Towards a New Paradigm in Architecture and Urbanism

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Tools for human-centered design

- Digital tools are just tools. They are incapable by themselves of creating either adaptive architecture or a new paradigm for architecture. Useful tools come from science, and we are ready to program this information into software. But the design method has to match intuition — it can in no way go beyond intuition because then it becomes a tool for generating monsters.
Is this building beautiful?
That’s a nasty question!

• Architecture students are taught that such minimalist, “brutalist” buildings (those showing rough, unfinished concrete surfaces) are beautiful.
• But common people often react with horror and repulsion at such structures.
• So — should we trust what we are told by experts, or our own intuition?
A medieval cloister
How do we judge?

• The brutalist concrete building is loved by architects but is hated by common persons

• The cloister is loved by common persons but is hated by architects (who might enjoy it for tourism, yet violently reject it as a model to use in building today)

• Is there an objective manner to judge what type of architecture is actually good for us?
Visceral attraction to abstract patterns depends upon our biological evolution
A biological basis for beauty

• Humans do not define beauty: nature does, based upon forms that help our survival
• If we responded wrongly to forms in our environment, we were dead or got eaten!
• Our evolution hard-wired structural preferences in our body and brain
• *We need structural criteria for beauty that don’t contradict what our neural system is tuned to!*
1. Scale-free fractals

• A fractal shows complex structure at every magnification
• Just like our lungs and nervous system, because those are linked networks working on many different scales
• Plants are intrinsically fractal: ferns, cauliflowers, branching plant forms
• *Each of these arises from its function!*
Fractal scaling
Healing environments

• Specific configurations, surfaces, and volumes promote our body to heal naturally
• Those patterns come from biology
• There is strong evidence that those same qualities increase children’s intelligence
• Applied to hospital design until the 20th Century; after that, the model for hospitals has been a shoe-last factory in Germany
Thus, humankind creates artefacts
... and traditional buildings
2. Summary of biological rules

• Complex details: every detail contains more details when magnified
• Symmetry emphasizing the vertical axis attaches us to gravity
• Multiple symmetries condense and order visual information that might otherwise overwhelm our cognitive system
Some buildings are organic
Descriptions of complexity

• SIMPLE systems require a short description
• COMPLEX systems require a rather lengthy description (Kolmogorov-Chaitin measure)
• Symmetries create redundancies, which cut down on the necessary descriptive length
• The most complex system has no symmetries at all, and thus requires a description as large as the system itself — often a random set
Reflectional symmetry
Rotational symmetry
Translational symmetry
3. Life occurs in a vector space

• The abstract vector space axioms explain why we humans seek symmetries
• 1. Closure under addition
• 2. Every vector has its reflection
• 3. Closure under scaling
• 4. Existence of the zero vector
Additivity depends upon similarity

• We intuitively seek visual relationships in the built environment, trying to match similar components into pairs or groups
• Look for coupling at a distance, reflectional and rotational symmetries
• Only geometrically and texturally related components can add conceptually
Reflections generate mirror symmetry

• A design coupled to its reflection is a bilaterally-symmetric pair
• But our body doesn’t feel comfortable with every possible reflection axis
• Gravity (sensed by our inner ear) establishes our preference for a vertical symmetry axis in our surroundings
4. Scaling symmetry generates fractals

- Multiplying a design by some factor scales it up — include multiple factors
- Vector spaces require all scaled copies to be included, but fractals include only discrete magnifications — quantization
- Traditional architecture magnifies arches and rectangles by a factor of $e \approx 2.7$
Quantized vector space

- Not all multiples of components are present, only multiples with some scaling factor.
- Instead of every point of the vector space being occupied, there are only discrete points.
- Quantized set, useful for condensing data in computer science into a small number.
- Every discrete point is the average of a cluster of neighboring points.
Where does $e$ come from?

- Solution of the growth equation:
  
  \[
  \frac{dy}{dx} = ky \Rightarrow y = ce^{kx}
  \]

- Description of logarithmic spirals in land and marine snails, horns of sheep and goats, etc. in polar coordinates:
  
  \[
  r(\theta) = ce^{k\theta}
  \]

- In design, empirical “rule of 3” applied to subdivide a form in a harmonious way
Divide length into 3 parts
5. The Golden Mean doesn’t work the way everyone thinks it does!

- We cannot use a scaling factor of $\Phi = 1.618$ to divide a form into parts!
- This elementary error was made by Le Corbusier in proposing his useless “Modulor” scheme for design
- Instead, the Golden Mean establishes scaling according to the ratio of sizes
The Golden Rectangle has no special attractive properties!
Universal scaling lengths in the *same* dimension correspond to $\Phi^2$
Generate the scaling sequence

• Cut a square out of a golden rectangle
• The remainder is another similar golden rectangle, sitting vertically
• Do the same thing to the vertical golden rectangle to obtain an even smaller golden rectangle sitting horizontally
• Compare the lengths of the sides of all the horizontal golden rectangles
Mathematical scaling ratio

• 1, 3, 8, 21, 55, 144, 377, 987, 2584, …
• Alternate terms of the Fibonacci sequence
• The limit of the ratio of alternate terms of the Fibonacci sequence as the terms get large is a fixed irrational number, \(2.618 = \Phi^2\)
• One cannot use powers of 2.618 instead of the integers 3, 8, 21, 55, etc. to compute the scaling ratios, because the Fibonacci sequence is not a geometric sequence.
From the Golden Mean to $e$

- It just so happens that universal scaling is related to the square of the golden mean $\Phi$
- $\Phi^2 = \Phi + 1 = 2.618$
- This interesting coincidence has nothing to do with rectangular proportions of credit cards, the front elevation of the Parthenon, and other buildings!
The exponential sequence

- Practical tool: use a geometric sequence of powers of the logarithmic constant $e \approx 2.718$, which determines the shape of animal horns, shells, etc.
- $e^2 \approx 7.4$, $e^3 \approx 20.1$, $e^4 \approx 54.6$, $e^5 \approx 148$
- This geometric sequence is approximately equal to the universal scaling sequence, but differs in the larger terms
Practical design rule

- **Either:** Begin from the smallest size component, then make sure to include larger-size components with factors approximately times $3, 7, 20, 54$, etc.
- **Or:** Start with the largest size, and make sure to include well-defined structure at $1/3, 1/7, 1/20, 1/54$, etc., all the way down to the material details
Scaling symmetries

- Magnify components to create fractals
- Change in thinking about “proportion”
- The secret is *NOT* the ratio of the two sides of a rectangle, but instead ratio of objects *measured along the same direction*
- Nothing magical or mystical about this
Symmetries used in architecture
6. Inverse-power 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 internal system connectivity, flows, forces, etc.
Allometric scaling law

• 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
Universal distribution
Sierpinski fractal gasket (showing only the three largest scales)
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 scale is inversely-proportional 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
• \( m = D = \log_3(2) = 1.58 \)
7. Monotonous repetition

• Something, usually a simple module, repeats in one or more directions
• If some new larger structure DOES NOT ARISE through grouping components on a bigger scale, then…
• This violates fractal scaling, where something new is defined every time the scale increases
How units group into larger wholes
Grouping into clusters of four
8. Symmetry breaking is good

• Sophisticated concept from theoretical physics — generates mass
• Establish an overall symmetry, but violate it *slightly* on the smaller scales
• Advantage: when a global symmetry is only approximate, it can no longer be collapsed into a simple repetition
Broken translational and reflectional symmetry
Perfect global symmetry is collapsible

• Can be condensed into a very simple description — a generative rule:
  • “Take one unit and repeat it indefinitely”
  • Or, “cover a wall with one simple tile”
• The most viscerally attractive examples of symmetry in architecture DO NOT REPEAT SIMPLISTICALLY
Local rotational symmetries; broken global translational symmetry that appears perfect, but isn’t
Columns with variety
Preventing information collapse

• According to Kolmogorov-Chaitin, a short description is needed for a simple system
• Having to define new structure on increasing scales introduces manageable complexity
• The opposite: a computationally irreducible system exceeds the capacity of the human mind to interpret it, thus causing alarm
The opposite goal: eliminate obvious symmetries on all scales!
Architectural culture uses a design dogma that is scientifically false!

- The surrounding geometry doesn’t affect people’s bodies in any way
- We can situate people within minimal spaces — they don’t react to packing
- Design buildings and cities as sculptures, as if people don’t interact with their environment
Conclusion: Tools you can use

- In judging the built environment, be sensitive and rely on your gut feeling and intuition
- Don’t accept what so-called experts tell you if that contradicts your own body signals
- Design in the 20th Century reversed its aims and cut itself off from its biological roots
- Be aware that massive propaganda tricks worked in the past to mislead entire nations
Conclusion: Trust biology

• Everyone’s body reacts the same way to objects and environments
• For those who prefer “contemporary” environments, their mind is in constant conflict with their body — causing stress
• Scientific results give us tools to design and build healing environments
• Demand buildings that follow those rules!