

# **Borders in Architecture and Urban Design: Science Explains How Life is Influenced by Physical Boundaries**

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**Abstract:** *How can we make spaces that are more accommodating to human uses and psychological needs? The key is to design their boundaries. Generalizing this concept, the border of any region determines to a large extent how that region is experienced, hence the utility of any design depends strongly upon its border. At the same time, borders between socially and economically incompatible regions define many divisions of today's world. It is essential to understand how these borders arise spontaneously; how they could be eliminated; and when it's best to leave them alone. Explanations for proposed design solutions come from mathematics and scientific mechanisms in cosmology and elementary particle physics. To the best of my knowledge, these applications are novel, and appear in architecture and urbanism for the first time.*

## **Introduction. Bringing science into design**

Science applied to architecture and urbanism uncovers many design typologies that degrade spaces. By "degradation", I mean that the user experience is not what was originally expected or promised, because the geometry of the spaces makes use difficult or unpleasant in the long term. This negative effect is the opposite of what a good designer and architect ought to aim for: namely, that the built spaces should accommodate and promote the entire range of human activities that were stated on the design brief.

My claim is surprising to many, because every designer claims that his/her creation makes a positive contribution to the built environment. Therefore, the problem is certainly not one of intent, but rather of misunderstanding the nature of space itself, and of the parameters that need to be satisfied in order to produce an adaptive, usable space. Hopefully, I can point to some neglected phenomena that will help designers generate better spaces in the future.

The problems are traced to the properties of different types of borders, whose properties are either misunderstood, or deliberately suppressed in the interest of expressing a visual “style”. Yet those results responsible for adaptive solutions are documented in existing built fabric, and are available for all who wish to learn from those examples. Techniques for building a more adaptive human environment are ready and available. New scientific insights combined with the older “Pattern Language” can create a new type of nourishing human space.

## PART I. MATHEMATICS

### How a region is defined by its boundary

- Duality between functions defined inside an object and its closed boundary
- A volume (e.g. a sphere) has a closed boundary: a spherical shell
- An area has a closed boundary: the perimeter around it
- An open line has a boundary: its two endpoints

### Architectural borders

- Every architectural form is bounded
- Its border or boundary defines it
- We need to perceive spatial limits

### Interior and boundary

- Mathematical notion is one of the most important results in Calculus:
- The “Stokes Theorem”
- Take a region  $V$  with closed boundary  $\partial V$
- Some complex quality  $f$  varying inside  $V$
- Then relate the integral (average) of the change (exterior derivative) of  $f$  inside  $V$
- $\int df \text{ over } V = \int f \text{ over } \partial V$

### Meaning for spaces

- Knowing the values of  $f$  on the boundary is enough to compute the average of the change of  $f$  inside the region

- Whatever happens inside a space is related to what happens on its boundary
- The average of a function over a closed boundary gives the average of the change of that function inside the space
- A topologically closed boundary
- The Barcelona Pavilion is not closed, hence it violates Stokes' Theorem



*Ambiguous open space in the Barcelona Pavilion. Here I'm definitely standing "outside", but once I ascend the stairs behind me, the situation is no longer clear at which point I actually enter the building.*

### **How biophilia disguises the breakup of space**

This iconic building of the Modernist style provides no distinction between inside and outside. An intentional feature of its design has led to poor results when copied by later buildings that depend upon enclosing a space (as most buildings do). Architects ask "how, then, do we experience the Barcelona Pavilion positively?" The answer is because Ludwig Mies van der Rohe used biophilic design principles to establish a positive connection between the user and the structure. Those include the natural detail and patterns on the travertine limestone and giant marble slabs; the pools of water on the sides; lots of natural light; and the naturalistic statue of a woman set in one of the pools. The casual visitor is seduced by the biophilic elements and fails to notice the lack of enclosure (see my booklet "Biophilia and Healing Environments"). People's attention is distracted so they don't notice when an essential quality of inhabitable space has been destroyed.

### **Lessons for design**

- People need a semi-enclosed place
- Traditional architecture is composed of well-defined boundaries

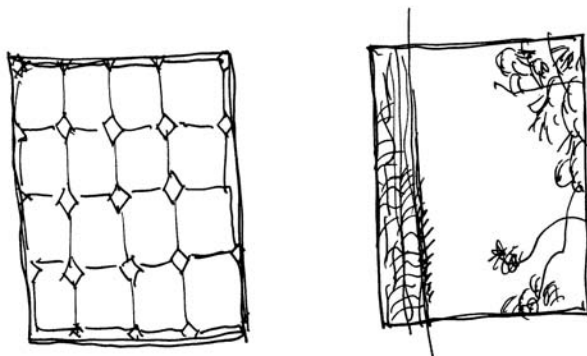
- Modernism eliminated the boundary
- Glass curtain wall causes anxiety and stress: the brain does not perceive a physical boundary, but the body does

### **Mathematics applies to all scales**

The geometrical properties of borders are scale-free: that is, it doesn't matter how big they are. Therefore, our discussion encompasses all possible scales, from a window frame to the border between two countries. This ability to jump scales is disconcerting to designers, who are used to working within very restricted dimensions. The results also cut across professional boundaries that separate interior design, architecture, urban design, and planning. And yet, despite the traditional separation of disciplines, the relevant mechanisms can be understood without reference to any particular scale (see "Connecting the Fractal City", Chapter 6 of my book *Principles of Urban Structure*).

### **Bad versus good windows**

- Plate glass does not provide a boundary!
- Intentional confusion between in and out
- Need to divide windows into small panes, re-introducing muntins and mullions
  - SMALL PANES, Pattern 239 (from Christopher Alexander *et al.*, "A Pattern Language" — explained further below)
  - The spatial boundary is defined not by the glass panes, but by the window muntins that are of human size



*Windows showing human scales. Mullions, lace curtains, and plants establish visual contact with structures on scales from 1mm up to the size of the window, which span*

*the sizes of an arm, hand, finger, eye, nostril, etc. As a result of this scale inclusivity, the window is experienced more organically, hence positively.*

### **Classical moldings**

- Linear borders of planes (walls)
- Complex and detailed enough to attract visual and cognitive attention
- A frame composed of moldings defines the walls of the room
- The walls, ceiling, and floor simply fill in between the moldings

### **Space without definition**

- Removing complex moldings erases the duality between a wall and its boundary frame
- Modernist design deliberately removes all framing elements
- The eye has nothing to fix itself where a wall meets another wall or the floor

### **Moldings as perceptual frames**

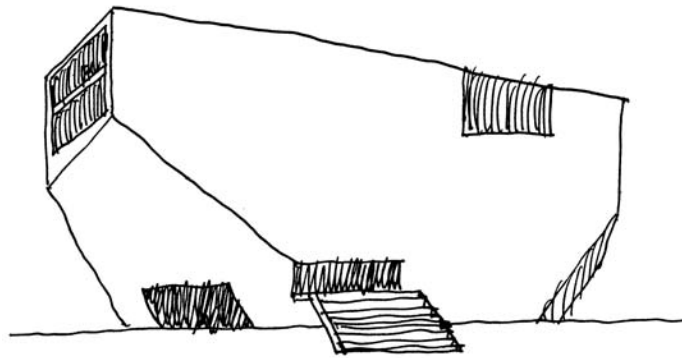
We could in fact design habitable space primarily through skeleton frames made of moldings (sufficiently complex to fix our visual attention). Those linear perimeters fix the boundaries (edges) of flat or curved surfaces. Without cornices or baseboards, however, we don't perceive the border of a wall, and this leaves us perceptually frustrated. The walls, which could be flat or curved in the appropriate enclosing manner, simply fill in the two-dimensional space between moldings: it really doesn't matter how. The frames turn out to be just as important as the surfaces they bound.

Jumping up in dimension, the three-dimensional volume of inhabitable space is defined by those enclosing surfaces. Human perception is fixed on the two-dimensional borders, which are the walls, floor, and ceiling, and which are in turn bounded by moldings. But when modernism eliminated moldings, there is nothing fixed to refer to and the user is left unattached to the space. Walls come right up to each other, to the floor, and to the ceiling as abruptly as possible without any "join". The ultimate erasure was achieved with glass curtain walls, which remove the spatial border altogether. "Design purity" makes the user pay a heavy psychological toll.

## **PART II. URBAN DESIGN**

## **Self-centered principles of Modernist buildings**

- Modernism is largely self-referential
- Buildings stand alone to grab our attention
- External space is consequently left-over
- Modernist urban space is not bounded
- In it, we feel threatened and exposed
- When open exterior space fails our instinctive perception, it is never used



*Leftover space is junk. This building, as most signature buildings today, concentrates attention from the surroundings onto itself, leaving no coherent geometry in the surroundings themselves.*

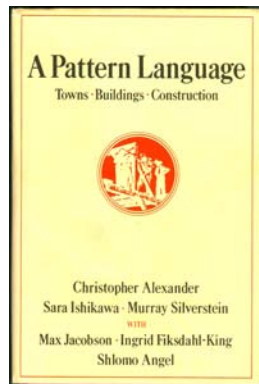
## **Should space surround buildings, or buildings surround space?**

Urban space relies upon using the surrounding buildings as an enclosure to define the space. Open space is usable in the psychological sense only when it has a built border with special characteristics. This living situation where buildings become perimeters is topologically the opposite of a free-standing “look-at-me” building that uses open space as its own perimeter. That doesn’t work for human use: it switches the roles of user and building. The basis of our understanding of open space was negated when the topology was reversed. Modernism erased evolved human patterns guaranteeing the use of urban space. Needless to say, modernist urban space mostly lies unused when compared to more traditional public spaces.

## **Some good examples**

- Urban space needs to be surrounded by complex yet coherent building façades

- “Geometry and life of urban space”, article by myself & Pietro Pagliardini available in English, Italian, and Spanish
- Partially enclosed public space with roof and columns but no walls focuses activity
- PUBLIC OUTDOOR ROOM, Pattern 69 of “A Pattern Language” by Christopher Alexander



*“A Pattern Language”, 1977, discovered and documented spatial configurations that optimize the users’ experience. These design patterns provide a repository of timeless solutions on how human beings use space, thus offering a crucial and invaluable aid to design.*

### **Traditional typologies**

- Connect pedestrian paths of two streets through the middle of a large building
- BUILDING THOROUGHFARE, Pattern 101 of “A Pattern Language”
- This Pattern generates transverse arcades
- Outdoor space needs to have concave boundaries, otherwise it will not be used
- POSITIVE OUTDOOR SPACE, Pattern 106

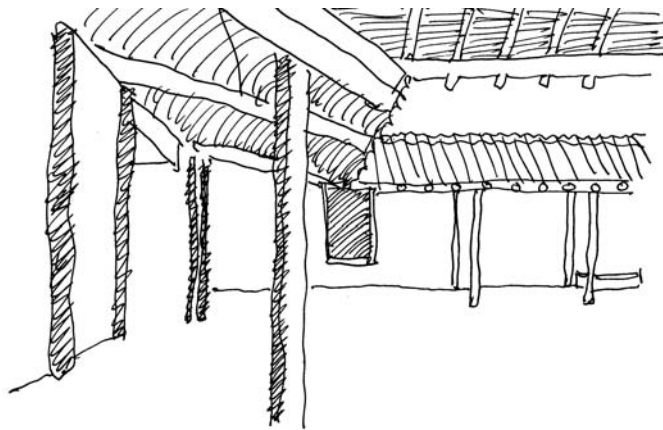
### **The drive to eliminate borders**

Beginning with early modernism, a major design objective has been to eliminate borders from the built environment: window and door frames; transitional spaces; and the distinction between inside and outside. Many practitioners explicitly state this as their goal. The justification, however, is a confused appeal to political freedom: “removing borders frees society”, although it achieves nothing of the sort.

Nevertheless, linking a design style to powerful ideological slogans has made it seductive and almost impossible to criticize.

### **Success of urban space**

- Life of urban space depends upon ease of activities occurring along its inner edges
- ACTIVITY POCKETS, Pattern 124
- Complex geometry of boundary  $\Rightarrow$  invites activities in real time  $\Rightarrow$  use of urban space
- Complex ground perimeter of building invites walking, leaning, and sitting
- BUILDING EDGE, Pattern 160



*Inviting courtyard space works because it provides several psychologically attractive features. It has complex visual interest along its border, surfaces that can be used (they do not repel a person, nor are they ambiguous), and sheltering spaces along the perimeter of the larger space.*

## **PART III. INDOOR SPACES**

### **Living spaces require special borders**

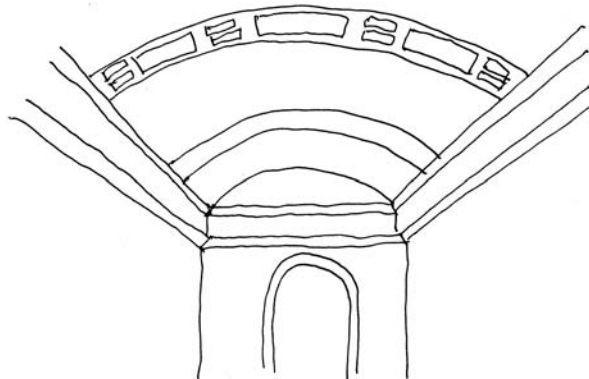
- Volume of “living space”
- Depends largely on its border surfaces
- Primal, biological sense of protection



- Instant informationally-based decision on whether to stay, flee, eat, or find a mate
- Positive responses are built into our body
- Beyond image of design “purity”

### **Spaces within spaces**

- An intimate smaller space within a room, partially enclosed, and with lower ceiling
- ALCOVES, Pattern 179
- Use straight, vertical walls but concave corners and symmetrical vaulted ceiling
- THE SHAPE OF INDOOR SPACE, Pattern 191
- CHILD CAVES, Pattern 203

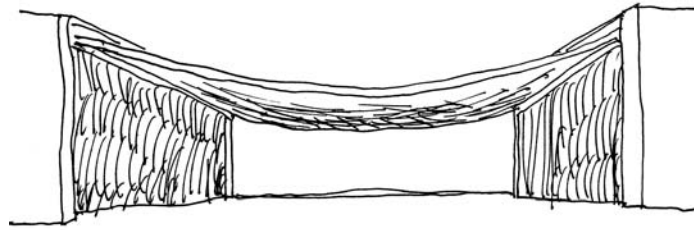


*Concave ceiling is good. It gives a sense of enveloping and stability against collapse. While everyone experiencing this space feels reassured, most people will not notice the geometrical reasons responsible for this effect (see the essay series “Living structures should come from living patterns”).*

### **Bad versus good ceilings**

- Good ceilings should be made high enough for psychological comfort
- Bad ceilings are too low for their activity
- Le Corbusier introduced inhuman ceilings at 2.26 meters so that he could touch them
- Either flat horizontal, or symmetric vaulted in the concave sense are good

- Re-entrant or convex ceilings oppress



*Convex ceiling is oppressive. It appears to come down on your head, giving the ominous feeling that it will squash you. Walking under it so I could experience it first hand, I had to move to the sides and out as quickly as possible.*

### **Inhuman space depends on walls and ceilings**

Architectural historians are severely challenged to explain why modernism reversed tried-and-true design guidelines for generating accommodating interior space, to create unpleasant anxiety-inducing spaces. Surely this was not intentional? I cannot imagine professionals generating environments to make people suffer! But why did the users not object? It seems that almost everybody accepted hostile spaces as the price to pay for “progress”, and even identified an obvious degree of psychological discomfort as the criterion of a successful “modern” space. At the same time, accommodating spaces were judged as too “old-fashioned” and were rejected by architectural culture as deviating from the accepted canon. We have rarely created healing spaces for a century.

## **PART IV. PATH AS THE EDGE OF A REGION**

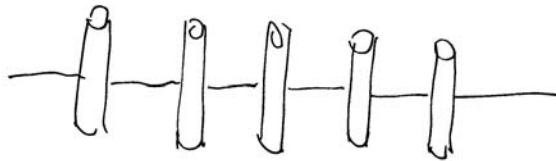
### **Edges and paths are one**

- Paths coincide with edges in graph theory
- “Theory of the Urban Web”, Chapter 1 of my book *Principles of Urban Structure*. Also in FINNISH: “Kaupunki Verkostona”
- Urban elements can damage each other unless separated by an appropriate border

- Low/high walls and green strips should reinforce paths, not cut across them

### **Pedestrian urban boundaries**

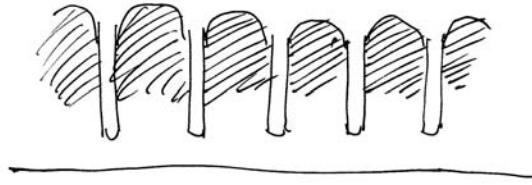
- Protect pedestrians by bollards, low wall, balustrade, railing, and raise the path
- RAISED WALK, Pattern 55
- Strict boundary for vehicles, yet visual connection and pedestrian permeability
- Arcade with columns is semi-permeable
- Pedestrians use the protected space, yet have immediate access to the car realm



*Line of bollards protects pedestrians, both physically and psychologically, from vehicles moving next to them.*

### **Arcades with columns**

- Reinforce a major pedestrian path along buildings by building an arcade
- ARCADES, Pattern 119
- Arcades are misunderstood as simply providing shelter against the weather
- Their major function is psychological
- Bologna lives because of its arcades



*Arcade with columns creates that invaluable connective space between indoors and outdoors. The transition is physically easy, yet psychologically protected.*

### **Design purity eliminates crucial elements of urban design**

All the solutions for creating intermediate spaces and protective semi-permeable borders are thrown out by designers who focus exclusively on “design purity”. Unfortunately, that stylistic approach gets rid of important geometrical elements of an accommodating environment. Without those elements, the built urban environment becomes both deadening and dangerous because specific protective barriers are no longer erected. Bollards, colonnades, and arcades are deemed to be “geometrically impure” because they introduce structure at smaller scales. But that is precisely the point of fractal design: the presence of coordinated elements on all scales including the human scale. By contrast, design purity removes everything but the largest scale, which is inadequate to define a human environment.

### **Semi-permeable urban boundaries**

- Encourage the spontaneous formation of subcultures, each with its own region
- MOSAIC OF SUBCULTURES, Pattern 8
- A healthy neighborhood is defined by its semi-permeable boundary with gateways
- NEIGHBORHOOD BOUNDARY, Pattern 15
- Working complex borders are never “pure”

### **Borders are semi-permeable**

- Most international borders still allow movement across them, in two ways:
- Legal movement controlled by authorities
- Illegal movement of people and contraband through crossings and tunnels

- Human ingenuity and corruption find a way to cross supposedly sealed borders

## PART V. COSMOLOGY

### Particles and antiparticles

- Every elementary particle has its own antiparticle, so they come in pairs
- For example:  $\{e^-, e^+\}$ ,  $\{p^+, p^-\}$
- Whenever a pair meets, they annihilate each other, producing pure energy
- $e^+ + e^- \rightarrow 2\gamma = \text{two photons} = \text{light energy}$
- This is why we don't observe complete symmetry between matter and antimatter

### Antimatter in the universe

- Hannes Alfvén proposed that indeed, there exists as much antimatter as matter
- But wherever they meet, they annihilate each other, so they must be separated
- Parts of our universe could be composed of matter, and others of antimatter
- They can meet at a destructive boundary, which turns out to be insulating

### The Leidenfrost effect

- A drop of water lands on a hot stove
- The heat forms a thin border of steam
- This vapor layer actually insulates the drop from the heat, so it hovers over the surface
- Alfvén conjectured a similar effect to occur when a "World" meets an "Antiworld"
- This would keep them stably apart, preventing their mutual annihilation

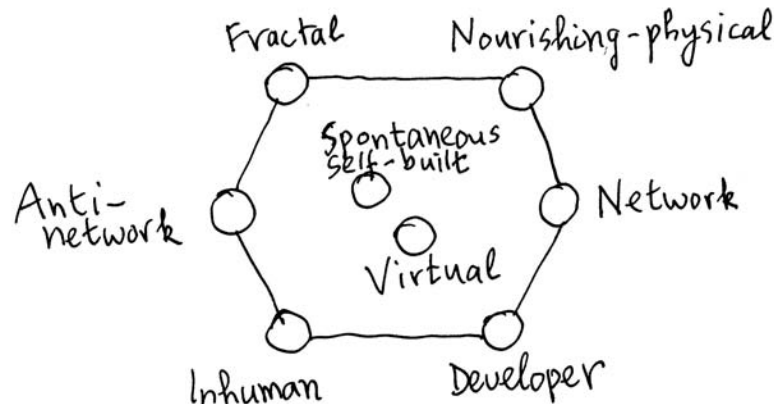
### The value of physical analogies

We introduce interesting mechanisms from physics, which can provide a descriptive model for architectural and urban structure. A model that is sound will

predict architectural and urban phenomena, which then validates the model as being useful. This is entirely separate from its original utility as a model in physics. We face a problem, however, since predictive models of any kind are unknown in architectural culture: explanations are usually based either on artistic whim, or on idolizing power. Students and practitioners follow what the famous architects do, without applying any sort of analytic criterion or logic. That's simply the nature of the discipline.

### Mutually-annihilating city types

- “Eight City Types and Their Interactions”, a Keynote Speech I gave in Krakow, Poland in 2016
- Some city types destroy each other
- Mutually-annihilating pairs of city types:
  - {*Spontaneous self-built*, *Developer*}
  - {*Network*, *Anti-network*}
  - {*Nourishing-physical*, *Inhuman*}



*Classification of eight city types*

### Mutual exclusion of city types

- Opposite city types cannot act at a point
- Either one or the other wins out
- (Other city types can indeed combine)
- In practice, an impenetrable border forms

- Informal settlements can thus co-exist next to upper-class high-rises
- View this as a natural phenomenon



*Slum next to posh high-rises*

### **Stabilizing urban boundaries**

- Tearing down the wall destroys one type:
  - 1. The developer works with the state to forcibly evict the residents from the slum, and then erects more luxury high-rises
  - 2. The alternative governing power in the slum — local organized crime — invades the high-rises, forcing the upper and middle classes to move far away

### **Balanced forces create and maintain a border**

It is worth investigating this urban phenomenon further. It is not the border itself that protects the distinct city regions on each side, but the forces acting within each of the two regions that oppose each other. The border is simply the geometrical expression of where opposing forces meet in a balanced tension. For example, government and large commercial forces that run the official city oppose the small businesses and organized crime that run the informal settlement. The border delineates where one set of forces transitions into the other. Wherever these two sets of forces are comparable, the border is more-or-less stable. Otherwise, one of them takes over and displaces the other.

# PART VI. EPISTEMOLOGY

## **Impermeable cognitive boundary**

- Practice is closed to thinking that threatens canonical images and forms
- Architectural culture works by images
- It isolates itself with a border
- Architects bring concepts from the outside to justify accepted images

## **Borders to creative thinking**

- A mental border around architecture
- Inside we find the modernist canon
- Outside are adaptation, traditional and vernacular architectures, self-building process, peer-to-peer collaborative city
- Architectural culture exports its canonical images into the outside world
- But fiercely protects its internal dogmas

## **The border between architecture for people and architecture for architects**

Everyone has been aware of the curious and inexplicable phenomenon whereby common people don't like modernist architectural solutions. This dichotomy has divided architectural culture from the rest of the world (see "Architectural Myopia: Designing for Industry, Not People" by Michael Mehaffy and myself). But instead of realizing that something fundamental is separating architects from everyone else, all I hear is repeated and insistent calls to "educate" the people on why those rejected and unloved structures should be warmly embraced. Never has the possibility that something may be dreadfully wrong crossed the mind of professionals situated within architectural culture. Hence the perpetuation of this isolating border.

## **Consilience of knowledge**

- Edward O. Wilson proposed that all explanations in nature are connected
- Artificial intelligence, evolutionary biology, and cognitive neuroscience are linking the humanities to science
- By contrast, an epistemological border indicates errors that damage knowledge
- Or it's a cult protecting its belief system



## **Global money supports design ideology**

Modernist ideology is not enough to explain the remarkable insularity of architectural culture. The tenacity of an exclusive and inward-looking philosophy is due to vast money interests that profit from modernist industrial building techniques. The global material industries of steel, plate glass, and reinforced concrete found it highly profitable to promote early modernist projects, and have never seen any reason to change that formula for maximizing profit. For this reason, extractive industry goes hand-in-hand with architectural ideology based on glass and steel buildings, which in turn are cheaper to design according to minimalist modernism. Architectural stars are hand-picked by global construction companies, because they best represent their financial interests.

## **Origin of modernist images**

- Where do the canonical images of architectural culture come from?
- They were a reversal and negation of traditional architectural typologies
- Traditional design elements evolved by adapting to human use and psychology
- Whereas “pure” modernist images simply cleaned up superficial appearance

## **Mutually annihilating**

- Canonical typologies — those inside architectural culture — negate those traditionally found on the outside
  - Obviously, the two sets cannot coexist
  - Whenever the dominant paradigm imports adaptive design tools, they are nullified
  - A new beginning for design will take place once architectural culture realizes this

## **Opposites cannot combine helpfully, only annihilate**

Taken as an accurate description of architectural culture, the present model raises frightening questions. What if human-centered design is mathematically incompatible with the design toolbox being taught to and applied by the majority of working architects today? This seems to be a desperate situation without any obvious solution. It’s not that adaptable design can be brought into the discipline to fix a few misunderstandings: the current basis of conceiving architecture is opposed to human sensibilities. Whether this is true or not is up to the reader to decide. But one cannot simply dismiss these concerns and come on the side of power, since power could be inflicting tremendous damage on our world.

## Conclusion

- Architecture students are exposed to canonical images of what is “good”
- But are taught to fear the new scientific ideas applicable to adaptive, human-scale design
- Students will have to learn all of this important material by themselves

## FURTHER READING

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