Algorithmic Sustainable Design: The Future of Architectural Theory.

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Lecture 9
9.1. Symmetry production.
9.2. Symmetry breaking.
9.3. Classical moldings.
9.4. Elementary particle symmetries.
9.5. Binding energy.

9.1. Symmetry production

- Humans throughout history have produced multiple symmetries in artifacts, buildings, and cities
- The cultural record demonstrates an essential need for symmetry in our environment
- Not simplistic, but complex symmetry

I need to point out that most architects and urbanists understand "symmetry" to refer only to a simplistic overall symmetry, such as bilateral symmetry, but that's not what I am talking about. I am describing multiple types of symmetries on many different scales.

Why we need symmetries

- Random information is too much for human cognitive system to handle
- In a random design, every single point has to be coded for representation
- Symmetries significantly reduce the amount of information that needs to be processed by the brain

Cognitive alarm

- Our neural system evolved to interpret our environment
- Random information overwhelms our cognition, thus causing alarm
- The same occurs for visually empty environments — unnatural, hence physiologically threatening

The evolutionary mechanism that created our neural/sensory system is tuned to signal alarm at identifiable threats, but also unease at situations we cannot interpret, which

could hide a threat. We either understand a threatening situation through our information processing system, or feel uneasy if we do not have sufficient information to make an informed judgment. We feel at ease only in positive feedback situations that resonate with our cognition: i.e., those we can interpret positively as non-threatening.

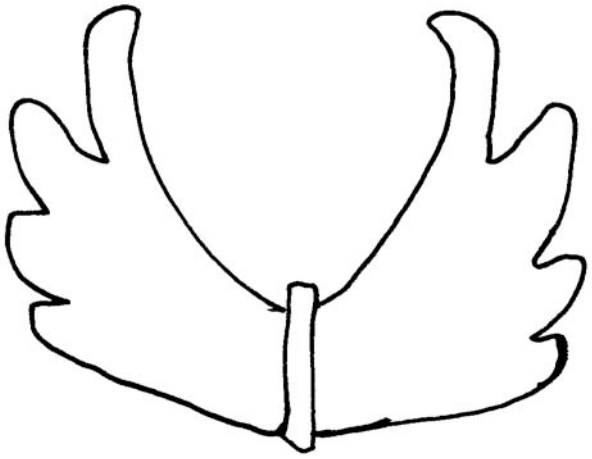
Different types of symmetry

- **Translational symmetry** — shift something along one direction
- **Reflectional symmetry** about an axis
- **Rotational symmetry** about a point
- **Glide reflection** — combines translation with reflection

Translational symmetry

Translational symmetry

- Straight line defines symmetry axis
- Repetition of non-trivial units
- Alternation defines the repeating unit better, by using contrast, than simply empty repetition
- "Alternating repetition" (Lecture 6)



Reflectional symmetry

Reflectional symmetry

- Mirror symmetry about some axis
- Any axis is fine on the floor
- But vertical axis is essential for our physiological feeling of stability
- Mirror symmetry must define an implicit vertical axis — otherwise design or structure feels unbalanced

A horizontal symmetry axis lying along the ground can be defined in an arbitrary direction, or by solar, planetary, or stellar alignment, such as occurred in ancient temples. The horizontal symmetry axis can also be dictated by cultural and religious considerations, as when pointing towards a specific compass direction. Any vertical symmetry axis that points up, on the other hand, is dictated by physics. Our physiology is set to the vertical axis.

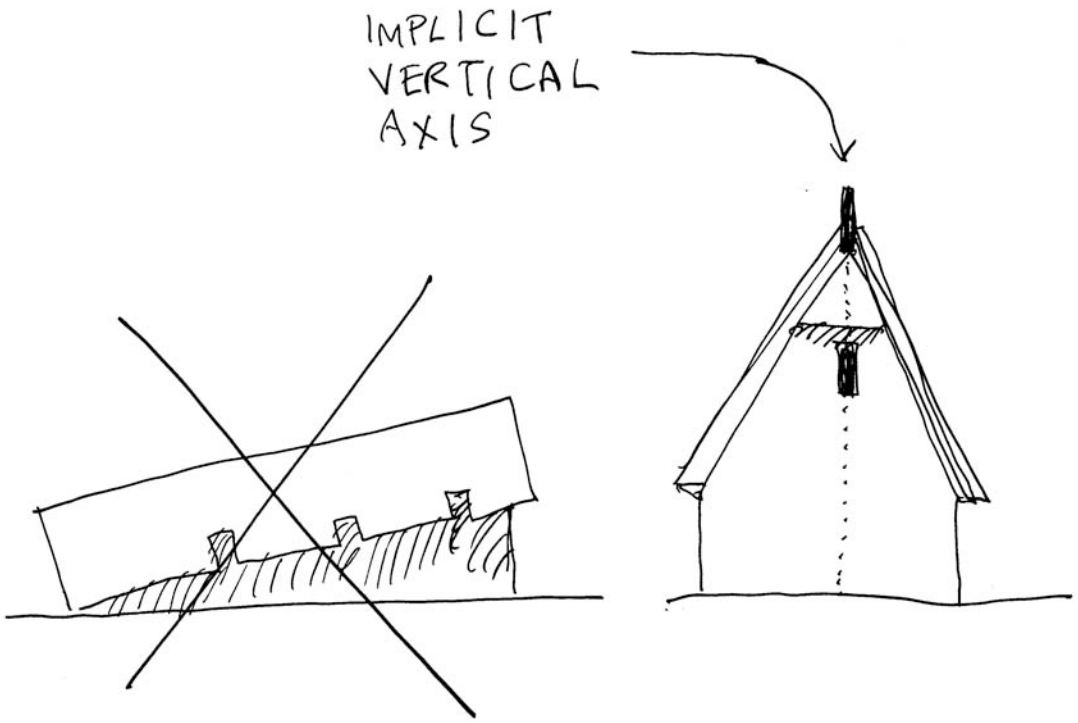
Implicit axis

- A symmetric form implicitly defines its axis of symmetry (not explicit)
- Human reaction to axis of symmetry is the same as the reaction to visible line
- Vertical or horizontal — **positive**
- Diagonal — **negative** (causes anxiety)

Physiological reaction

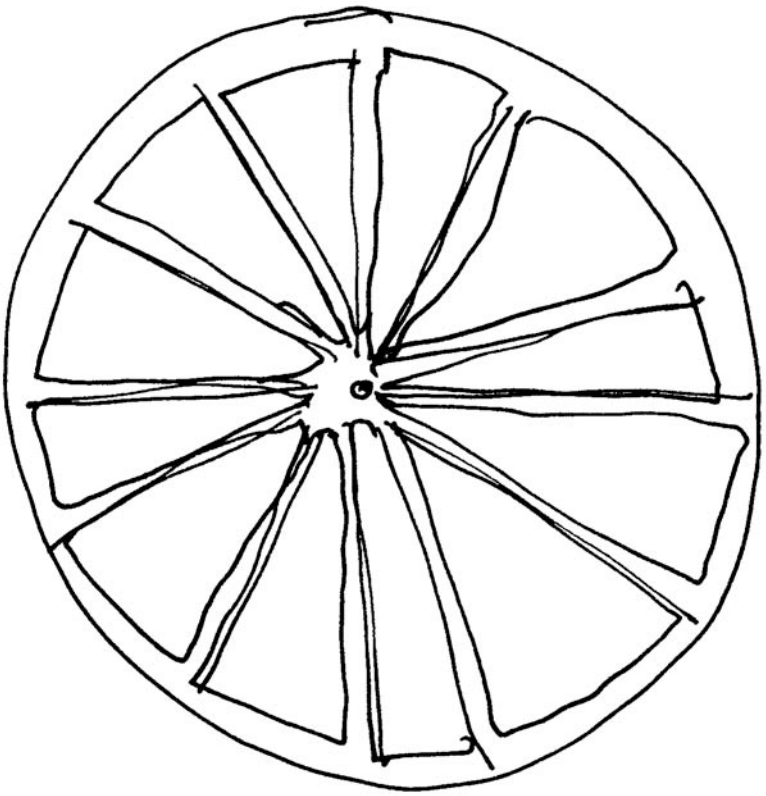
- Human sensory system evolved with gravity, to orient us to gravity

- Vertical axis built into our physiology
- We react with alarm or nausea to non-vertical axes (explicit or implicit)
- Reaction cannot be learned or changed



Implicit vertical axis

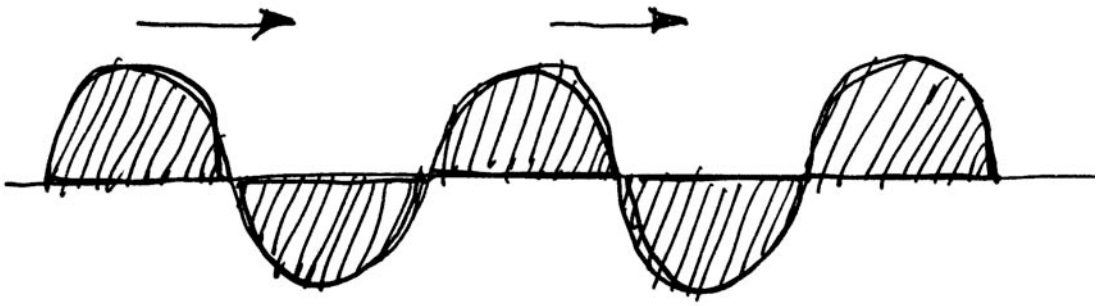
The vertical axis defined by gravity is not merely a visual effect, but involves the finely-tuned balance mechanisms of the inner ear. Those determine our orientation in three-dimensional space. Through a coincidence of our physiology, the inner-ear mechanism is linked to the sensation of nausea, thus dizziness from disequilibrium triggers nausea that induces vomiting, and vice-versa, food poisoning triggers vomiting that induces dizziness.



Rotational symmetry

Rotational symmetry

- Great stained-glass windows in medieval cathedrals
- Open ground plans of religious buildings and circular plazas
- Rotationally invariant architectural elements are usually embedded into a larger symmetric scale



Glide reflections

Glide reflections

- Combine translations with reflections into new symmetry
- There are a total of 14 ways we can combine the three fundamental symmetries nontrivially
- Glide reflections is only the first combination — there exist 13 more

The 17 plane symmetry groups

- Combinations of the basic symmetries: **translation**, **reflection**, and **rotation** — used on the small scales
- Regular tiling patterns — one complex tile repeats to fill in plane
- Known as the "wallpaper groups"

Symmetries of culture

- Great achievement of the human brain
- Found in all human art and artifacts
- Very sophisticated examples of the 17 plane symmetries throughout history
- But they were **ERASED BY 20TH CENTURY MINIMALISM!**

The arch-racist Le Corbusier

- "Decoration is of a sensorial and elementary order, as is color, and is suited to simple races, peasants and savages ... The peasant loves ornament and decorates his walls."
- — Le Corbusier, "Towards a New Architecture", 1927; page 143

Unfortunately, no one asked Le Corbusier while he was alive whether he was referring to the vast majority of human beings who use color and ornament to make their daily lives more pleasant. And what about the great religious traditions of the world, all of which identify color and ornamentation as necessary in seeking closeness to the Deity? Did Le Corbusier mean that all religious people who worship in traditionally ornamented temples are savages?

Authority condemns symmetries

- Ideology behind dominant design system erases multiple symmetries on all the smaller scales
- Instead, it insists upon simplistic overall symmetry on the largest scale
- Our artifacts and built environment are lifeless without complex symmetries

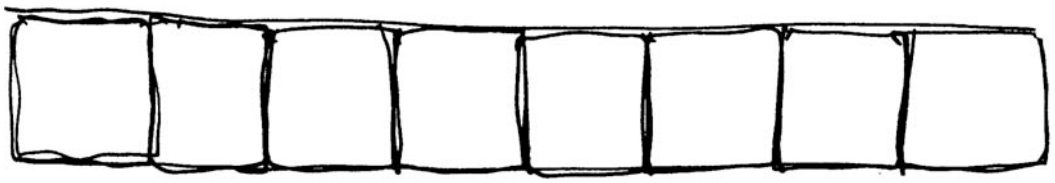
9.2. Symmetry breaking.

Prevents informational collapse

- It all has to do with information compression
- The human brain gains most sensory pleasure from designs that can be compressed, but not too easily
- Representation code should be neither too long (random design), nor too short

Identical repeated units

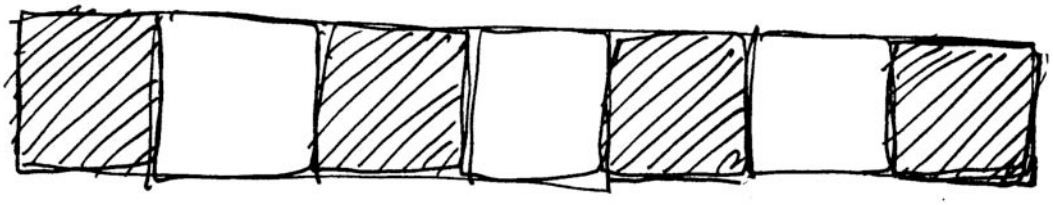
- Contain very little information
- Just one unit repeated indefinitely
- Representation code is very short: “describe one unit, then repeat it indefinitely”



Empty repetition

Just a little more information

- Establishes larger scale by taking advantage of symmetry breaking
- Change units enough so they are no longer informationally collapsible into one identical unit
- But do not change them so much that translation or reflection symmetry is lost — then they become random



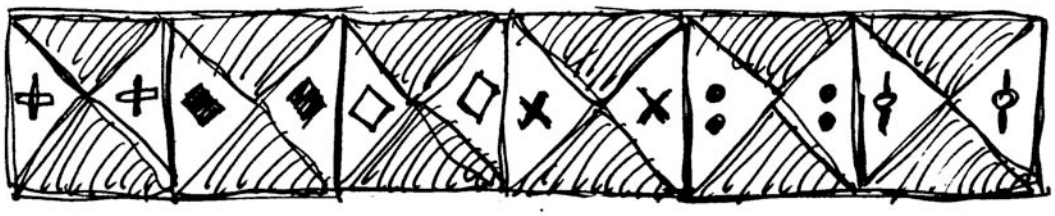
Alternating repetition (Lecture 6)

Informational richness

- Monotonous repetition is unsatisfying precisely because it is compressible
- The mind craves richer information
- Symmetry breaking provides variety by carefully introducing randomness on

particular scales

It is not unreasonable to assume that our mind seeks informational input that corresponds to the environment in which we evolved as a species. That would be a savannah: i.e., a complex, fractal environment in which the complexity is very highly ordered into separated trees, rocks, ground, etc. This degree of ordered complexity establishes a reference for our physiology. Departures from this reference in either direction signal alarm. Disordered environments create informational overload, whereas minimalist environments create information deficit.



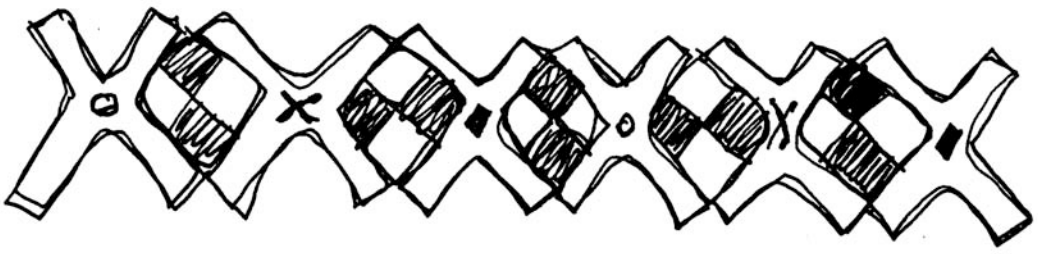
Symmetry breaking

Traditional artifacts

- Look carefully at traditional artifacts
- Repetition is most often NOT simple
- Repeating units always have subtle changes, on a certain scale
- Symmetry and symmetry breaking are found co-existing on distinct scales

Roughness

- Symmetries found in both nature and in human artifacts are approximate
- This is a much more sophisticated mathematical notion than regularity
- "Roughness" property (Lecture 6) breaks perfect symmetry



Alternating repetition with symmetry breaking

Symmetry breaking creates irreducible hierarchy

- Symmetry breaking establishes hierarchy in a sophisticated manner
- Larger scale in a scaling hierarchy is fixed when the smaller scale can no longer be collapsed into one unit
- Symmetry breaking stabilizes the hierarchy against collapse

Artisan work

- We value artisanal production of the same artifact, because of the inevitable minor variations
- A wall of identical machine-made tiles is not as attractive as a wall made of imperfect hand-painted tiles
- The brain perceives the effect of minor variations in the individual tiles!

One often sees a 20C design prejudice in describing traditional artifacts: "these people did not have the technology to make perfect symmetries, so their art is rough and approximate". This statement misunderstands the sophisticated mathematical goal of symmetry breaking and roughness, which is to prevent informational collapse. Cultures certainly could create much more perfect and accurate symmetries, if they wished, but they had no desire to do so. The connoisseur and antique markets, on the other hand, certainly value artisanal production for its sophistication due to minor variations.

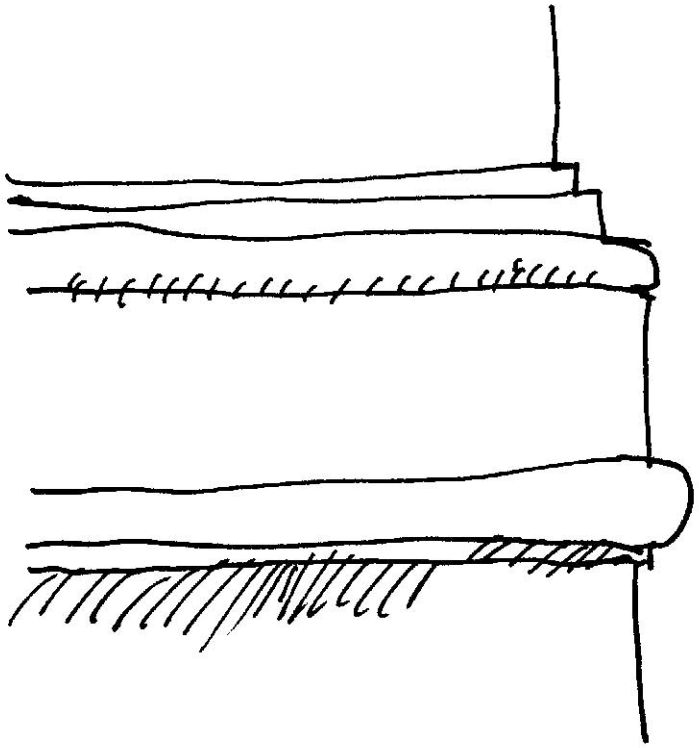
9.3. Classical moldings

Method of symmetry generation

- Unexpected support from (and for) the Classical form language
- Moldings presented as the atomic units of Classical architecture
- Educational system of Donald M. Rattner (architect, New York City)

Combinatorial elements

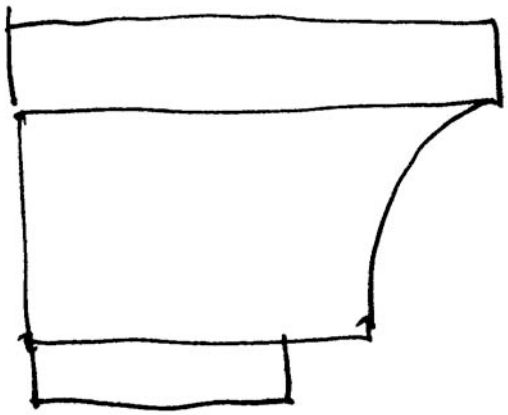
- Moldings are the smallest elements in the Classical form language
- THEY ARE ALL SYMMETRIC
- Classical moldings are used in combination to create large-scale units
- Never taught in architecture schools!



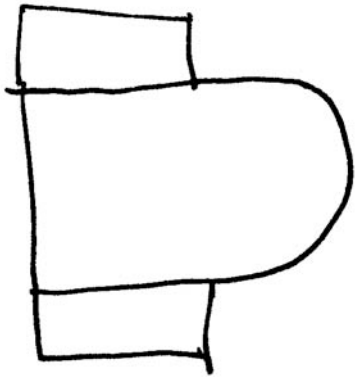
Moldings add translational symmetry

Express gravitational force

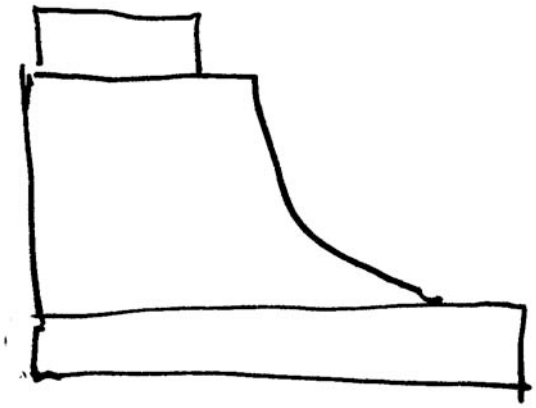
- Moldings express the effects of gravity by appropriate horizontal articulations
- Mimic the effects of squeezing materials through weight
- Moldings are NOT decorative, but directly enhance human wellbeing
- Opposite aim from Le Corbusier's deliberate "anti-gravity" typologies



Molding for top



Molding for middle



Molding for bottom

Variety of moldings

- Actually, within the three categories of moldings for top, middle, and bottom, there are further internal variations
- Classical architecture uses all of these to achieve solidity and balance
- Classical architecture also satisfies universal scaling through moldings

Combinatorics for moldings

- Language of moldings is already part of the Classical design vocabulary
- ALTERNATION, CONTRAST, SCALE, REPETITION, COORDINATION, PROPORTION, REDUCTION, etc.
- Compare with Alexander's observed 15 fundamental properties (Lecture 6)

The Classical design vocabulary already contains elements of Alexander's 15 fundamental properties. A two millennia-old design system provides a working example of the properties, as do other traditional systems of architectural design. We should not be surprised that all adaptive form languages satisfy these properties. Independent evolution converges upon similar results (in this case, form languages), precisely because of a mechanism of adaptation to both physical tectonics and human physiology.

Universality and adaptation

- The Classical form language is one of the most successful ever discovered
- It has evolved its own version of mathematical coherence
- This is why the Classical language has been so useful, and for so long

- It is also extremely adaptive!

World architecture

- Every place has evolved its traditional form language (not Classical)
- During many centuries, the Classical language was applied around the world
- Buildings adapted to include elements from the local form language
- Dismissed as "hybrid" by modernists!

Classical adaptations

- From the Greeks and Romans, to the European colonial powers, buildings have adapted to the local vernacular
- Extremely successful "colonial" buildings, now totally ignored by architectural historians
- Among the most loved older examples!

Colonial architecture gave rise to buildings in a Classical form language adapted to local climate and needs, successfully mixing with local traditional and vernacular form languages. Some colonial buildings are nowadays among the most beloved local buildings. At the same time, these buildings simply "don't exist" for modernist architectural historians. When those countries threw out occupying powers in the 20C, they inevitably accepted the modernist design vocabulary as the only politically correct expression of "independence". It was only later realized that modernist buildings are totally unsuitable to the local climate and culture, being far less adaptive than the formerly despised colonial buildings.

Emphasis on the smallest scale

- Classical moldings are an essential component of this form language
- They help to establish the smallest scale, by focusing on it directly
- According to our theory of design coherence, the smallest scale supports all the higher-order forms

New approach to design

- We take Donald Rattner at his word: **use moldings as atomic units of design**
- Design a project by starting with the most appropriate moldings
- Then connect the moldings with plane surfaces (wall, ceiling, floor)
- Bottom-up process of design

Duality between units and connections

- Which are the tectonic units, and which are the connections?
- Theory of centers tells us there is no distinction — we have a duality:

- A. MOLDINGS CONNECT PLANES
- B. PLANES CONNECT MOLDINGS

Duality between moldings and walls raises moldings to the same relevance as the walls themselves. Mathematically, moldings can no longer be considered as "irrelevant", whose worth depends strictly upon stylistic preferences. Moldings are just one of the essential structural elements that help to generate the hierarchy of scales necessary for coherence.

Support from the fundamental structure of matter

- The duality between units and their connecting "glue" has a precedent
- The same phenomenon occurs in elementary particle physics
- Basic units of the physical universe
- Physics supports our theory of design!

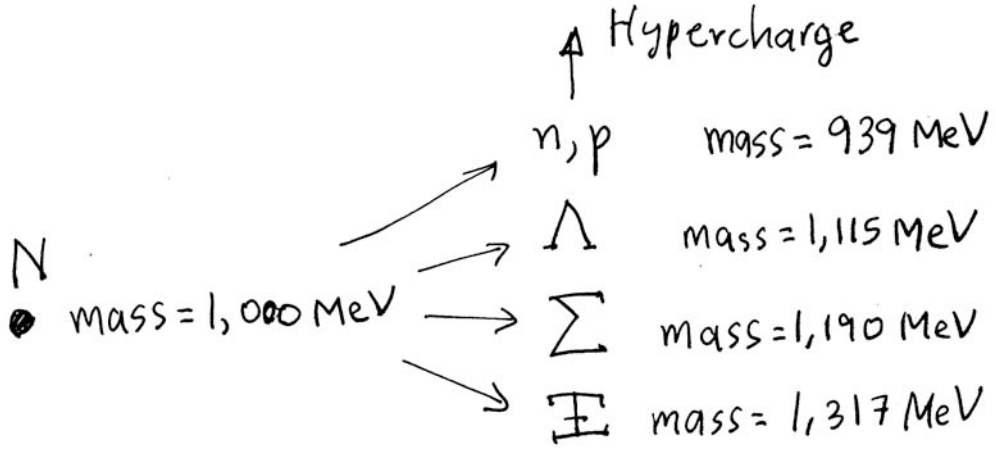
9.4. Elementary particle symmetries

Internal symmetries

- Analogy from fundamental physics
- Elementary particle interactions are symmetric under the group SU(3) (analogous to rotational invariance in a space of internal dimensions)
- But symmetry breaking also occurs in elementary particle symmetries

Degenerate nucleon

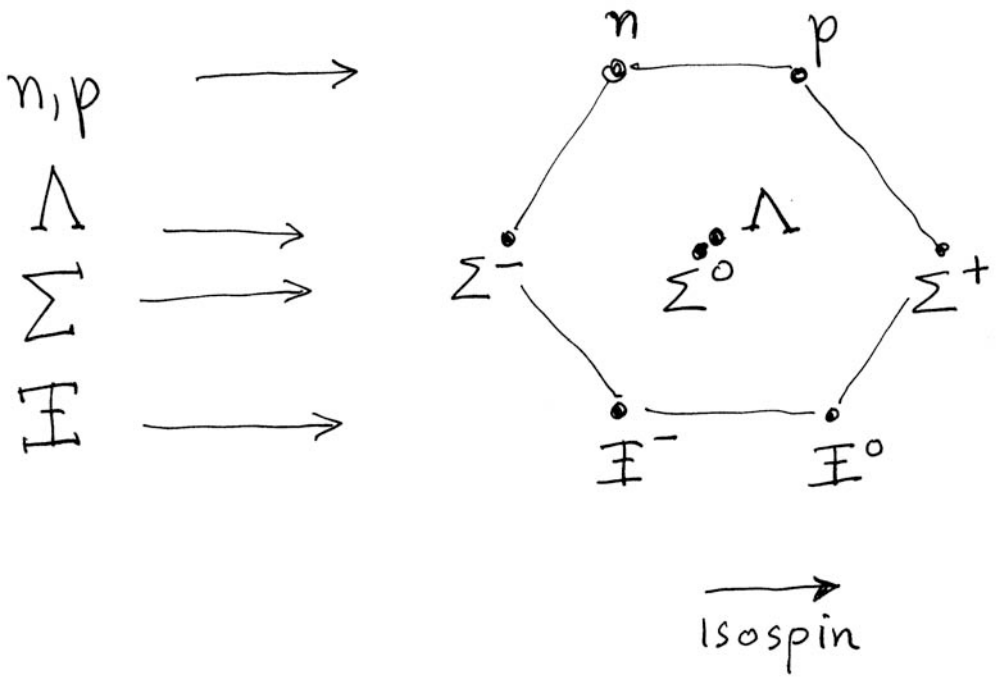
- With perfect hypercharge symmetry, there is only one nucleon (**neutron** and **proton** comprise the atomic nucleus)
- But that would mean no atoms!
- Spontaneously broken hypercharge symmetry creates different particles:
- N nucleon, Σ particle, Λ particle, Ξ particle, each with different mass



Breaking hypercharge symmetry

Electromagnetic symmetry breaking

- There is a further breaking of the symmetry along the isospin axis
- Creates particles with different charge
- N separates into ***n*** (neutral) and ***p*** (+)
- Σ separates into Σ^-, Σ^0 and Σ^+
- Ξ separates into Ξ^- and Ξ^0



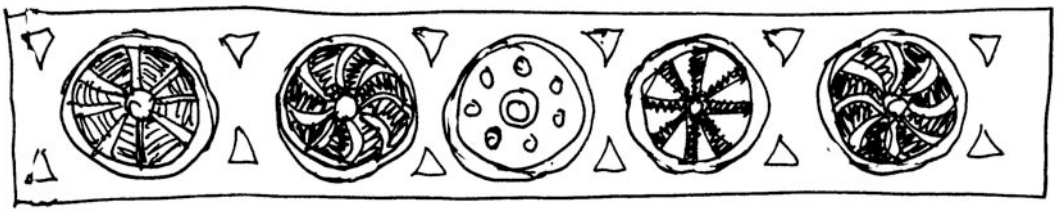
Breaking isospin symmetry

Summary of these results

- Fundamental constituents of matter have strong but approximate symmetry
- Small symmetry breaking is necessary to generate mass and charge
- **Mass is responsible for matter!**
- **Charge is responsible for atoms!**

Analogy and implications for design

- Strong but imperfect symmetries give rise to living structure
- Observed symmetry breaking has a remarkable parallel in broken elementary particle symmetries
- Local rotational symmetry on the small scales, imperfect on the large scale



Broken large-scale translational symmetry containing perfect small-scale rotational symmetries

Large-scale versus small-scale symmetries

- Analogy with fundamental physics
- Imperfect large-scale symmetries, but essential symmetries on the smallest scales — in internal dimensions
- **Something fundamental is happening on the small scale, also in architecture and urbanism**

Architecture is an expression of natural forces, and is not a separate, purely artistic endeavor. Therefore, the laws of structure of the natural universe are highly relevant for architecture, either directly, or by analogy. Strong but imperfect large-scale symmetries order the universe. At the same time, symmetry breaking is known to be responsible for the universe itself, since without symmetry breaking in elementary particles, matter as we know it cannot exist.

9.5. Binding energy

Mass-energy relation

- Well-known conversion relation between mass and energy
- $E = mc^2$ (where c is the speed of light)
- Derived by Albert Einstein
- Energy is needed to bind components of mass together into larger wholes

Combine subatomic constituents

- Constituents will not bind together without extra binding energy, but will forever remain as separate units
- Binding energy is the "glue" of matter
- Mass of the whole equals mass of constituents plus the binding energy

In both physics and architecture, if you just position components next to each other, they will not necessarily bind to create a larger, coherent whole. Proximity does not guarantee cohesion. Extra "binding energy" is necessary, otherwise all we have is a collection of disconnected units that are not really components of any system. Binding requires energy.

Some basic physical bound states (in decreasing size)

- Atoms bind together to form molecules
- Nuclei and electrons bind together to form atoms

- Nucleons (***n*** and ***p***) bind together to form the atomic nucleus
- Quarks bind together to form nucleons (**neutron**, **proton**, other octet members)

Amount of binding energy

- How much binding energy is required to bind masses together into a larger coherent whole?
- It depends on the size of the whole!
- As we go down in scale, **the binding energy becomes as large as the mass**

Binding energy as percentage of total mass of composite unit

- Atoms made from nuclei and electrons: ratio is 5eV/0.5MeV = 10^{-5} = 0.001%
- Nuclei made from nucleons: ratio is 8MeV/940MeV = 10^{-2} = 1%
- Nucleons made from quarks: ratio is 1GeV/1GeV = 1 = 100%

Binding energy in architecture

- In physics, binding energy becomes matter on the lowest scale
- In architecture, the smallest perceivable scale is ornamental
- Here, the binding energy becomes the design itself
- **Ornament becomes substance**

If components are large (on some relative scale), the binding energy needed is small. If components are small, the binding energy needed is large. This result gives an extremely interesting analogy for architecture. I take results from subatomic physics and apply them by analogy to the macroscale. According to this thesis, large forms need a little binding energy, whereas small architectural components require a lot of binding energy. At the limit of the smallest architectural scales, the components cannot be distinguished from the binding energy (connections) used to hold them together coherently.

Analogy with architecture

- Perceivable quality of **substance** in architecture is analogous to the mass in physical matter
- Positive **substance** anchors a building in our cognition, making it possible for us to connect to that structure
- Achieved by combining different tectonic components into a whole

“Glue” becomes substance

- In architecture and urbanism, the strongest binding energy acts on the smallest perceivable scale to humans
- Tectonic components are held together in our mind by connections, symmetries, and

symmetry breaking

- At the smallest scale, the binding glue itself becomes the substance!

The necessity for ornament

- Binding on the smallest scale is essential for coherence and sense of substance in any building, of any shape or size
- At the level of ornamentation, the connections become the object itself
- All larger scales are dependent upon the smallest scale — ornamentation

Precision is not ornament!

- Modernist buildings sometimes have a precision on the smallest scale
- Precise alignment of straight edges
- But precise edges do not generate any coupling or binding energy!
- No small units; no coupling; no binding energy — form is dead

Precision of design and construction is an attractive intellectual idea, but it does not generate any binding energy, hence does not contribute to the coherence of the whole. Nevertheless, the idea of precision and alignment is highly touted by modernist architects as something to strive towards. I believe that this obsession with precision obscures the need for binding energy. Arguing from another direction, binding often results in "roughness", and ornament is most often imprecise. Therefore, insisting upon precision in design may actually prevent design coherence through binding. Those very precise, intellectually pleasing buildings then have a "dead" design.

Ornament is often imprecise

- Ornament often requires imprecision
- "Roughness" property of Alexander
- This is not a celebration of sloppiness, but an intrinsic phenomenon
- Paying attention to the binding energy does not permit us the luxury of being concerned with useless precision

Conclusion: architectural life depends upon ornament

- Living quality of structure and form comes from binding energy
- Ultimately depends strongly upon lowest scale — that of ornament
- Architecture = form + ornament
- **Ornament becomes substance**