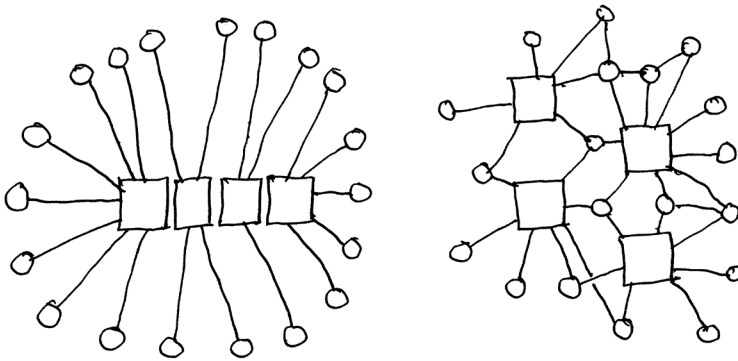


*Figure 1.1. An illustration of a resilient architecture: fossils of a marine ecosystem from the Permian period, about 250 to 300 million years ago. These ecosystems were resilient enough to endure dramatic changes over millions of years. (Image by Professor Mark A. Wilson/Wikimedia.)*

Aside from a nice idea, what is resilience really, structurally speaking? What lessons can we as designers apply towards achieving it? In particular, what can we learn from the evident resilience of natural systems? Quite a lot, it turns out.

### **Resilient and non-resilient systems**

Let's start by recognizing that we have incredibly complex and sophisticated technologies today, from power plants, to building systems, to jet aircraft. These technologies are, generally speaking, marvelously stable within their design parameters. This is the kind of stability that C. S. Holling, the pioneer of resilience theory in ecology, called "engineered resilience". But they are often not resilient outside of their designed operating systems. Trouble comes with the unintended consequences that occur as "externalities", often with disastrous results.

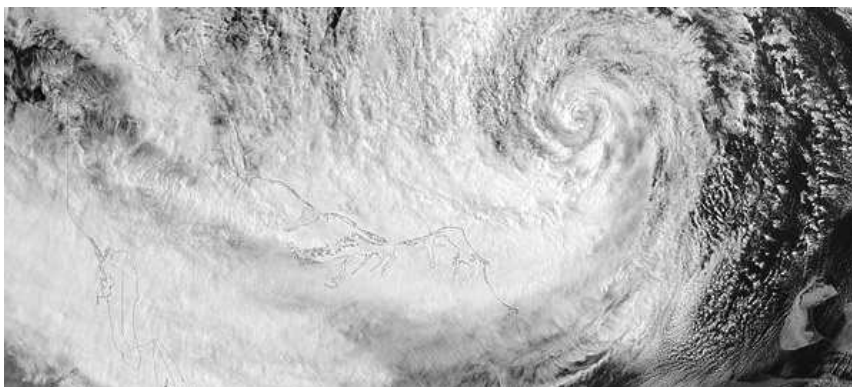


*Figure 1.2. On the left, an over-concentration of large-sale components; on the right, a more resilient distributed network of nodes. (Drawing by Nikos Salingaros.)*

A good example is the Fukushima nuclear reactor group in Japan. For years it functioned smoothly, producing reliable power for its region, and was a shining example of "engineered resilience". But it did not have what Holling called "ecological resilience", that is, the resilience to the often-chaotic disruptions that ecological systems

have to endure. One of those chaotic disruptions was the earthquake and tsunami that engulfed the plant in 2010, causing a catastrophic meltdown. The Fukushima reactors are based on an antiquated U.S. design from the 1960s, dependent upon an electrical emergency cooling system. When the electricity failed, including the backup generators, the emergency control system became inoperative and the reactor cores melted. It was also a mistake (in retrospect) to centralize power production by placing six large nuclear reactors next to each other.

The trouble with chaotic disruptions is that they are inherently unpredictable. Actually we can predict (though poorly) the likelihood of an earthquake and tsunami relatively better compared to other natural phenomena. Think of how difficult it would be to predict the time and location of an asteroid collision, or more difficult yet, to prepare for the consequences. Physicists refer to this kind of chaos as a “far from equilibrium condition”. This is a problem that designers are beginning to take much more seriously, as we deal with more freakish events like Hurricane Sandy — actually a chaotic combination of three separate weather systems that devastated the Caribbean and the eastern coast of the U.S., in 2012.



*Figure 1.3. Hurricane Sandy on 28 October 2012. (NASA image courtesy LANCE MODIS Rapid Response Team at NASA GSFC.)*

As if these unforeseen dangers were not enough, we humans are contributing to the instability. An added complication is that we ourselves are now responsible for much of the chaos, in the form of our increasingly complex technology and its unpredictable

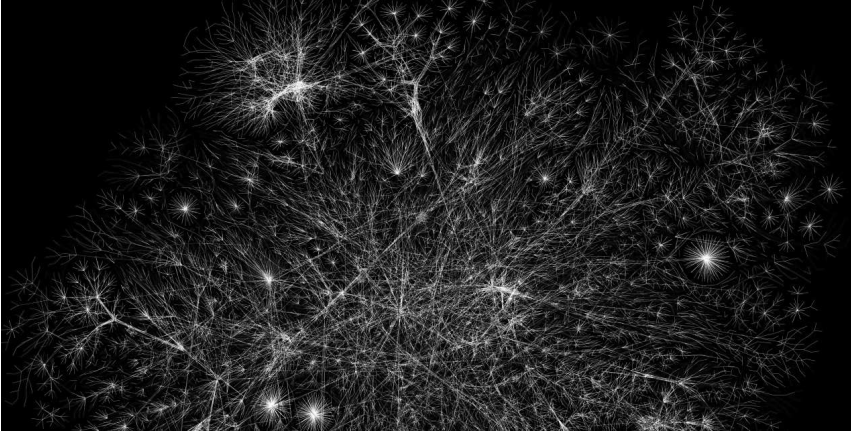
interactions and disruptions. Climate change is one consequence of such disruptions, along with the complex and unstable infrastructures we have placed in vulnerable coastal locations. (In fact, Japan's technological infrastructure has been heavily damaged over a much wider area by the chaotic "domino" effects of the Fukushima disaster.) Our technological intrusion into the biosphere has pushed natural systems into conditions that are far from equilibrium — and as a result, catastrophic disruptions are closer than ever.

### **Properties of Biological Systems**

So what can we learn from biological systems? They are incredibly complex. Take, for instance, the rich complexity of a rainforest. It too generates complicated interactions among many billions of components. Yet many rainforests manage to remain stable over many thousands of years, in spite of countless disruptions and "shocks to the system". Can we understand and apply the lessons of their structural characteristics?

It seems we can. Here are four such lessons extracted from distributed (non-centralized) biological systems that we will discuss in more detail below:

1. ***These systems have an inter-connected network structure.***
2. ***They feature diversity and redundancy*** (a totally distinct notion of "efficiency").
3. ***They display a wide distribution of structures across scales,*** including fine-grained scales.
4. ***They have the capacity to self-adapt and "self-organize".*** This generally (though not always) is achieved through the use of genetic information.

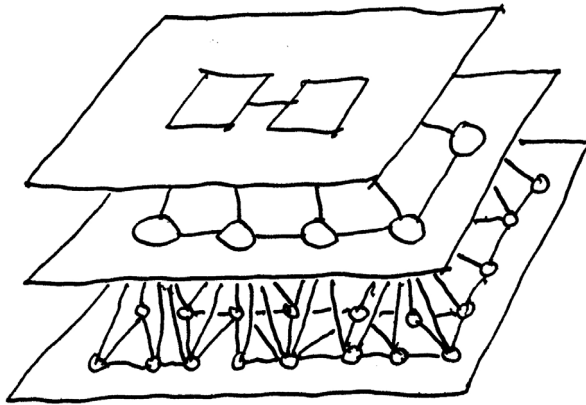


*Figure 1.4. Map of the Internet: a paradigmatic resilient network in part because it is scale-free and redundant. (Image by The Opte Project/ Wikimedia.)*

The Internet is a familiar human example of an inter-connected network structure. It was invented by the U.S. military as a way of providing resilient data communications in the event of attack. Biological systems also have inter-connected network structures, as we can see for example in the body's separate blood and hormone circulation systems, or the brain's connected pattern of neurons. Tissue damaged up to a point is usually able to regenerate, and damaged brains are often able to re-learn lost knowledge and skills by building up new alternative neural pathways. The inter-connected, overlapping, and adaptable patterns of relationships of ecosystems and metabolisms seem to be key to their functioning.

Focusing upon redundancy, diversity, and plasticity, biological examples contradict the extremely limited notion of "efficiency" used in mechanistic thinking. Our bodies have two kidneys, two lungs, and two hemispheres of the brain, one of which can still function when the other is damaged or destroyed. An ecosystem typically has many diverse species, any one of which can be lost without destroying the entire ecosystem. By contrast, an agricultural monoculture is highly vulnerable to just a single pest or other threat. Monocultures are terribly fragile. They are efficient only as long as conditions are perfect, but liable to catastrophic failure in the long term. (That may be a pretty good description of our current general state!)

Why is the distribution of structures across scales so important? For one thing, it's a form of diversity. By contrast, a concentration at just a few scales (especially large scales) is more vulnerable to shocks. For another thing, the smaller scales that make up and support the larger scales facilitate regeneration and adaptation. When the small cells of a larger organ are damaged, it's easy for that damaged tissue to grow back — rather like repairing the small bricks of a damaged wall.



*Figure 1.5. Distribution of inter-connected elements across several scales. (Drawing by Nikos Salingaros.)*

Self-organization and self-adaptation are also central attributes of living systems, and of their evolution. Indeed, this astonishing self-structuring capacity is one of the most important of biological processes. How does it work? We know that it requires networks, diversity, and distribution of structures across scales. But it also requires the ability to retain and build upon existing patterns, so that those gradually build up into more complex patterns.

Often this is done through the use of genetic memory. Structures that code earlier patterns are re-used and re-incorporated later. The most familiar example of this is, of course, DNA. The evolutionary transformation of organisms using DNA gradually built up a world that transitioned from viruses and bacteria, to vastly more complex organisms.

## Applying the lessons to resilient human designs

How can we apply these structural lessons to create resilient cities, and to improve smaller vulnerable parts of cities by making them resilient? Developing the ideas from our previous list, resilient cities have the following characteristics:

**(1) They have inter-connected networks of pathways and relationships.** They are not segregated into neat categories of use, type, or pathway, which would make them vulnerable to failure.

**(2) They have diversity and redundancy of activities, types, objectives, and populations.** There are many different kinds of people doing many different kinds of things, any one of which might provide the key to surviving a shock to the system (precisely which can never be known in advance).

**(3) They have a wide distribution of scales of structure,** from the largest regional planning patterns to the most fine-grained details. Combining with (1) and (2) above, these structures are diverse, inter-connected, and can be changed relatively easily and locally (in response to changing needs). They are like the small bricks of a building, easily repaired when damaged. (The opposite would be large expensive pre-formed panels that have to be replaced in whole.)

Following from (3), **they (and their parts) can adapt and organize in response to changing needs on different spatial and temporal scales, and in response to each other.** That is, they can “self-organize”. This process can accelerate through the evolutionary exchange and transformation of traditional knowledge and concepts about what works to meet the needs of humans, and the natural environments on which they depend.

Resilient cities evolve in a very specific manner. They retain and build upon older patterns or information, at the same time that they respond to change by adding novel adaptations. They almost never create total novelty, and almost always create only very selective novelty as needed. Any change is tested via selection, just as changes in an evolving organism are selected by how well