Algorithmic Sustainable Design: The Future of Architectural Theory.

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Lecture 3

A. Universal distribution of sizes

B. Fractal design, ornament, and biophilia

C. Sustainable systems

A. Universal distribution

- Although different from *universal scaling*, both concepts are related through fractals
- Count how many components there are in a complex system, according to their relative size — defines a distribution
- All components work together to optimize the system’s function

Correct distribution helps systemic stability

- Surprising result for most people:
- *The stability of a system depends upon the relative numbers and the distribution of sizes of its components*
- Stability also depends on other factors such as system interconnectivity on the same level, and among different levels

Common features

- *Universal distribution = inverse-power law*
- Central quality that contributes towards sustainability in ecosystems
- Contributes stability to artificial complex systems

Universal distribution

- An enormous number of natural and artificial complex systems obey an inverse-power law distribution
- Invertebrate nervous systems, mammalian lungs, DNA sequences, ecosystems, rivers
- Internet, incoming webpage links, electrical power grids

Fractal structure

- Pure fractals are abstract geometrical objects
- All fractals obey a universal distribution
- But there are many more non-geometrical systems that obey the universal distribution
- We may describe all stable complex systems as having “fractal properties”

Key question in design

- Every design contains different elements on different scales: structural, functional, etc.
- Is there any rule for determining how many elements should exist on each scale?
- *YES*. For adaptive design, this decision is not only intuitive, but depends upon mathematics
- NOT style-driven

Design as bricolage

- Once we have all the appropriate pieces, we can assemble them to form a whole
- Conversely, visualizing a form, we know better how to subdivide it into components
- Knowing how many pieces of each size we need solves one problem; the only question is how they all fit together!

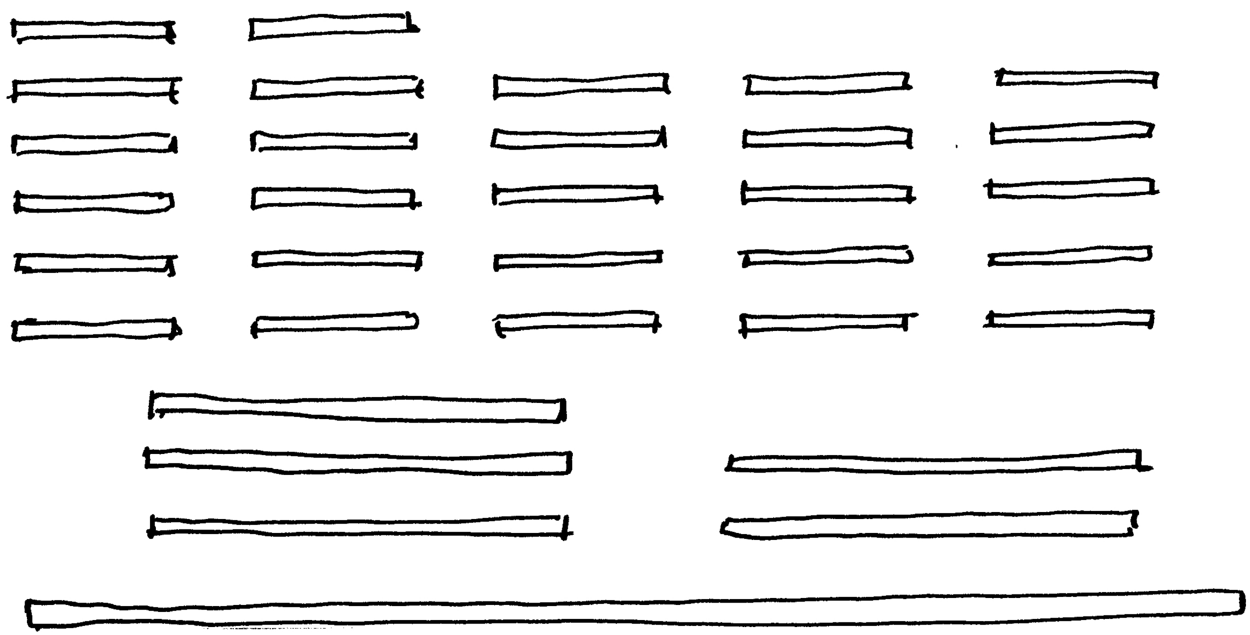
Architectural systems

- Go with a tape measure to an existing building and find its definite scales
- Say, there are several components or subdivisions of about 90cm
- Count how many there are
- Next scale is defined by components of 25cm — how many of these?

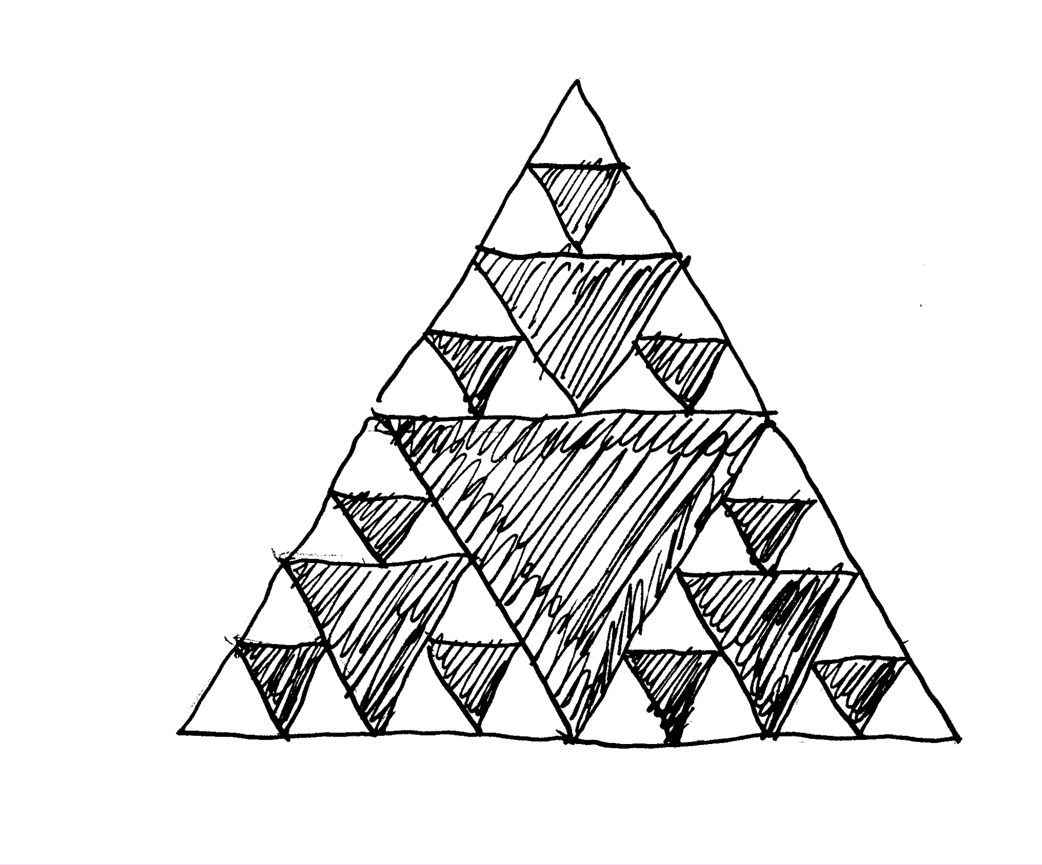
Sustainability

- Much deeper question — is a system sustainable?
- We will examine the mathematical structure of sustainable systems
- It turns out that one common feature is how many components they have of each size — *UNIVERSAL DISTRIBUTION OF SIZES*

Universal distribution



Sierpinski gasket (showing only three scales)



Revisit Sierpinski gasket

- This fractal has an infinite number of smaller and smaller equilateral triangles, pointing both up and down
- All the black triangles that point down are self-similar
- "*HOW MANY SELF-SIMILAR TRIANGLES ARE THERE OF EACH SIZE*?"
- They can be easily counted

Universal distribution in the Sierpinski triangle

- Let p_i be the number of design elements of a certain size x_i
- Count how many downward-pointing black triangles there are in the Sierpinski gasket
- Each triangle's size is $x_i = (1/2)^{i+1}$
- The number of triangles having this size equals $p_i = 3^i$

Inverse power-law

- ***The number of self-similar triangles at each size is related to their size***
- The distribution is universal, and is known as an inverse power-law
- $p_i = 0.33/(x_i)^m$, where $m = 1.58$
- Here, the index m is equal to the fractal dimension of the Sierpinski gasket
- $m = D = \ln 3/\ln 2 = 1.58$

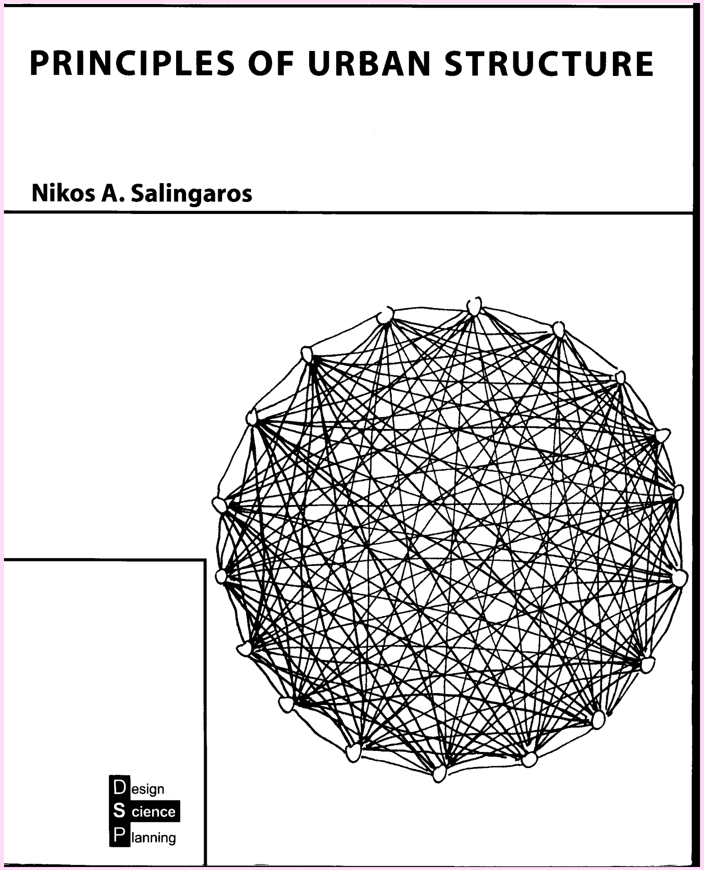
In simple terms

- Smaller design elements are more numerous than larger ones
- Their relative numbers are linked to their size: “***the multiplicity of an element (design or structural) having a certain size is inversely proportional to its size***”
- I propose that this rule applies to all adaptive design, for systemic reasons

"A Universal Rule for the Distribution of Sizes"

- Derived in Chapter 3 in my book "*Principles of Urban Structure*", Techne Press, Amsterdam, 2005
- Work done in collaboration with physicist Bruce J. West, who earlier worked with Jonas Salk

“Principles of Urban Structure”



Obvious in cities

- Traditional cites contain a few large buildings, many average-size buildings, very many smaller buildings, and an enormous number of structures on smaller scales: kiosks, fountains, memorials, columns, low walls, benches, bollards, etc.
- All of these cooperate to make a living city loved by human beings

Networks

- Living cities also function as networks
- Connective paths obey universal distribution: a few highways, many roads, many more local streets, even more alleys, bicycle paths, and footpaths
- Modern cities skewed towards the large scale become hostile to humans

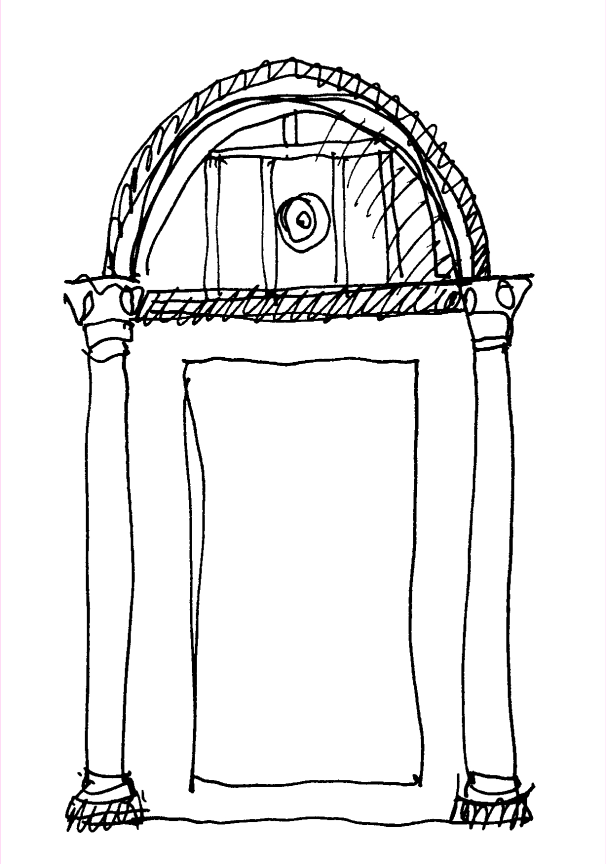
Destruction of pedestrian realm

- Very simple explanation: ***urbanists erased geometry and network connectivity on the human range of scales*** — 2 m to 1 cm
- Violated universal distribution found in traditional cities
- Post World-War II interventions privilege the largest scale and eliminate the small

B. Fractal design, ornament, and biophilia

- Which subdivisions or articulations on smaller scales make the user feel more comfortable in a space?
- Substructure conforms to *universal scaling* and *universal distribution*
- Intermediate scales are tectonic
- Smaller scales will be ornamental

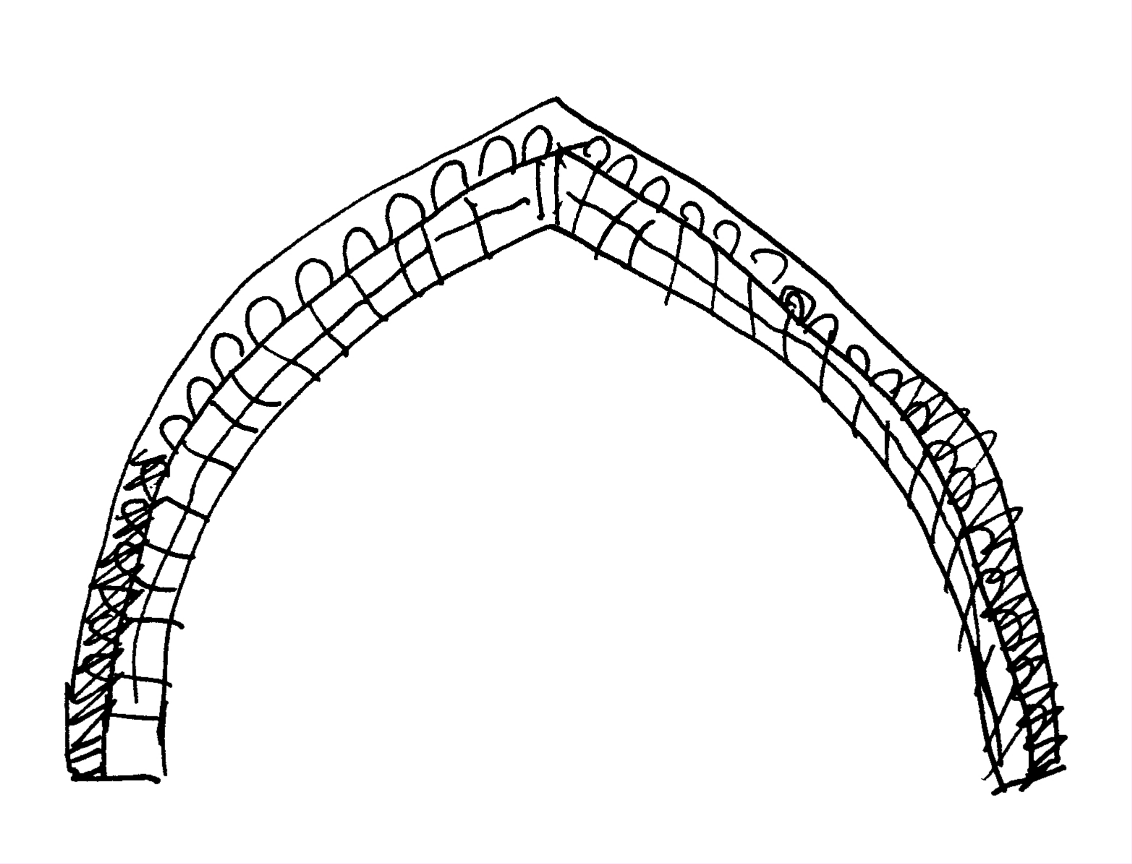
Ornament is necessary for coherence



Lack of ornament is unnatural

- Some architects will say "We want our buildings to look unnatural!"
- Therefore, not a strong enough argument
- But lack of ornament violates universal distribution, which is necessary for system stability
- No architect can counter this argument!

Ornament necessary for mathematical stability



Stability from biophilia

- Biologist Edward O. Wilson used the term "Biophilia" to describe an innate connection between all living beings
- More specifically, human beings have a biologically-founded link to other life-forms
- The connection is genetic — it resides in the common parts of our DNA

Human sensory systems

- Have evolved to respond to natural geometries of fractals, colors, scaling, symmetries
- Fine-tuned to perceive positive aspects (food, friends, mates) and negative aspects (threats) of the environment
- Also fine-tuned to detect pathologies of our own body, signaled by the departure from natural geometries

Biophilia and Health

- Human beings require contact with the geometry of biological structures
- Experiments in hospitals show much faster post-operative healing in rooms looking out at trees
- Social and mental health deteriorates in nature-less and minimalist surroundings

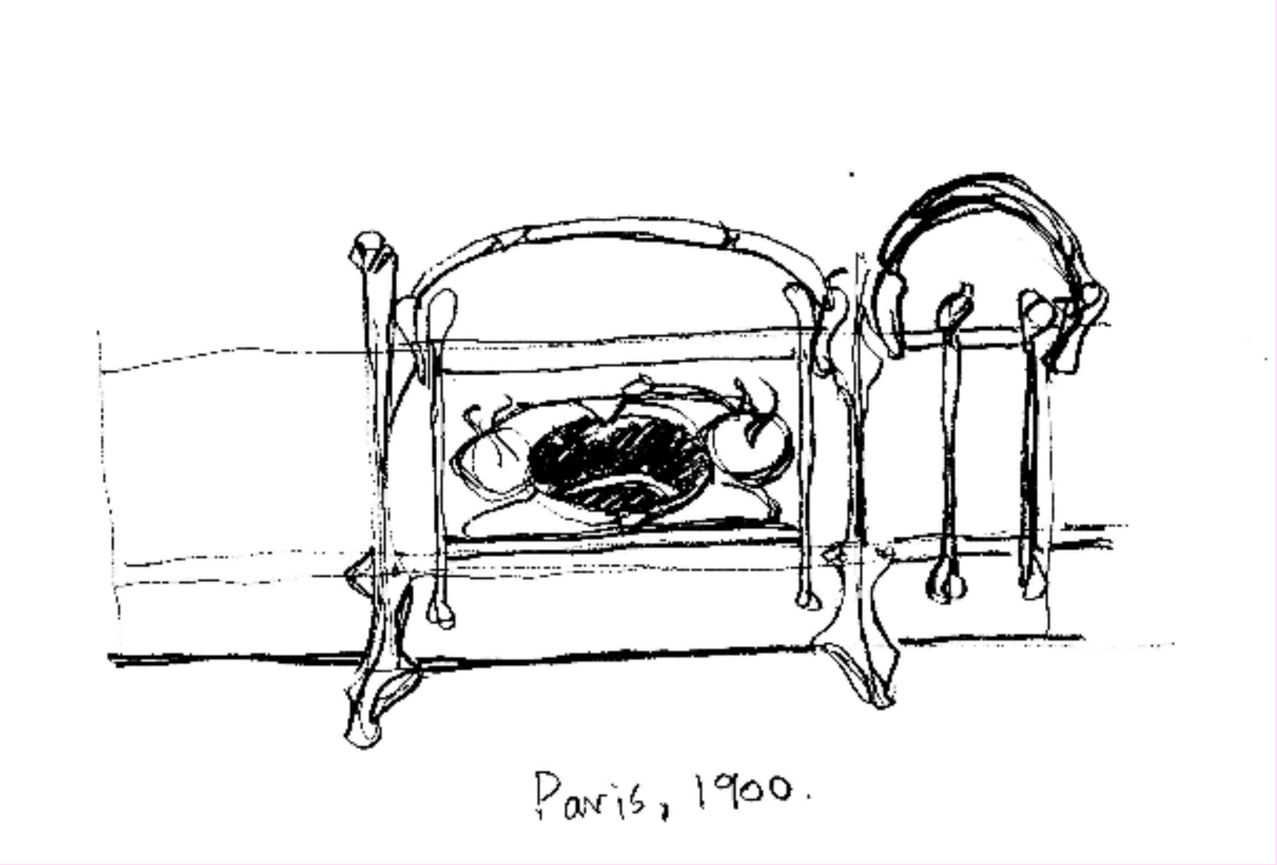
Healthy environments

- A healthy mind in a healthy body — which is situated in a healthy environment!
- Positive emotional response to the environment reduces stress and thus raises resistance to disease (external & internal)
- Emotional regeneration: the feelings inside a great Mosque, Cathedral, or Temple

Biophilic Ornament

- First ornament was copied from plants
- First cave art represented other life forms: bears, bison, cattle
- Abstract early art uses the same mathematical structure as natural forms
- Hierarchy; fractal scaling; symmetries, rhythm

Biophilia in Art Nouveau Architecture



Fractal dimension

- The Sierpinski gasket has dimension D = 1.58 (instead of 2 for a regular triangle)
- A fractal gasket is punched full of holes
- Its dimension is therefore SMALLER THAN THAT OF A PLANE, where $D = 2$
- We could use a fractal line to fill in some area, getting an accretive fractal with $D > 1$ (instead of $D = 1$ for a straight line)

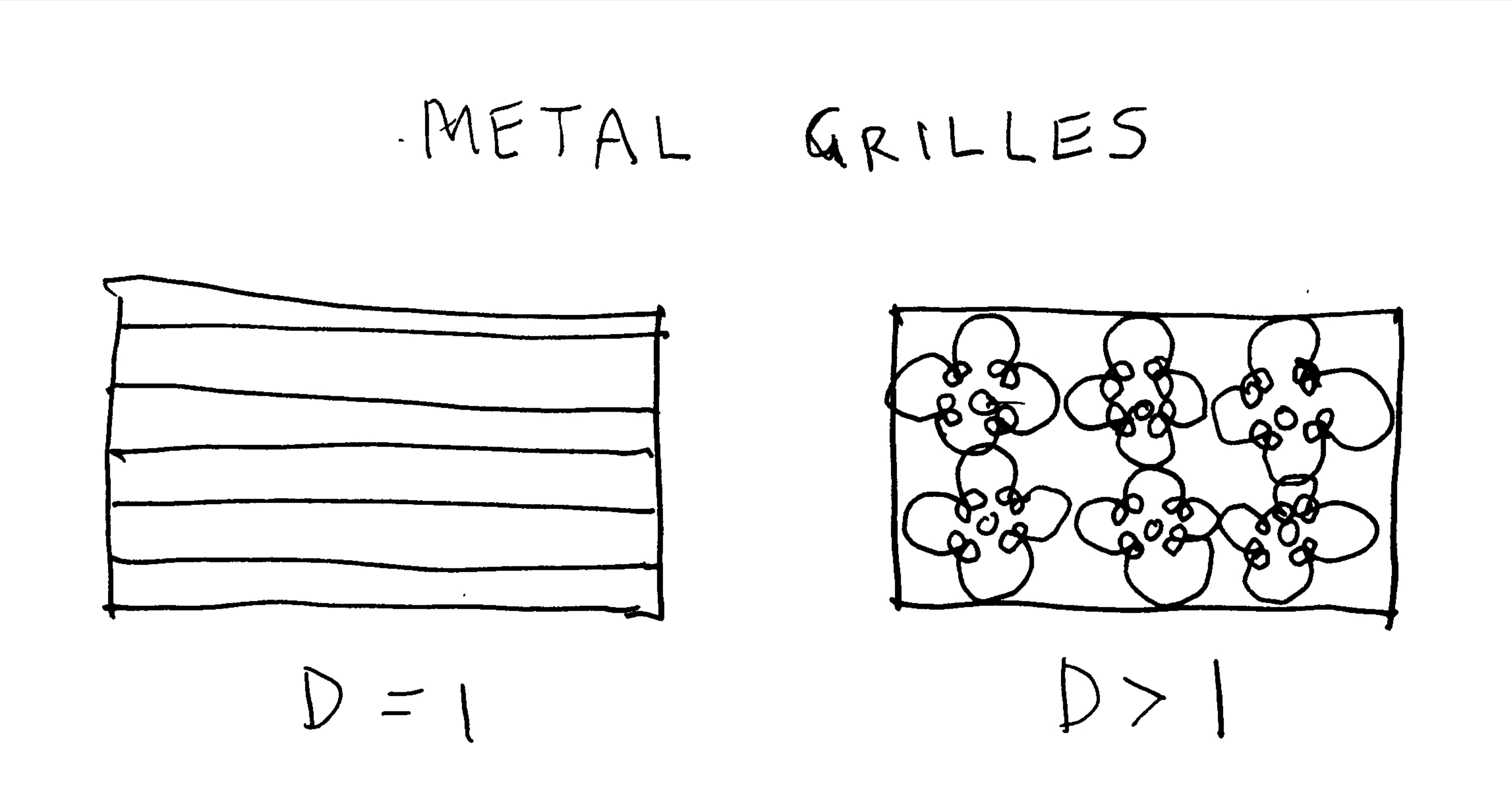
Fractal dimension (cont.)

- Recall that $D = 1$ for a straight line, $D = 2$ for a plane, and $D = 3$ for a solid volume
- $D = 1.58$ for the Sierpinski gasket, which has properties between a line and a plane
- All biological, natural, and (most) architectural forms are fractals — lie in-between smooth lines, planes, and volumes!

What this means for architecture

- Adaptive buildings have:
- *lines of dimension not exactly* 1
- *surfaces of dimension not exactly* 2
- *volumes of dimension not exactly* 3
- Architectural ornament makes sure that geometry is dimensionally “in-between”

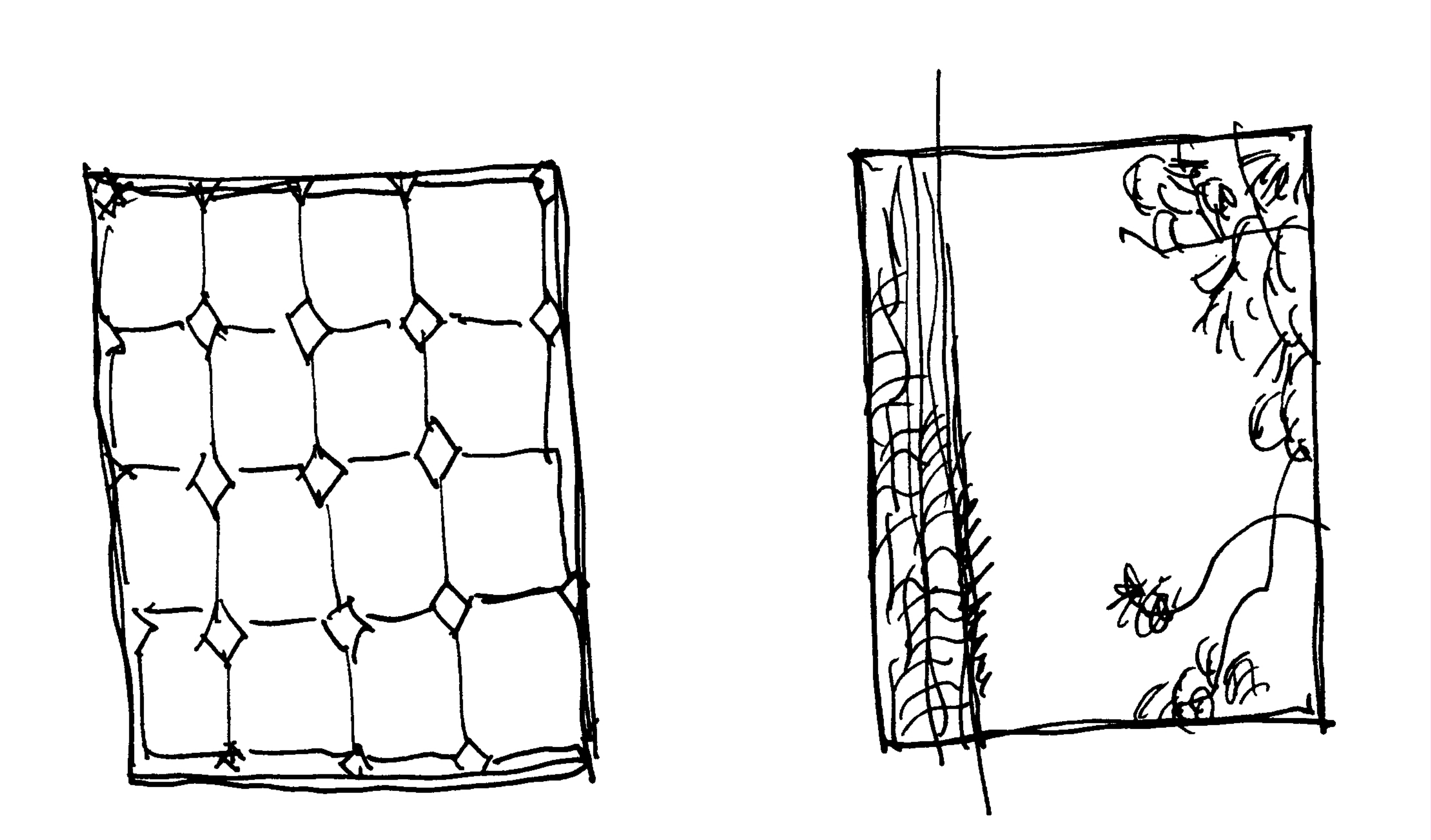
Two different metal grilles



Fractal windows

- There is a reason for using ornament in utilitarian components
- Plate-glass window shocks by juxtaposing 0-D rectangle next to 2-D wall
- Net curtains, small window panes & plants raise fractal dimension from 0 to > 1, enhance view to the outside, and also connect better to the surrounding wall

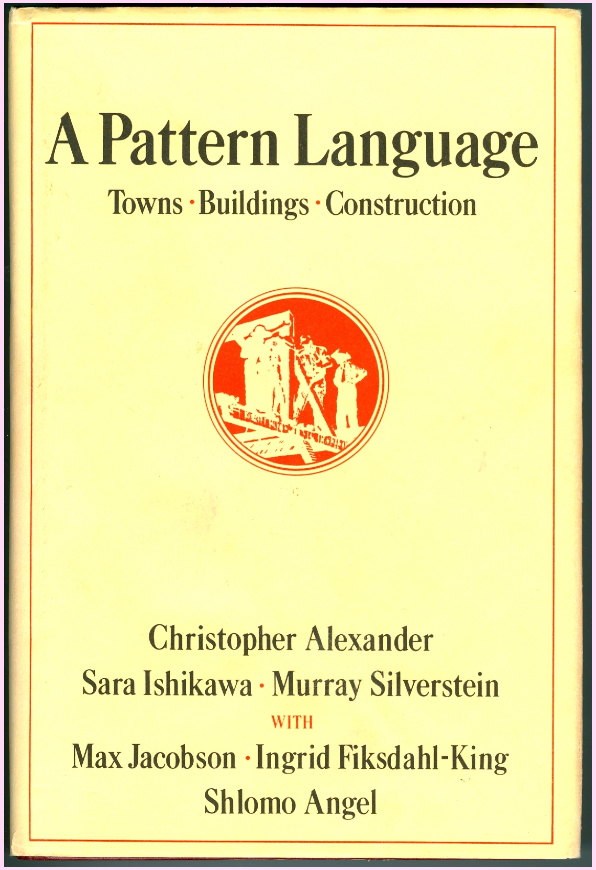
Windows with fractal structure



Windows come from Alexander's "A Pattern Language"

- PATTERN 238: FILTERED LIGHT
- PATTERN 239: SMALL PANES
- Two of Alexander's 253 patterns given in his monumental "*A Pattern Language*", Oxford University Press, New York, 1977
- Anticipated biophilic design

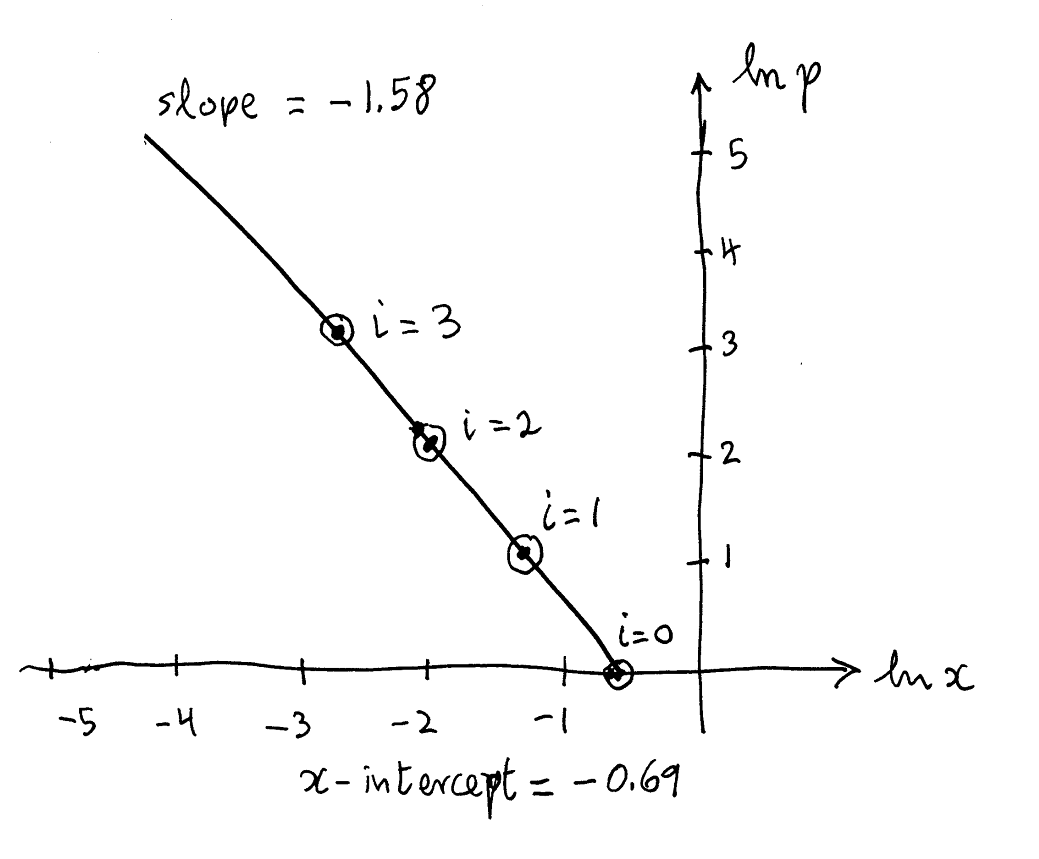
"A Pattern Language"



Morphological features

- Plot multiplicity p (how many) versus size of elements x on a log-log graph
- For a fractal distribution, we obtain evenly-spaced points on a line with negative slope $-m$, where m is the fractal dimension
- For the Sierpinski gasket, the slope of the graph equals $-D = -m = -1.58$

Log-log plot of p versus x



Interpret graph

- Bottom point is the largest component
- Higher points represent smaller components
- Smaller components have higher multiplicity

Good check for design

- Count the multiplicities of all design elements
- Plot them against their size on a log-log graph
- One criterion for coherence is for the design to show evenly-spaced points on a straight line with negative slope

Two laws related

- 1. Straight line in the log-log graph shows ***universal distribution***
- 2. Evenly-spaced points on the log-log graph show ***universal scaling***
- A design or actual structure needs to satisfy both of these related concepts
- This graph checks for them together

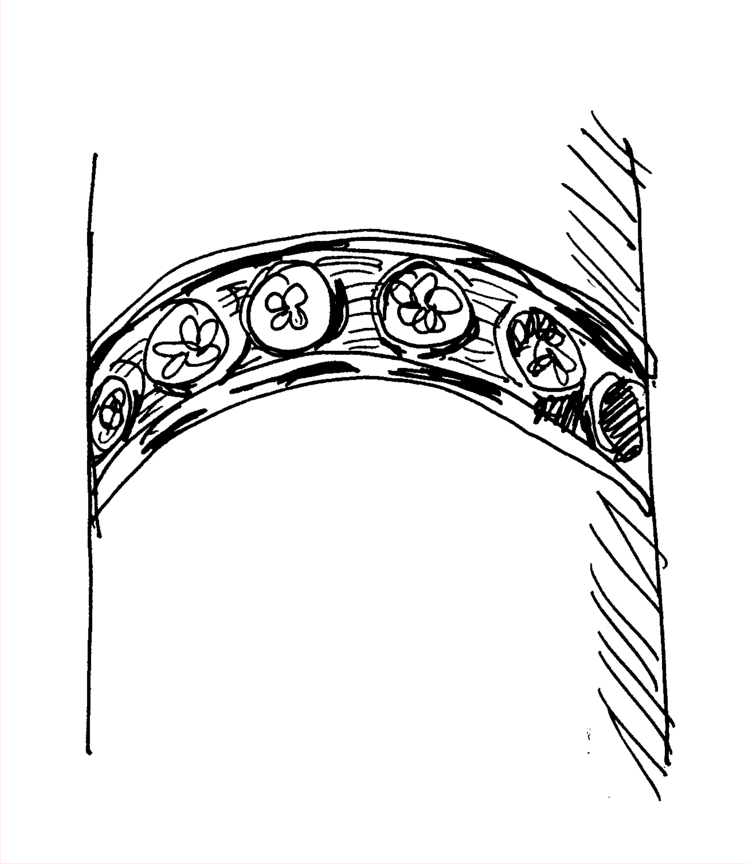
Technical questions

- In the Sierpinski gasket, if we add up all self-similar triangles, what area do we get?
- All the black triangles sum up to exactly one-half the area of the Sierpinski triangle
- We have added an infinite number of smaller triangles to get a finite area, equal to only half of the outline triangle!

Necessity for larger elements

- By concentrating on the smaller subdivisions, it is easy to miss the importance of the larger ones
- A fractal distribution necessitates a few larger elements
- Thus, a fractal cannot be composed only from a large number of small elements

Balance ornament with plain regions



C. Sustainable systems

- Look at evolved systems that have all the required features to function
- Stability — those systems have worked successfully over a long time
- Evolved to overcome instabilities (otherwise they have become extinct)
- Examples found in a majority of natural and many artificial systems

Examples of sustainable systems

- Ecosystems — many organisms interacting together
- Animals on top of the food chain feed on those lower down. Each level supports the entire system
- Electrical power grids (evolved)
- Internet and the world-wide web (evolved)

Animal size distribution

- In an ecosystem, count the different animals and classify them according to their mass
- We find discrete mass levels, where the heavier animals eat smaller animals
- Distribution is a universal distribution
- Eliminating one level disrupts or destroys the entire ecosystem!

Lessons from ecosystems

- Stability requires redundancy
- Distinct occupants of a single niche
- Eliminating any single level (either large or small) disrupts the ecosystem
- A gap invites invasion by alien species
- Alien species either evolve to adapt to existing ecosystem, or destroy it

Unsustainable systems

- Present-day banking system
- Large-scale industrial agriculture
- Suburban sprawl
- Skyscrapers
- Funding for urban projects and repair
- *All of these emphasize the largest scale — they have no fractal properties*

Unsustainable systems (cont.)

- SKEWED DISTRIBUTION OF SIZES
- Christopher Alexander already pointed out that funding for urban intervention is skewed towards the largest projects
- Smaller and smallest projects are neglected
- Pathology of "big-scale thinking" prevents repair of living urban fabric

Agribusiness

- Tries to eliminate the local small farmer
- Depletes soil, pollutes with fertilizers
- Depends on economies of THE LARGE SCALE, sacrificing everything else
- Unsustainable in the long term
- When system nears collapse, it ends up being subsidized by big government

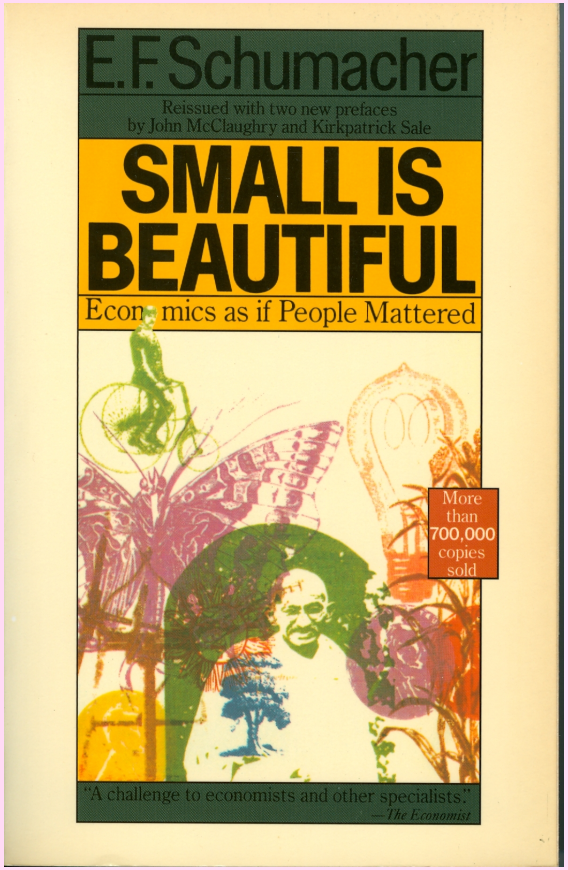
Lakis Polycarpou

- New York City writer
- Q: "*How can systems based on an unnatural scale distribution survive?*"
- A: "*With massive financial capital, huge expenditures of energy, and sheer force of will.*"
- UNSUSTAINABLE

E. F. (Fritz) Schumacher

- Small-scale economics
- Made a big impact on philosophers and ecologists several decades ago
- Was only able to marginally affect mainstream economy because of the massive power of global capital
- Still the only viable long-term solution!

“Small is Beautiful”



Schumacher’ s contributions

- His work comes from economics and intuition
- Not a mathematical analysis like ours
- Studied systems in the developing world that worked over generations
- Refers back to Mahatma Gandhi, who promoted small-scale economies

Some sustainable solutions

- Grameen Bank in the Islamic world
- Small-scale organic/local farming
- Owner-built social housing
- Focusing government onto people's problems on the local scale
- Circumvent global consumption that promotes only the largest scale

Muhammad Yunus

- Banks usually refuse to lend tiny amounts to poor persons, but will lend $100 million to one company
- *Microcredit* — Muhammad Yunus lent very small sums out to a large number of people
- Has enormous success in boosting local economies in the developing world

Social housing

- We have written a key paper on this topic (NS, David Brain, Andrés Duany, Michael Mehaffy & Ernesto Philibert-Petit)
- Competition between self-build on the small scale, against government pressure to build giant large-scale housing blocs
- Builders want to make a lot of money!

Systemic stability

- Narrow notion of efficiency (privileging one parameter) acts against stability
- Seeking only efficiency can eliminate diversity and hierarchical systemic support (different levels reinforcing each other)
- Artificially-supported system runs smoothly for a brief period, but eventually suffers a catastrophic collapse

Single building

- We can consider a building as a complex system of interacting geometric parts
- Universal distribution implies certain morphological features
- Small-scale structural subdivisions distributed as in traditional architecture
- Follows from systemic stability!

Conclusion

- Each lecture in this series gives one building block of a larger argument
- Each argument leads to a more general awareness of structure, geometry, and human wellbeing in the built environment