40 Inventive (Architecture) Principles With Examples

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This article seeks to explore the applicability of the 40 Inventive Principles of classical TRIZ across the field of architecture. The work comes in the wake of initial work to investigate the usefulness of TRIZ to help solve architecture problems (Reference 1). The intention here has been to develop an architectural analogue to previously published articles highlighting examples of the 40 Principles in both engineering (Reference 2) and business (Reference 3) environments.

Use this document as a reference when seeking to 'eliminate' architecture design contradictions using the 40 Inventive Principles. Future articles will explore the applicability of other TRIZ tools - most notably the Contradiction Matrix - in the definition and solution of architecture centred problems.

In the meantime, in common with findings from other fields of application of the 40 Principles, we suggest that users apply the Principles as a means of structuring systematic brainstorming sessions. Whether or not the Matrix proves useful in an architectural context, we have not found previous architectural solutions that fall outside the scope of the 40 Principles discussed here, and thus propose that if there is a solution to a defined architectural contradiction, it is highly likely to emerge from application of one or more of the Principles described below.

Our recommendation for using the Inventive Principles for architectural problems is to first try to use Principles recommended by the Contradiction Matrix. If these do not prove fruitful, the best option is to work through the remaining Principles - preferably in a randomised sequence.

Principle 1. Segmentation

A. Divide an object into independent parts.

- Multi-room/multi-storey housing
- Dual circuit wiring to provide back-up when failure occurs in one circuit
- Provide separate receptacles for recycling materials (glass, paper, cans, etc) in office buildings
- In factory design separate the office accommodation and manufacturing facility

- In hotel design separate the bedroom block from public areas
- Design against progressive structural collapse.

B. Make an object easy to assemble or disassemble.

- Partition walls
- Prefabricated construction
- Dry construction instead of wet.

C. Increase the degree of fragmentation or segmentation.

- Multi-pane windows
- Venetian blinds
- Pebble-dash as a way of making surface finish more robust
- Art galleries and museums can have different shapes and sizes for displaying different sorts of artefacts
- Multiple small doors on frozen-food cabinets

Principle 2. Taking out/Removal/Extraction

A. Separate an interfering part or property from an object, or single out the only necessary part (or property) of an object.

- Locate noisy equipment (air-conditioning plant, etc) outside a building
- Placing of quiet and meeting areas in places of work
- Non-smoking areas in restaurants or in public buildings
- Outside meters avoid need for utility companies to have access to property
- Cupboard accessible by key from inside or outside allows delivery of goods when occupants are not present
- Glass (noise-proof) partitions in office buildings
- Utility room/pet-room/garage
- Guttering takes rainwater away from structure of building
- Exterior fire escape or lift do not interfere with plan
- Bell-tower - needs height and also reduces noise and vibration effects
- Tram or bus stop indicated by a painted stripe high on a pole - nothing at ground level
- Pedestrian/vehicle segregation
- Frameless glazing
- Lightning conductor

Principle 3. Local quality

A. Change an object's structure from uniform to non-uniform

- Texture-finish building materials
- Material surface treatments/coatings - self-cleaning paint, etc
- Increased wall thickness at the base of buildings relative to higher up to accommodate greater structural loads
- Incorporation of low radar-cross-section features on airport buildings
- Location features on roof-tiles
- Compound façade constructions

- High-friction compounds and/or visibly stand-out features on stair edges
- Non-homogenous distribution of rebar in concrete gives tailored strength properties
- Low-emissivity film glass
- Black dots at the edges of windows serve to improve appearance (blending between transparency and solid structure) - as used in car windscreens
- Lotus Effect - self-cleaning paint
- Weakened/thinner break glass points on window-units
- Damp proof course in wall
- Reinforcement of openings
- Arch in masonry
- Vary standard of insulation
- Movement joints

B. Change an external environment (or external influence) from uniform to non-uniform.

- Make allowances for temperature, density, or pressure gradient instead of constant temperature, density or pressure when examining effects of local environment on airflows around (high-rise) buildings.
- Bias towards South-facing windows
- Greater standard of security for ground floor windows
- Different security arrangements for front and back of shop

C. Make each part of an object function in conditions most suitable for its operation.

- Different shaped rooms for different functions - plumbed and non-plumbed, for example
- Incorporation of a pantry room on externally placed walls to achieve lower temperature than living spaces
- In low energy design locate rooms with low design temperatures and buffer spaces to the north; locate large rooms with high design temperatures to the south

D. Make each part of an object fulfil a different and/or complementary useful function.

- Structural transparency tiles
- Ventilation tiles on a roof
- Cable-TV provides telephone, internet, tele-medicine and other services
- Gravel provides security as well as a ground surface finish
- Fire-retarding paint

Principle 4. Asymmetry *A. Change the shape or properties of an object from symmetrical to asymmetrical.*

- Introduce a geometric feature which prevents incorrect usage/assembly of a component (e.g. earth pin on electric plug)
- Corner bricks
- Keystone
- Coated glass or paper
- Introduction of angled or scarfed geometry features on component edges

- Non-circular section chimneys reduce drag against prevailing wind direction
- Sloped roofing
- Single-drainer sink unit
- High-flow gutter uses asymmetry to better control entry flow of rainwater from roof into down-pipe (30% more flow for a given entry area)
- "Modern" planning as opposed to classical planning
- Tongued and grooved flooring
- T beam floor construction
- Double doors where one leaf is wider than the other

B. Change the shape of an object to suit external asymmetries (e.g. ergonomic features)

- Human-shaped seating, etc
- Take account of differences between left/right handed, male/female users
- Finger and thumb grip features on objects
- Pull-handles versus push-plates on doors
- Aerofoil sections with different top and bottom surface geometries
- Passive solar house design
- Site Planning to respect an individual site

C. If an object is asymmetrical, increase its degree of asymmetry.

- Compound/multi-sloped roofing
- Cable assisted cantilever roofs
- Folding doors

Principle 5. Merging A. *Bring closer together (or merge) identical or similar objects or operations in space*

- Double/triple glazing
- Double panel radiators
- Sprinkler systems offers centralised 'fire-management' capability
- Networked neighbourhoods - permit load sharing between multiple properties
- Multi-purpose halls
- Sandwich panels

B. Make objects or operations contiguous or parallel; bring them together in time.

- Co-location of services - gas, cable, electricity, water, etc - minimises underground disruption
- Mixer taps
- Prefabrication
- "Design and Build" method of procurement (multi-skilling within company)
- "Partnering" - co-operative team based approach to construction reduces conflict, litigation and claims

Principle 6. Universality *A. Make a part or object perform multiple functions; eliminate the need for other parts.*

- Fire glass - glass with steel wire re-enforcement that prevents release of broken glass upon breakage.
- Built-in wardrobes/cupboards/etc
- Velux windows - provide illumination, heat insulation, ventilation and weather-proofing
- Water-drum walls
- Water tanks on top of buildings provide insulation and head for water supply
- Use power cables as a communication medium (e.g. control signals for 'central locking' system for house
- Gargoyle eliminates the need for downpipe
- Thermostatic radiator valves, shower mixers, etc
- Combined doorbell and smoke alarm
- Doormat senses visitors
- Self-latching door lock with deadlock

B. Use standardised features.

- Use of Standards in e.g. safety regulations
- Corporate-branded architecture for franchise or chain buildings
- Cavity walls with standard dimensions for masonry, insulation, cavity trays and wall ties
- Proprietary cladding systems with specified performance

Principle 7. "Nested doll"

A. Place one object inside another

- Place a safe inside a wall or under floorboards
- Introduce voids into 3D structures
- Injected cavity-wall insulation
- Dry-lining
- False ceilings
- Under-floor 'trench' heating
- Place electrical wiring inside architraving/dado rails/etc
- Roller shutters
- Cavity wall insulation batts
- Sound isolation of concert hall

B. Place multiple objects inside others.

- Stacking chairs
- Multi-layer erosion/corrosion coatings
- Integration of services
- Ducts for pipes, wiring etc.
- Shopping centres
- Franchises (e.g. car-hire offices and shops in airports and railway stations)

C. Make one part pass (dynamically) through a cavity in the other.

- Retractable seating in auditoria

- Services pass through the structure of a building
- Use circulation space as the return route with warm air heating systems
- Retractable loft stairs
- Adjustable floor levels and/or seating arrangements in theatres
- Sliding doors

Principle 8. Anti-weight *A. To compensate for the weight of an object, merge it with other objects that provide lift.*

- Floating floor
- Use of counterweights in lifts and sash windows
- Use of cranes/hoists, etc

B. To compensate for the weight of an object, make it interact with the environment (e.g. use aerodynamic, hydrodynamic, buoyancy and other forces).

- Houseboat.
- Design a building to float using a tanked basement
- Location of circulation pump in hot-water heating systems
- Passive solar heaters use natural convection currents to circulate water

Principle 9. Preliminary anti-action

A. If it will be necessary to perform an action with both harmful and useful effects, this action should be replaced with anti-actions to control harmful effects.

- Sustainable design
- Dust removal from power tools
- Minimise entropy increases
- Use recycled materials
- Plant trees to replace wood
- Use renewable energy

B. Create beforehand actions in an object that will oppose known undesirable working stresses later on.

- Pre-stress rebar before pouring concrete.
- Pre-stressed bolts
- Balancing laminates
- MDF can be worked in all
- Vapour-permeable paint helps prevent rot in wood
- Galvanising
- Prevent electrolytic corrosion by separating dissimilar metals

Principle 10. Preliminary action *A. Perform, before it is needed, the required change of an object (either fully or partially).*

- Pre-fabricated window units, bathrooms and other structures
- Pre-fabricated buildings
- ‘Design for re-cyclability’
- Ready-mix concrete
- IT infrastructure

- Copper pipe connections pre-filled with solder
- Double-glazing with vacuum or inert gas
- Night storage heater
- Supply chain management

B. Pre-arrange objects such that they can come into action from the most convenient place and without losing time for their delivery.

- Audubon Society HQ building features integral recycling chutes allowing pre-sort of different materials by individuals within the building
- Piped water and other services especially in hospitals
- Central vacuum cleaning
- Sprinkler systems for fire
- Pre-payment machines in car-parks
- Pre-compressed sealing tape
- Standardised objects with known specification
- Servery on same floor as dining area when kitchen is not

Principle 11. Beforehand cushioning

A. Prepare emergency means beforehand to compensate for the relatively low reliability of an object ('belt and braces')

- Emergency circuit lighting
- Dual channel control system
- Battery/Stand-by generator power back-up
- Mask borders of objects to be painted, use stencils
- Emergency stairways/fire-escapes
- Crash pillars prevent ram-raiding on shops
- Lightning rods
- Factors of safety
- Cavity trays
- Overflows

Principle 12. Remove Tension

A. In a potential field, limit position changes

- Counter-balance elevators
- Inclusion of an inspection pit inside a garage eliminates the need to raise and lower the car during maintenance
- Bungalows have only one floor
- Use cleaning platforms to clean large objects
- Add electrically grounded surfaces in electronic component manufacture facilities
- Ramps for wheelchairs
- Pressure equalised facades

Principle 13. 'The other way round'

A. Invert the action(s) used to solve the problem (e.g. instead of cooling an object, heat it).

- To loosen stuck parts, cool the inner part instead of heating the outer part.
- Negative-lift ridge tiles - press down harder the higher the wind - so less likely to be damaged
- Burolandshchaft (open plan offices)
- Self-service stores
- Open prisons
- Tilt and turn windows can be cleaned from the inside
- Instead of providing more and more car parking, provide NO car parking

B. Make movable parts (or the external environment) fixed, and fixed parts movable.

- Wind tunnels
- Moving sidewalk with standing people
- Drive through restaurant or bank
- Use of credit instead of cash reduces the need for face to face transactions and hence office space
- Instead of people's having to come to hospital use travelling medical facilities

C. Turn the object (or process) 'upside down'.

- Lloyds building places pipes and services outside rather than inside the building
- Most architectural structures rely on compressive forces, use of tension wires/tensegrity structures permits construction of lighter structures with greater internal space
- Downstairs bedrooms (cooler); upstairs living rooms (better view)
- Houses constructed from the inside out
- Auxetic (negative Poisson Ratio) foams and structures
- Pedestrianise streets

Principle 14. Spheroidality - Curvature

A. Instead of using rectilinear parts, surfaces, or forms, use curvilinear ones; move from flat surfaces to spherical ones; from parts shaped as a cube (parallelepiped) to ball-shaped structures.

- Use arches and domes for strength.
- Introduce fillet radii between surfaces at different angles
- Introduce stress relieving holes at the ends of façade and other structures
- Curved driveways improve aesthetics
- Port-hole windows
- Circular-section buildings - light-houses, towers, etc
- Geodesic structures - maximum space coverage with minimum material usage
- Circular-section pillars and columns
- Architraving - blends join between wall and ceiling
- Curved floor edges make bathroom/changing-room floors more easy to clean

- Rounded edges soften appearance of electrical sockets and switches
- Curved roof shape avoids the need to construct a ridge
- Use curved retaining walls for extra strength
- Use monocoque construction for better strength to weight ratio

B. Use rollers, balls, spirals, domes.

- Archimedes screw pumps concrete/sealants/etc into cavities
- Domed roofs
- Spiral plan for an infinitely extending museum

C. Go from linear to rotary motion (or vice versa)

- Revolving doors help keep heat inside a building
- Rotating observation tower on top of tall buildings
- Screw thread versus nail.
- Linear city design maximises access to transport corridors
- Use shot-bolt fixings instead of drilled

D. Use centrifugal forces.

- Centrifugal casting for even wall thickness concrete structures
- Radius of gyration affects stability during earthquakes

Principle 15. Dynamics

A. Allow (or design) the characteristics of an object, external environment, or process to change to be optimal or to find an optimal operating condition.

- Opening windows/self-regulating windows
- Thermo- or Photo-chromic glass
- Shape memory alloys/polymers
- Flexible office layouts
- Moveable insulation
- Thermostats

B. Divide an object into parts capable of movement relative to each other.

- Articulated piles allow pile to be sharp (for ease of driving in to the ground) and blunt (to create a positive location once in place)
- Roofing slates
- Movement joints
- Bleacher seating

C. If an object (or process) is rigid or inflexible, make it movable or adaptive.

- Retractable roof structures
- Flexible joint
- Floating floors

- Collapsible hose is flexible in use, and has additional flexibility of cross-section to make it easier to store
- Multi-purpose halls
- Use escalators instead of stairs
- Structural and other redundancies allow future changes

D. Increase the degree of free motion

- 'Moving internal wall' systems allow house layout to be changed to suit evolving needs of occupants
- Demountable structures
- Telemedicine facilities
- University outreach facilities

Principle 16. Partial or excessive actions

A. If 100% of a solution is hard to achieve, then, by using 'slightly less' or 'slightly more' of the same method, the problem may be considerably easier to solve.

- Over spray when painting, then remove excess.
- Over-fill holes with plaster and then rub back to smooth
- Over designing floor joists results in negligible deflection
- Use skilled craftsmen on site to complete prefabricated work
- Hot dip galvanising
- Design for say 95% of requirement is often the practical solution for e.g. heating systems, car parking
- (Use of Pareto analysis to prioritise actions when not all can be achieved with the available resources.)

Principle 17. Another dimension

If an object contains or moves in a straight line, consider use of dimensions or movement outside the line.

- Use of triangles (cross-members, etc) improve strength/stability of frame structures
- Bay windows
- Frank Lloyd Wright 'Fallingwater' house blends architecture with natural slope of landscape
- Pyramidal structures (non-vertical walled structures)
- Indirect lighting
- Stair lifts
- Slotted fixings
- A curve at the base of a roof slows down the rainwater

If an object contains or moves in a plane, consider use of dimensions or movement outside the current plane.

- Spiral staircase uses less floor area
- Corrugated roofing materials offer high stiffness and low weight
- Introduction of down and up slopes between stations on railway reduces train acceleration and deceleration power requirements

- Score key-slots into a wall before plastering improves adhesion of plaster
- ‘Round-the-corner’ windows provide better views and cross-ventilation
- Curved or profiled roofing materials have superior spanning capabilities
- Shell and monocoque construction

C. Use a multi-storey arrangement of objects instead of a single-storey arrangement.

- Multi-storey office blocks or car-parks
- Automated parts warehouses
- Multi-use buildings e.g. shopping centres

- *D. Tilt or re-orient the object, lay it on its side.*
  - Hang a mirror with corners (rather than edges) top and bottom to cater for greater variety of user heights for a given size of mirror

  Take a door off its hinges to plane top and bottom surfaces to size

  Vertically mounted radiators (use less floor space)

  Angled glazing/tilting windows

  Modern kitchen overlooks street/front

E. Use 'another side' of a given area.

- ‘Invisible’ door hinges
- Hydrostatic pressure keeps waterproofing layer attached to outer face of basement wall

Principle 18. Mechanical vibration

A. Cause an object to oscillate or vibrate.

- Vibration exciter removes voids from poured concrete
- Use non-parallel walls to prevent acoustic standing waves
- Use radius of gyration for earthquake design

B. Increase its frequency (even up to the ultrasonic).

- Use white noise to disguise conversation
- Ultrasonic cleaning
- Non-destructive crack detection using ultrasound

C. Use an object's resonant frequency.

- Use Helmholtz resonators to absorb sound
- Use resonance to speed the flow of concrete from hopper

D. Use piezoelectric vibrators instead of mechanical ones.

- Piezoelectric vibrators improve fluid atomisation from a spray nozzle

E. Use combined ultrasonic and electromagnetic field oscillations.

- Geo-physics techniques to aid identification of sub-soil structures
- Crack detection using ultrasound

Principle 19. Periodic action *A. Instead of continuous action, use periodic or pulsating actions.*

- Take account of day/night temperature and light difference effects when designing thermal/illumination management systems
- Ditto seasonal effects
- Pulse-showers use less water than conventional continuous jets
- Spot welding
- Pile driving
- Use railings or bollards instead of walls

B. If an action is already periodic, change the periodic magnitude or frequency.

- Replace a pulsed siren with sound that changes amplitude and frequency
- Column frequency
- Vary column spacing
- Tartan grids

C. Use pauses between actions to perform a different action.

- Clean barrier filters by back-flowing them when not in use.
- Use of energy storage means - e.g. batteries, fly-wheels, etc
- Refill WC cistern while not in use

Principle 20. Continuity of useful action

A. Carry on work continuously; make all parts of an object work at full load or optimum efficiency, all the time.

- Flywheel stores energy
- Improve composting process by continuously turning material to be composted
- Multi-purpose spaces
- Multi-function spaces and personnel

B. Eliminate all idle or intermittent actions or work.

- Self-cleaning/self-emptying filter eliminates down-time

- Rapid-drying paint
- Reduce or eliminate circulation by staff
- Reduce or eliminate circulation space
- Use every part of a building to "sell" etc

Principle 21. Skipping

A. Conduct a process, or certain stages (e.g. destructible, harmful or hazardous operations) at high speed.

- Cut plastic faster than heat can propagate in the material, to avoid deforming the shape.
- Continuous pouring of concrete
- Large sheets of roofing material allow quick erection enabling other trades to work under cover

Principle 22. "Blessing in disguise" or "Turn Lemons into Lemonade"

A. Use harmful factors (particularly, harmful effects of the environment or surroundings) to achieve a positive effect.

- Use waste heat to generate electric power.
- Composting toilets
- Secure piles by exploding a cavity around the base and then pouring concrete into the cavity
- Negative-lift ridge tiles - press down harder the higher the wind - so less likely to be damaged
- Combined heat and power
- Double-glazing
- Use a narrow soft cork strip at the edges of a timber floor to allow expansion and contraction

B. Eliminate the primary harmful action by adding it to another harmful action to resolve the problem.

- Use toxic chemicals to protect timber from infestation and rot

C. Amplify a harmful factor to such a degree that it is no longer harmful.

- Fully glazed conservatories maximise solar gains, but cannot waste heat because they are not heated artificially

Principle 23. Feedback

A. Introduce feedback (referring back, cross-checking) to improve a process or action.

- Motion sensitive lighting/toilet flush/etc systems
- Thermostatic temperature controls

- Heat/smoke sensors used to detect fire
- Supply chain management
- Glass doors and breast-high partitions allow people on either side see when there is someone on the other side

B. If feedback is already used, change its magnitude or influence in accordance with operating conditions.

- Change sensitivity of a thermostat when cooling vs. heating, since it uses energy less efficiently when cooling.
- Fuzzy-logic thermostats
- Involve manufacturers during early design stages
- Use clerk of works, cladding consultants etc.
- Increase frequency and/or detail of inspection for certain site operations

Principle 24. 'Intermediary'

A. Use an intermediary carrier article or intermediary process.

- Lead-flashing forms leaf-proof seal between external wall and attached structures
- Skirting boards protect delicate plaster from damage by vacuum cleaners, etc
- Fly-screen door
- Small ceramic tiles and woodblock flooring power supplied stuck to a disposable sheet
- Pipe lagging

B. Merge one object temporarily with another (which can be easily removed).

- Abrasive particles enhance water jet cutting
- Demountable insulating window shutters

Principle 25. Self-service

A. Make an object serve or organise itself by performing auxiliary helpful functions

- On-site water purification plant.
- Use building contours to channel wind energy towards wind-turbine
- Earth covered roofing ‘maintains’ itself
- ‘Self-cleaning’ guttering - prevents blockage by leaves, etc
- Self draining cladding systems
- Door with glass panel
- Self-latching locks
- Self-levelling screed

B. Use waste resources, energy, or substances.

- Use heat from a process to generate electricity: "Co-generation".
- Grey water recycling systems
- Solar panels/collectors to heat water or generate electrical power
- Heat exchanger takes heat from waste hot water
- Use waste heat from internal equipment (e.g. from computer rooms, heavy machinery) to generate thermal gradients to drive 'natural' ventilation systems
- Geothermal energy
- Combined heat and power
- Air-to-air heat exchanger
- Brick rubble used for hardcore

Principle 26. Copying

A. Instead of an unavailable, expensive, fragile object, use simpler and inexpensive copies.

- Virtual reality
- Virtual mock-ups/electronic pre-assembly modelling
- Astroturf
- Cast-concrete 'sculpture'
- Multimedia presentations for tourism, training etc
- Spoken announcements (recorded - railway stations, synthesised - lifts)

B. Replace an object, or process with optical copies.

- Do surveying from aerial photographs instead of on the ground.
- Measure an object by measuring the photograph
- Colour prints of paintings
- Mural "views"
- Imitation wood grain veneers

C. If visible optical copies are already used, move to infrared or ultraviolet copies.

- Make images in infrared to detect heat sources, such as diseases in crops, or intruders in a security system.
- Use UV as a non-destructive crack detection method
- Detect heat losses through facades using infra-red photography
- Use X-rays to detect structural faults

Principle 27. Cheap short-living objects

A. Replace an expensive object with a multiple of inexpensive objects, compromising certain qualities (such as service life, for instance).

- Disposable doormats

- Paper towels
- Port-a-loo (foundations for)
- Regular painting to protect otherwise non-durable surfaces
- Plastic one-piece chairs

Principle 28 Mechanics substitution

A. Replace a mechanical means with a sensory (optical, acoustic, taste or smell) means.

- Replace a physical fence to confine a dog or cat with an acoustic "fence" (signal audible to the animal).
- Motion-sensitive switches remove need for occupant having to locate mechanical switch
- Light-locks
- Wireless data transmission between computer systems
- Electro-opaque glass eliminates the need for curtains
- "White noise" for acoustic privacy

B. Use electric, magnetic and electromagnetic fields to interact with the object.

- Electric lock 'keys'/swipe keys
- Electromagnetic stays hold fire doors open, released by fire alarm
- Electric fence

C. Change from static to movable fields, from unstructured fields to those having structure.

- Intelligent lock 'keys' - unique signal attached to each key permits increased flexibility of use - e.g. only allowed at certain times of day
- Zoned heating systems
- Occupant-adjustable colour lighting in hotel rooms

D. Use fields in conjunction with field-activated (e.g. ferromagnetic) particles.

- Heat a substance containing ferromagnetic material by using varying magnetic field. When the temperature exceeds the Curie point, the material becomes paramagnetic, and no longer absorbs heat.
- Radiopaque powders placed inside cement in critical regions in order to enable integrity by x-ray analysis

Principle 29. Pneumatics and hydraulics

A. Use gas and liquid parts of an object instead of solid parts (e.g. inflatable, filled with liquids, air cushion, hydrostatic, hydro-reactive).

- Inflatable furniture/mattress/etc

- Hydraulic elevator systems replace mechanical drives
- Self-levelling screed
- Use internal water features to assist climate control
- Use water level to ensure flat surface for foundations
- Warm air heating systems
- Natural ventilation and stack effect

Principle 30. Flexible shells and thin films

A. Use flexible shells and thin films instead of three-dimensional structures

- Use inflatable (thin film) structures.
- I, C or U beams instead of solid section beams
- Webbed structures
- Honeycomb door in-fill gives strength with lightness
- Buckminster Fuller 'Dymaxion' House
- Intumescent paint protects steel structures against fire
- "Stretch" ceilings

B. Isolate the object from the external environment using flexible shells and thin films.

- Bubble-wrap
- Egg-box
- Draft proofing
- "Thinsulate" heat insulation

Principle 31. Porous materials

A. Make an object porous or add porous elements (inserts, coatings, etc.).

- Drill holes in a structure to reduce the weight.
- Breeze block
- Air-bricks
- Cavity wall insulation
- Extruded foam under-floor insulation
- Passive stack ventilation systems
- Transpiration film cooled structures
- Foam metals
- Use sponge-like structures as fluid absorption media
- "Breathable" membranes
- Pressure equalised cladding systems

B. If an object is already porous, use the pores to introduce a useful substance or function.

- Use a porous metal mesh to wick excess solder away from a joint.
- Desiccant/pest repellent in cavity wall insulation

- At night pass air through hollow structure to cool it

Principle 32. Colour changes

A. Change the colour of an object or its external environment.

- Electro or photo-chromic glass
- Camouflage
- Use lighting effects to allow occupants to interactively 'change the colour' of a room.
- Employ interference fringes on surface structures to change colour (as in butterfly wings, etc)
- Albedo effect

B. Change the transparency of an object or its external environment.

- Put glass in doors on corridors so that users can see if someone is on the other side
- Light-sensitive glass
- Electro-chromic glass allows occupant to vary transparency
- Deciduous trees give shade in summer but let sunlight pass through in winter

C. In order to improve observability of things that are difficult to see, use coloured additives or luminescent elements

- Fluorescent safety markings help guide people out of a building after power failure
- Use opposing colours to increase visibility - e.g. butchers use green decoration to make the red in meat look redder
- Specify undercoats to be different shades to help inspection

D. Change the emissivity properties of an object subject to radiant heating

- Use of light and dark coloured panels to assist thermal management in building spaces.
- Use of parabolic reflectors in solar panels to increase energy capture.
- Paint object with high emissivity paint in order to be able to measure it's temperature with a calibrated thermal imager
- Low emissivity glass

Principle 33. Homogeneity

A. Make objects interacting with a given object of the same material (or material with identical properties).

- Make the container out of the same material as the contents, to reduce chemical reactions
- To avoid cracking make sure that abutting materials have similar coefficients of expansion
- Ensure that adjacent metals are similar in order to avoid electrolytic corrosion

Principle 34. Discarding and recovering

A. Make portions of an object that have fulfilled their functions go away (discard by dissolving, evaporating, etc.) or modify these directly during operation.

- Ice structures: use water ice or carbon dioxide (dry ice) to make a template for a rammed earth structure, such as a temporary dam. Fill with earth, then, let the ice melt or sublime to leave the final structure
- Reusable form-work for concrete
- Pour concrete directly into trenches (no form-work needed)

B. Conversely, restore consumable parts of an object directly in operation.

- Grey-water recycling systems
- Heat exchanger recovers lost heat from (for example) water emptied from a bath

Principle 35. Parameter changes

A. Change an object's physical state (e.g. to a gas, liquid, or solid).

- Adhesives instead of mechanical joining methods
- Use injected (liquid) silicon rubber sealants
- Liquid plastic, paint-on roofing top-coats
- Pouring concrete

B. Change the concentration or consistency.

- Change aggregate mix in concrete to alter properties
- Dilute paint to achieve ‘wash’ effects
- Different grades of MDF

C. Change the degree of flexibility.

- Use adjustable dampers to provide active vibration damping in buildings.
- Rubber-mounted windows improve vibration damping
- Flexible service run pipes

D. Change the temperature.

- Climate control
- 'Thermal curtain' (blown warm air) used in doorways of public building
- Use natural thermal gradients to create natural convection heat management in tall buildings
- 'Thermal mass' used to store thermal energy

E. Change the pressure.

- Use vacuum suction to improve flow of concrete/sealants/etc into awkward shaped cavities
- Set prefabricated structures under loads that will mimic installed loads
- Use barometric pressure gradients to improve ventilation in tall buildings

F. Change other parameters

- Shape memory alloys/polymers - self regulating window hinges
- Use Curie point to alter magnetic properties - thermal switching

Principle 36. Phase transitions

A. Use phenomena occurring during phase transitions (e.g. volume changes, loss or absorption of heat, etc.).

- Heat pipes
- Use a phase change to store energy - e.g. store energy as ice, or, where heating is the issue use sodium acetate to store heat energy
- Refrigeration plant
- Store thermal energy using phase transition materials (e.g. sodium sulphate)
- Use melting ice as a way of gently lowering heavy structures

Principle 37. Thermal expansion

A. Use thermal expansion (or contraction) of materials.

- Fit a tight joint together by cooling the inner part to contract, heating the outer part to expand, putting the joint together, and returning to equilibrium.
- Through-bars help straighten buckling walls in old buildings
- Expansion joints

B. If thermal expansion is being used, use multiple materials with different coefficients of thermal expansion.

- Bi-metallic strips used for thermostats, etc
- Shape-memory blind fasteners
- Bi-metallic (or shape memory) hinges offer self-opening windows/ventilators in order to regulate climate inside building (e.g. industrial greenhouse)

Principle 38. Enriched atmosphere

A. Replace common air with oxygen-enriched air.

- Place plants in living spaces
- Introduce oxygen into hospital intensive care facilities

B. Replace enriched air with pure oxygen.

- Cut at a higher temperature using an oxy-acetylene torch

C. Expose air or oxygen to ionizing radiation.

D. Use ionized oxygen.

E. Replace ozonized (or ionized) oxygen with ozone.

- (No examples identified)

Principle 39. Inert atmosphere

A. Replace a normal environment with an inert one.

- Creation of 'calm' spaces into office buildings
- Helium filled double-glazing units
- Sealed museum displays
- Clean rooms for silicon chip manufacture
- Fire extinguishing systems

B. Add neutral parts, or inert additives to an object.

- Non-flammable additives into cavity wall foams
- Dampers
- Sound absorbing panels
- Timber treatments for pest control
- Aggregate in concrete
- Hollow block floors

Principle 40. Composite materials

A. Change from uniform to composite (multiple) materials where each material is tuned to a particular functional requirement.

- Concrete aggregate.
- Rebar re-enforced concrete
- Glass-re-enforced plastic
- Fibre re-enforced spray/paint-on roofing treatments
- Fire-glass
- Hard/soft/hard multi-layer coatings to improve erosion, etc properties
- Straw and pressed earth building materials
- Mixed fibre carpets

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