TWELVE GOLDEN RULES *for* BUILDING DESERT CITIES

Supporting energy efficiency by honoring cultural heritage

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Twelve Golden Rules *for* Building Desert Cities

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The twelve guidelines presented in this report combine research findings in traditional desert architecture, urban planning, construction methods, energy efficiency, architecture design, residential density, traffic calming, and cultural identity that can contribute to creating desirable, comfortable cities in desert regions. They are presented to serve as an aid in the building or renovation of desert structures as well as in the planning and design of new areas. The twelve principles for building desert cities discussed in this report are:

- Massive Walls
- Vaults and Domes
- Shaded Courtyards
- Passive Ventilation
- Narrow Lanes
- South Oriented Arcades
- Low Rise, High Density
- Preventing Unwanted Mass Motor Traffic
- Urban Greenery
- Water
- Advantages of Low Humidity and Daily Temperature Changes
- Grown Structures

Rule 1: Massive Walls

– Well-insulating (low k values), helpful to keep an interior cool
– High heat-storing capacity
– With moderate openings, well-oriented windows
  • avoid undesired sun irradiation
  • minimize loss of cool air
  • protect privacy

Mud brick house in Nile Valley, by Hassan Fathy

Comments:

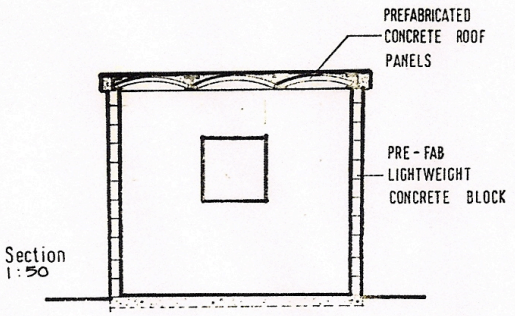
Bricks are the best choice and they are recyclable. In rural settlements with experienced craftsworkers or self-builders, mud bricks (mechanically reinforced with the fibres of straw or chaff and–if no sticky mud is available–adding 7% cement to the local sand) are still a good choice. These require the least energy input and have the lowest heat conduction (k value). Thick walls are desirable for static reasons. Mud bricks allow energy-saving domes and barrel vaults to be built even without wooden scaffolding. Yet they have some drawbacks: mud bricks require permanent maintenance and thick walls consume some additional space compared with other methods. Basements must be protected against moisture.

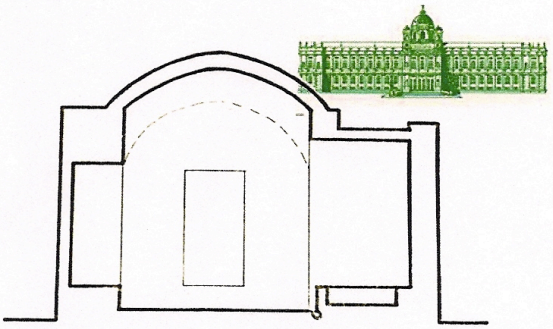
A contemporary building in an old environment. Baked brick is an appropriate, and even recyclable, material. (Isfahan)

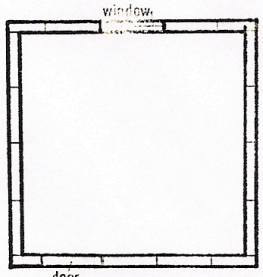
Where space economy (expensive land prices) are critical, together with statics, fired brick stone is more appropriate. Also, a concrete core coated by insulating material such as adobe plaster (as in the contemporary examples in Nizwa, Oman or Santa Fe, New Mexico) or foam glass, cork, etc., covered by roughcast, may be recommendable, although mud brick offers three times as much heat insulation as concrete of the same thickness. For reasons of statics, mud brick walls are four to five times as thick, increasing insulation up to 15 times that of a concrete wall.

Heat Conductivity of Building Materials

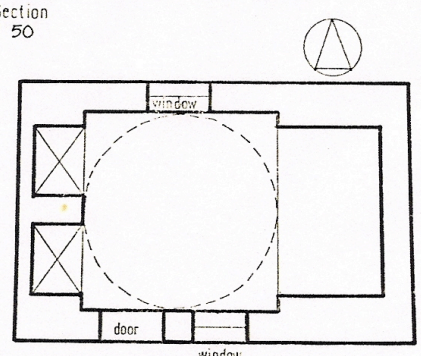
Mud bricks (air dried)	0,22 - 0,32 cal per minute and cm^2 and unit of thickness
Baked bricks (red bricks)	0,40 - 0,48 cal per minute and cm^2 and unit of thickness
Hollow concrete blocks	0,8 cal per minute and cm^2 and unit of thickness



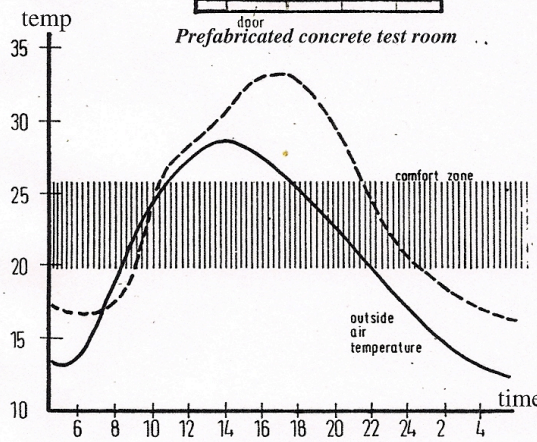




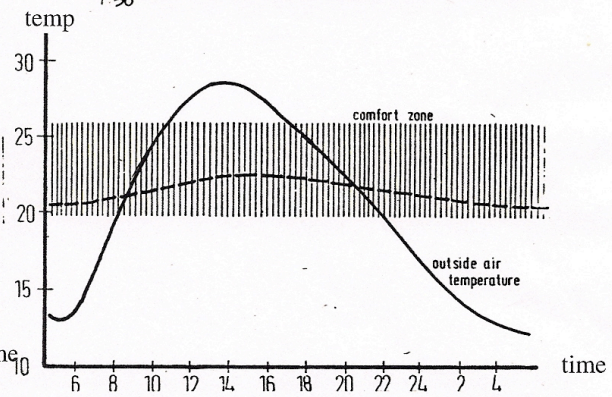
Prefabricated concrete test room



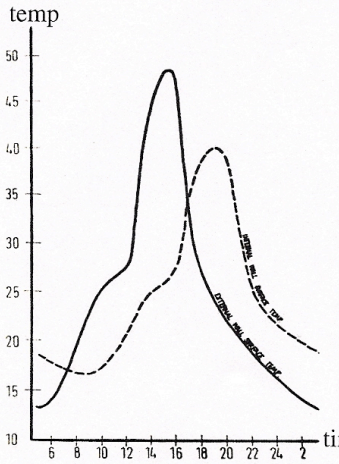
sun dried mud brick vault and dome test room



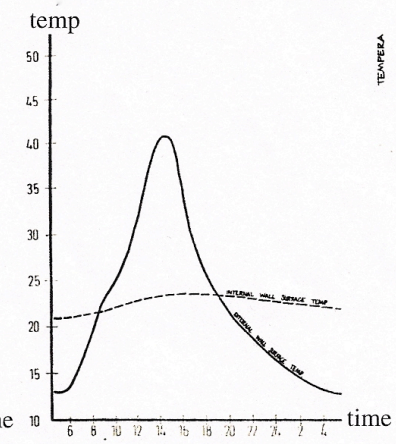
: Prefabricated concrete room interior air temperature - it even climbed higher than outside extremes



: Mud brick room interior air temperature - here the house was able to even out the extremes never leaving the hatched „comfort-zone“



west wall - prefabricated concrete room

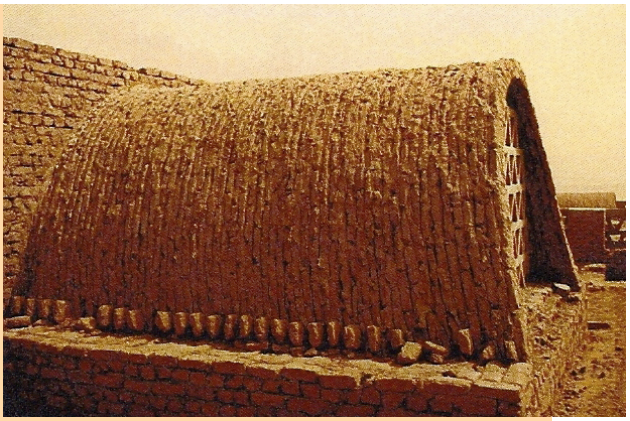


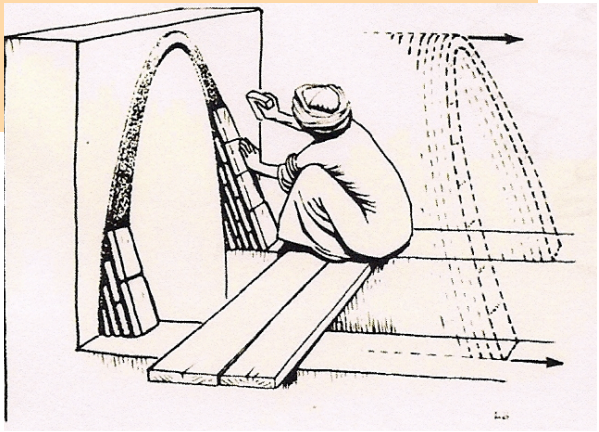
west wall – mud brick room

comparison of exterior and interior wall temperatures
west walls usually are exposed to highest extreme temperatures

Rule 2: Vaults and Domes

Vaults and domes are especially effective when built over assembly rooms. Public and semipublic areas where people gather (lecture halls, restaurants, artisanats, department stores, bazaars, sukhs, etc.) should be at least two stories high in hot climes, allowing body heat to escape upwards through openings on top of rooms and vaults. Winds flowing over curved surfaces generate a ventilating upward suction (Venturi effect).

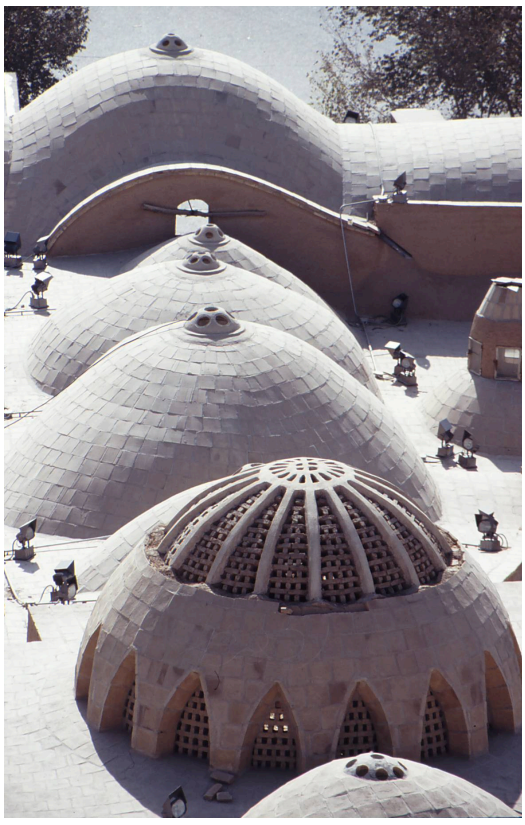




The brick rows are laid on the supporting wall in a slightly oblique, inclined direction. This deviation from the vertical is sufficient to prevent the next lot of bricks from sliding off. Unplastered walls and domes show this slightly oblique texture.

Comments:

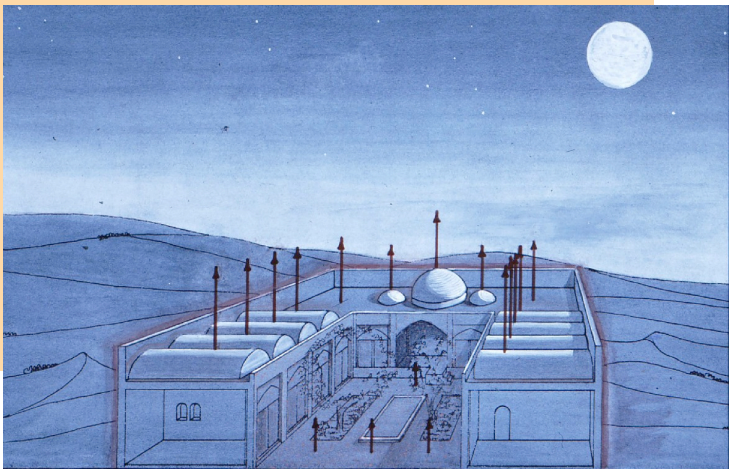
Vaults and domes are part of the cultural identity of desert cities. Surprisingly simple and ingenious traditional skills for building barrel vaults without wooden scaffolding (except for the bricklayer's sitting board) were demonstrated by Nubian master masons in the 1940s to Prof. Hassan Fathy. The professor had been desperately searching for the ancient technique after he had failed to build structurally sound mud brick vaults even using expensive scaffolding.



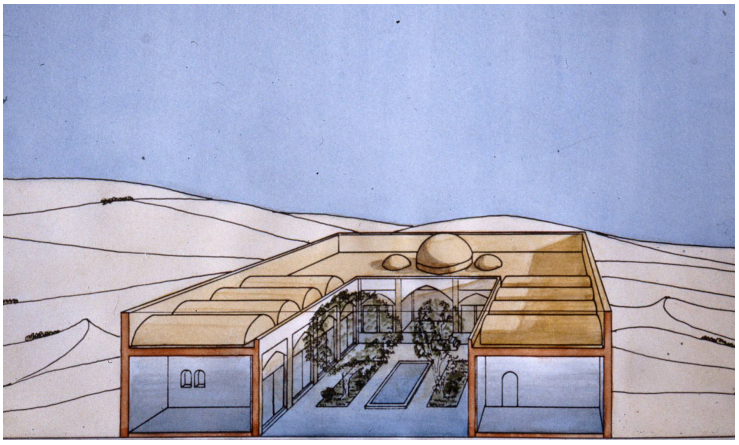
Domes over public buildings are not only beautiful, they keep the buildings ventilated and cool. These are in Yazd (left) and Qasvin.

Rule 3: Shaded Courtyards

During clear desert nights, buildings radiate their heat up into the cloudless sky. Enclosed on all sides, shaded courtyards form reservoirs of cool night air (because it is heavier than warm air) persisting during morning hours and prolonged by the shade of trees and evaporation cooling of pond surfaces. As deserts have extreme T-differences between hot days and cold nights, the benefits of courtyards are highest in desert climes.



Cold night air fills the courtyard house.



Heavier than warm air, the cool air (blue) is stored for some hours.

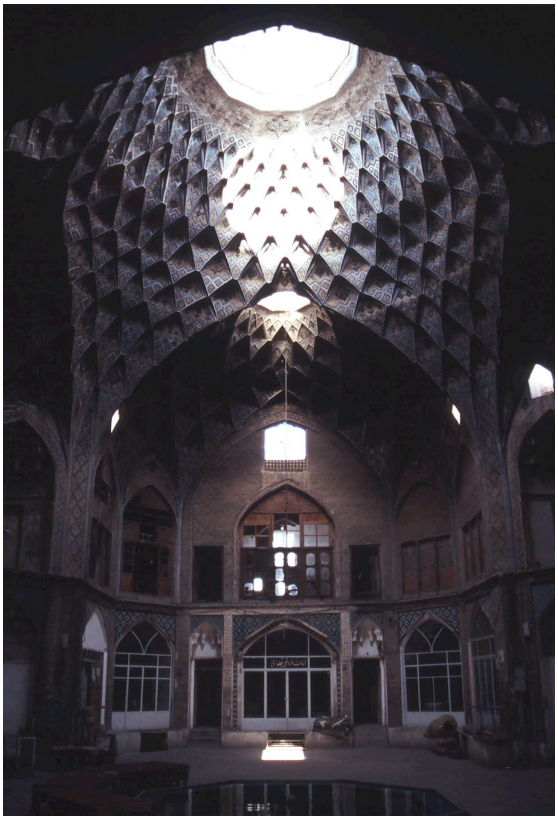
Comments:
The optimal ratio of courtyard size to height of surrounding buildings is about one to two or three. At the same time, closed courtyards secure privacy and protect against dust. Roadside traffic noise is reduced by a factor of five (-25 dBA). So lanes (kuchés) should be lined by buildings, not merely by fences – because open spaces and front gardens facing the street are no shield from noise, dust nor from foreign glances into the private sphere. The life form of the extended, multi-generational family is encouraged by closed yards. Sometimes it may be favourable to build a courtyard house partly under ground level – thereby using also the insulating and heat storing capacity of the surrounding earth.

Night and day views of an architectural school in Yazd that now occupies this old, noble courtyard house. The pool, trees and courtyard contribute to the cooling of the school.

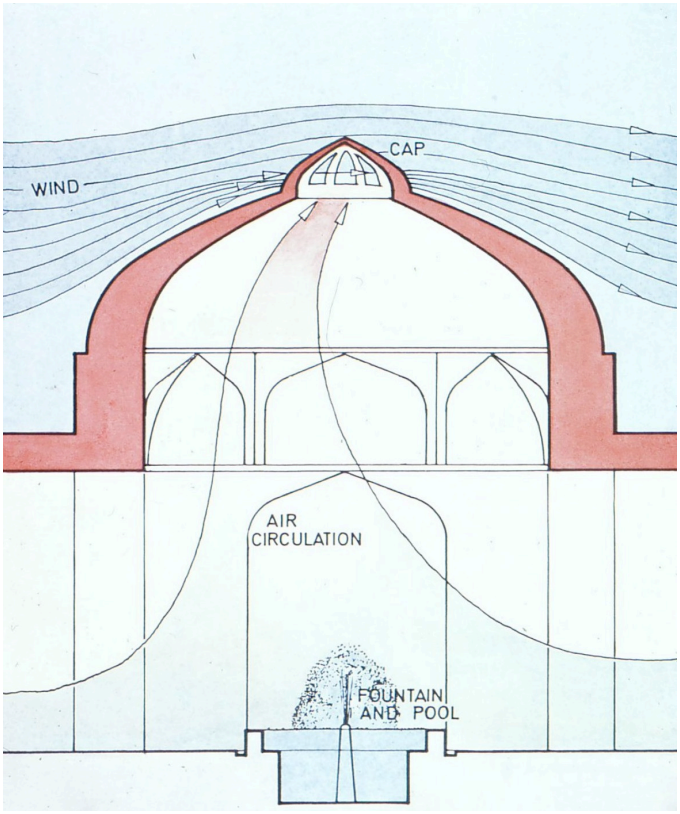
A shaded courtyard for a carpet house in Yazd provides a comfortable space. Also in Yazd is this underground-level green courtyard.

Rule 4: Enhancing Ventilation

Proper ventilation is essential in desert climates. Convection, caused by rising hot air, sucks in cool air from courtyards. Using air passing over cool stones or clay masses and moist surfaces results in the whole house becoming a passive cooling system without a single kilowatt-hour for air conditioning. Modern desert buildings can be greatly improved just by intelligent design, making use of the accumulated wisdom of many generations, who found such solutions while suffering the heat on their skin. Contemporary city builders should test, verify and improve this experience through modern science.



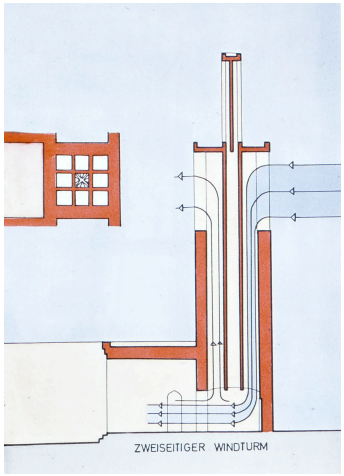
This open dome in Keshan effectively allows cool night air to enter and warmer air to rise and escape through the dome's cap. It is not enough to be concerned that hot air may escape upwards – but also to know from where cool air can be drawn in to replace it (such as from either a cool courtyard or even through an earth tunnel under the garden).



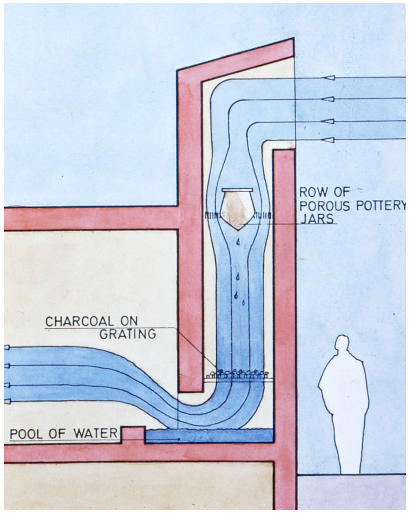
Wind over the curved surface generates a ventilating suction. While the hot air under the cupola is being sucked out by the Venturi effect over the curved dome, cool air is drawn in from courtyards and shaded alleys. (The Venturi Effect over curved wings is responsible for half of the uplift of birds and airplanes.) A finely dispersed water spray in the center of a small pond contributes to even greater cooling.

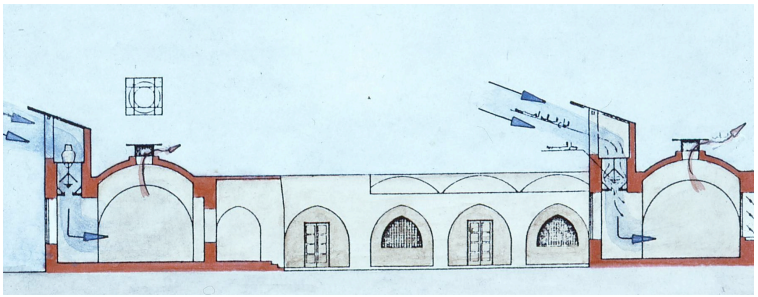
Comments:
Masterpieces of passive cooling are the "badghirs" (baudgeers) in traditional Iranian architecture, as described and practically proven by Prof. Mehdi Bahadori of the Iranian Academy of Science. Also the "malkafs" of traditional Arab architecture as applied by Hassan Fathy in his Girl's Elementary School in New Gourna (in the 1940s), which lowered internal temperatures by 10°C merely by passive cooling. These are inspiring climatic adaptations to keep cooling costs low even if electric cooling is added, to fully satisfy today's standards. Daytime coolers should be run on solar electricity (compression refrigeration) or solar heat (absorption refrigeration).

Much more beautiful and economical than electric coolers, wind towers known as badghirs, dominate the townscape of Yazd.



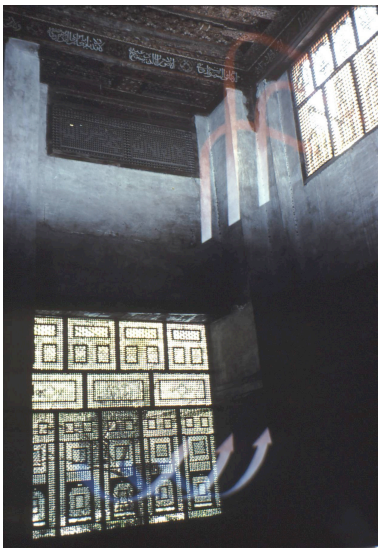
A badghir showing two movements: 1.) "chimney function" with escaping warm air (mostly during the early night) and later, 2.) intruding cool night wind, additionally cooled by contact with inner clay walls which are never exposed to the sun.





Above: This wind-catcher ventilation system which also allows hot air to escape via openings in cupolas was built in the mud brick technique by Hassan Fathy for a school near Luxor in the Nile Valley.

Left: A Malkaf wind catcher provides cooling by diverting the air stream over a moist jug, wet charcoal and a water surface.



Blue and red arrows show passive air movement in the Seheimi House in Cairo.

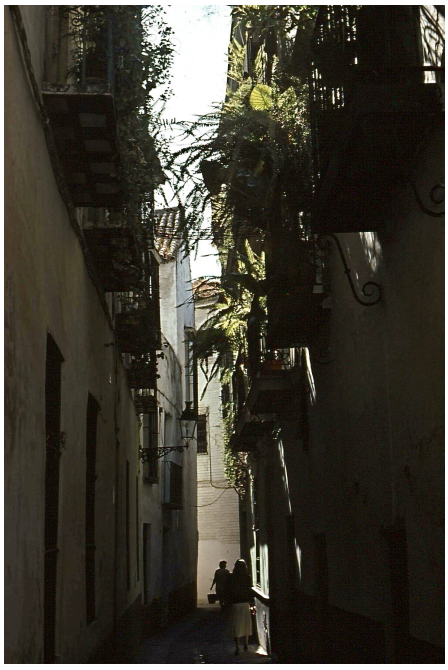
The house's green courtyard provides cool air.

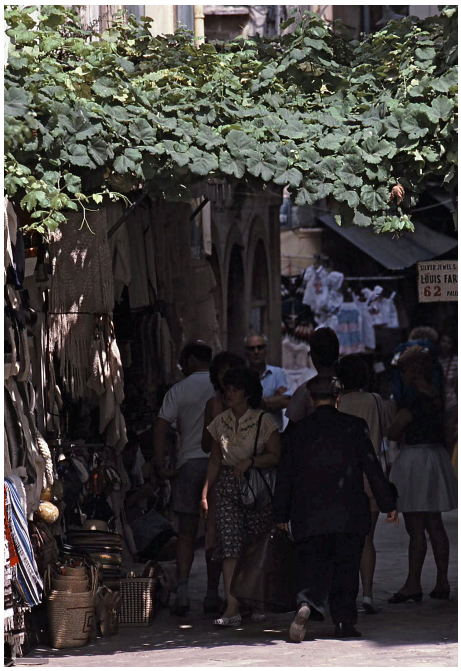
Rule 5: Narrow Lanes

Buildings along narrow lanes cast shade over each other. The effect is even enhanced by upper stories extending over some dead end streets or "kuchés," thereby making best use of urban space in residential areas.

Comments:
In addition to climatic advantages of narrow alleys forming a maze of branched and twisted lanes with dead end streets, they offer a most important defence strategy against intrusion of mass motorization – maintaining a chance for human street life and places for children to play in safety, guarded by the elderly.

Tea houses and workshops may also extend on public space. Still existing examples in old parts of Iranian and Arab cities should be studied and used as models for new pedestrian zones.



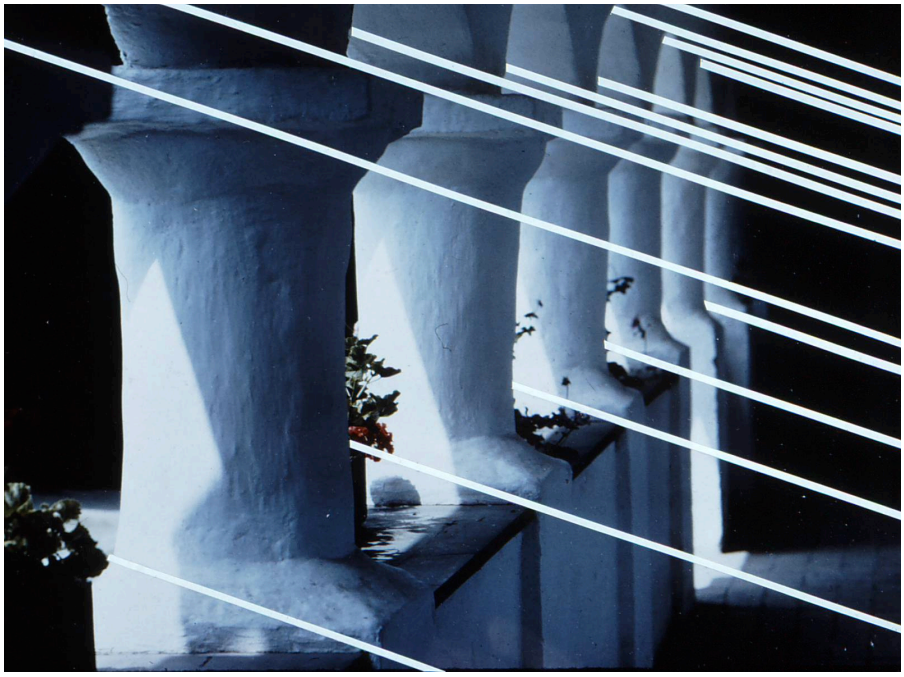


Shade provides comfort in these narrow lanes in Spain, Egypt and Sicilia, above, and in Kerman, below.

Sometimes, extending upper stories over alleys results in shaded pedestrian spaces in addition to extra, useful living space.

Rule 6: Arcades, South Oriented

South-oriented arcades provide much needed shade from the high and hot summer sun. In winter, when the sun is low and welcome, the arcades allow the sun's rays to enter and shine deeply into the interior. Arcades are air conditioning structures suited to the changing seasons.



White lines graphically demonstrate the low winter sun while real shadow lines on columns show high summer sun rays being kept off of the main building by the arcades.

City Arcades

Today, facades of shops and offices, with their loud and glaring nameplates and huge glass-front chaos of commercial advertising can be mitigated and harmonized by constructing arcades in front of the shops. Arcades, roofing the sidewalks of busy streets, shade shop windows and serve an aesthetic function with their rhythmic beauty. Neither exposed products and articles nor office signs and nameplates are hidden to passers-by on the side walk, but the general appearance of streets in ancient parts of oriental cities may be improved.

A contemporary building merges harmonically with traditional design in the restored city centre of old Nizwa, Oman.

New arcades over sidewalks provide shade, allow ventilation, mitigate chaos of shop signs and improve the general appearance of the townscape.

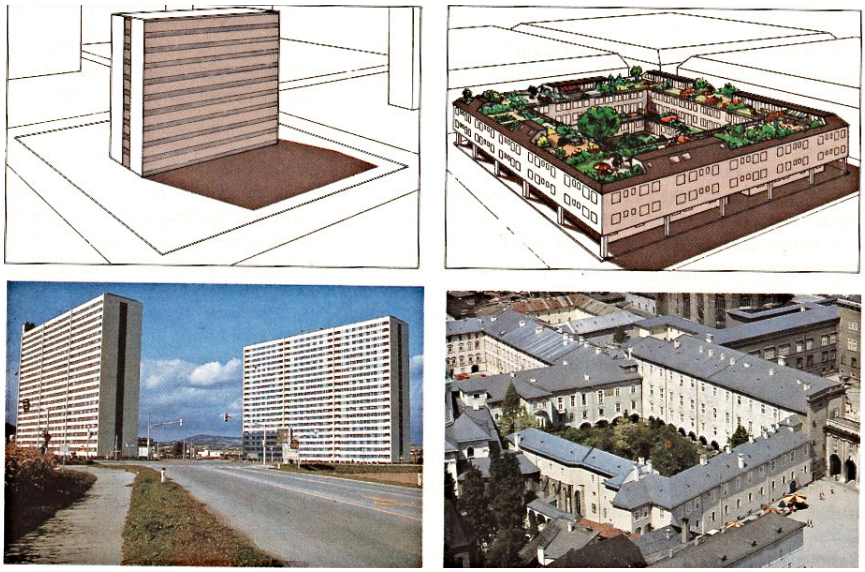
Rule 7: Low Rise – High Density

Residential areas, districts for living, should avoid high rise structures (see arguments below). Houses with no more than two to four stories help attain satisfying densities (40 – 80 units or 140 – 300 inhabitants per hectare) allowing attractive and liveable urban structures of mixed use, diversity and infrastructure. Traditional cities with surprisingly high population densities are structured by courtyard houses, towered only by mosques and fortresses (or churches and fortresses in the Mediterranean).

Comments:

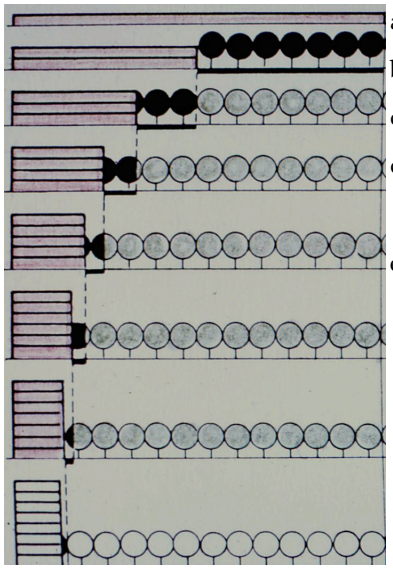
Reasons against high rise buildings for residential purposes are:

1. Even in densely built European cities only 20% of a city's area is covered by residential use – the rest by roads, traffic, commerce, public buildings, public green spaces, etc. So, if one could, in a mere theoretical train of thought, reduce the area for living almost to zero, by building residential high rises of infinite height – we could at most save only one fifth of city area, even by such inhumane measures.



Lower left: These residential high rise buildings of 20 stories have been demolished and replaced by low rise, high density ones. Right, a traditional courtyard in the city of Salzburg, Mozart's birthplace.

2. An example from European city building: Compare high-rise buildings on a given site, their distances from each other according to **European** building laws, with courtyard houses (right). The higher the buildings, the wider the distances have to be kept between them to avoid shading the neighbor and to guarantee sunlight in winter. Under these conditions, a courtyard house of three floors offers 20% more residential space than a ten-story high rise. In addition, on each floor of the courtyard house, residents could be provided with private green space under open sky – first floor residents using courtyard gardens, second floor residents using a green terrace, and third floor residents having access to a green roof.



3. If city leaders want to develop a new area for residential purposes optimizing high density with best possible provision of green space, what number of stories should they choose?

a. Building only one story would cover the whole site.

b. Piling up the same volume in two stories saves half (1/2) of the site for green (net gain symbolised by blackened trees).

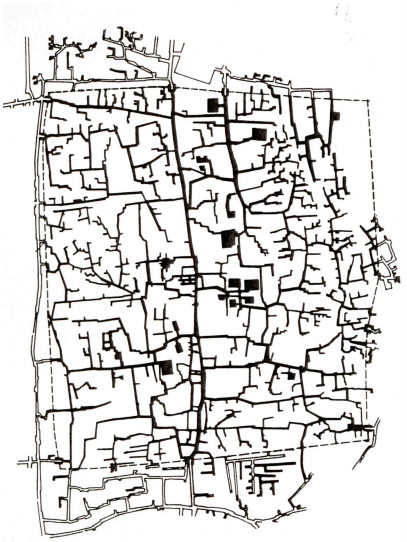
c. The same volume in three stories saves another one-sixth (1/6), compared with the two-story solution.

d. The same volume in four stories adds one-twelfth (1/12).

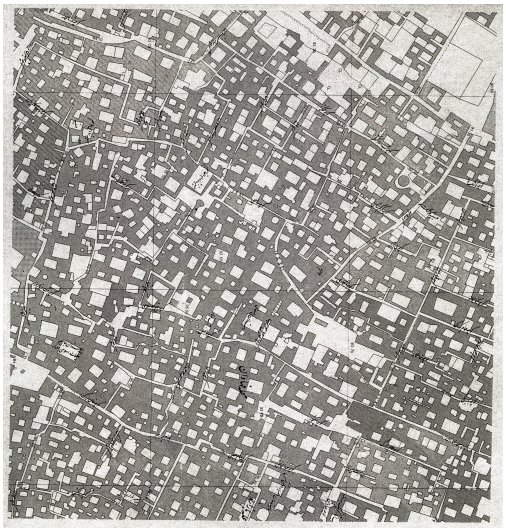
e. The same volume in five stories adds only one-twentieth to the four floor solution and so on (1/30, 1/42...). This means, when piling a given volume over two, three, four or more stories, the possible net gain of free green space by adding additional floors is considerable from one to two, or from two to three but becomes negligible beyond four stories.

Rule 8: Defence Strategies Against Intrusion of Unwanted Mass Motor Traffic

What ruins the quality of urban life is not local traffic; the most disastrous one is through-traffic. Unwanted motor traffic can be reduced by applying the "maze" (labyrinth) principle, excluding through-traffic, reducing speed by well-selected obstacles, and encouraging environment-friendly city technologies (e.g., for delivery vans), limiting parking lots but favouring residents, and diverting useless and disturbing car traffic around residential areas.

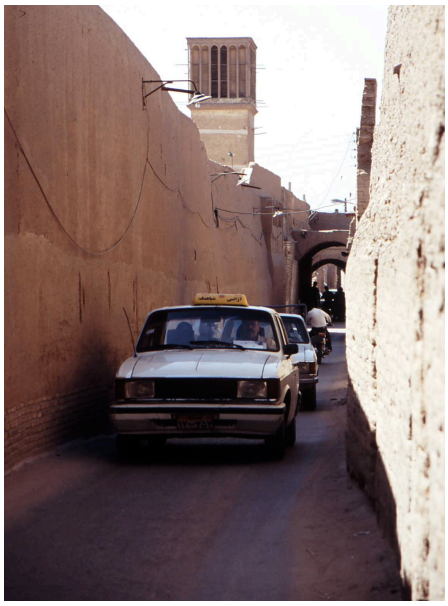


Cairo, 19th Century, street map



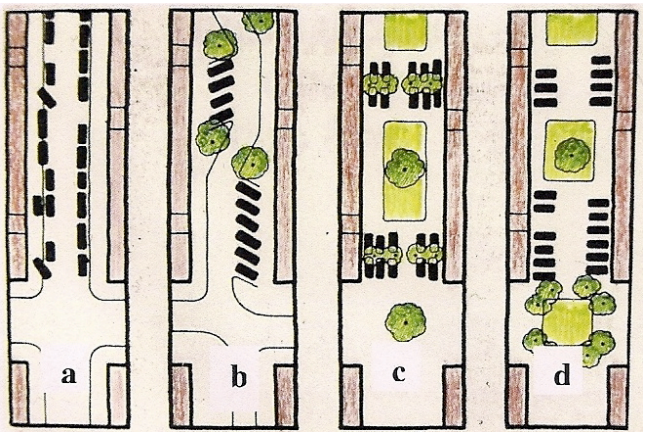
Yazd, a part of the old city

Cities for people, not the motor car: A maze or labyrinth dominated by courtyard houses leaves little space for streets. This design results in a liveable network of alleys, squares and dead-end streets. Later, if possible, a subway system should be built.



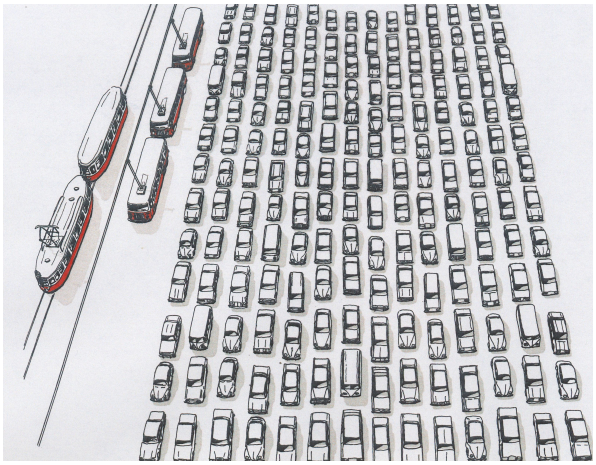
Conventional cars are completely incompatible with " kuchés" and should be restricted. There is a need for small, flexible delivery vans with no emissions and for electric bicycles and tricycles.

Compare the desolate situation, left, with the improved setting for residents of the same street. European planners try to keep through-traffic off the streets in residential areas, though the place may be accessible to cars of residents and local businesses. Narrowing the driveway by trees and parking lots forces cars to slow down, reducing noise and increasing safety for people.

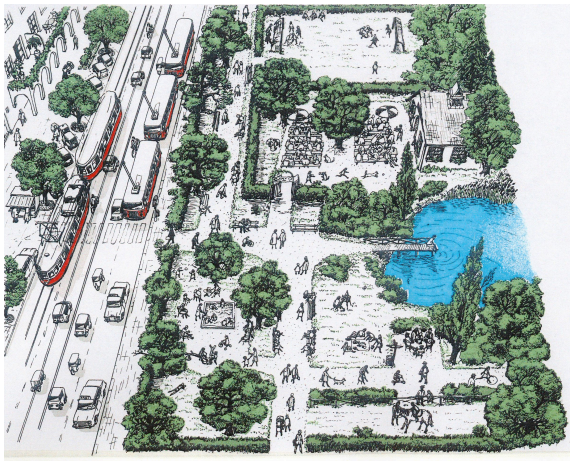


Planning alternatives for the same street. *a: Street, having become desolate by through traffic, lined by parked cars. b,c,d: Planing studies to improve life quality. b: Car drivers tolerate a narrowing down of driveway when this is done by parking lots. c,d: Even greening the street need not reduce the number of parking spaces or accessibility for delivery vans. Yet complete interruption of through-traffic has the most beneficial effect for residents.*

Livability is improved by limiting access, reducing speed by thresholds on the ground (so-called "sleeping policemen"), introducing urban greenery, and providing safe conditions for children and the elderly. Speed control also matters. When two car drivers, one going 50 km/h, the other at 30 km/h jump on their brakes at the same point, the 30 km/h-car stops after 14 meters, while the 50 km/h-car is still moving at 45 km/h—still a deadly speed when colliding with pedestrians.



Space demand for different modes of transport. *Typical trams and trolly buses hold 270 people. If 270 people use private cars (averaging 1,5 persons per vehicle), they need 25 times the road area even for standing. While driving, the distance from car to car must be much greater. What sacrifices for the motor car!*



Alternative for higher quality of life: Communal green areas, parks and shady footpaths improve the climate and enable human contacts to develop. Such contacts are only possible between pedestrians, not between car drivers (except, perhaps in an aggressive sense).

Florence on the Arno River: Scooters and other types of bicycles are indispensable for mobility in historic cities. They would be ideal if one could get them without noise and exhaust and if they could carry larger loads. China already has millions of small electric bicycles, tricycles, etc.

New Chinese-Austrian joint product: This bicycle features a silent 36 V electro-motor which works while the driver is pedaling. One car parking space is room for 18 bicycles. Similar three-wheel delivery vans are also available.

Rule 9: Urban Greenery

Air-condition the city by planting trees, their foliage gives shade, form green domes over streets, prevent the "baking oven effect" (overheating of asphalt roads and buildings), filter dust, cool by evapo-transpiration and reintroduce nature into the artificial, technical, concrete world.

Comments:
It is best to start city building with trees. It takes vegetation years to grow and, according to the traditional opinion held by Iranian city planners and gardeners, even up to the 20th Century, "you can't expect people to live without trees." In Europe, the sun is a welcomed friend; during Iranian summers the sun is an enemy and people seek the shade.

Climbing plants shade the walls of this narrow Mediterranean courtyard, humidify the air and reduce noise.

Roof terraces and little courtyards bring some green to a Spanish city, offer privacy and provide a quiet refuge from street noise.

Vegetation and water are efficiently used for cooling; shady green domes prevent asphalt roads from over-heating, shielding against the baking effect of urban stone masses. Little creeks, Djubbs, nourish standing trees. "Foot in water, head in fire." You need richly transpiring foliage to air-condition urban desert climates. A cactus offers neither shade nor transpiration. To heat 1 liter of water to boiling needs 100 Kcal. To evaporate 1 liter, foliage extracts 534 Kcal from its environment.

Rule 10: Water

Conserve resources by confining potable water to purposes where drinking water quality is necessary such as drinking, cooking and personal hygiene (showers, washing, etc).

Comments:
Iranian desert cities depend on water from the mountains. "Qanats" and "Djubbs" should be given special attention as a second water system, to:

- fill cisterns ("abanbars") which should be preserved for diverse non-drinking purposes such as cleaning, flushing the toilets, watering gardens;
- serve as a back-up water supply system in case of crises, e.g., firefighting or failure of tap water system;
- Cisterns, or "Abanbars," are an architectural heritage and a useful attribute of Iranian culture;
- Irrigate the roots of leafy trees like maple or poplar trees lining and shading the roads "foot in water, head in fire...."

1.

2.

1.) Mountains deliver water which is diverted to the town with the help of 2.) "qanats," underground water tunnels seen from an airplane (only the openings of their maintenance shafts are visible). 3.) The qanat-water fills "abanbars," cisterns, reservoirs of public buildings and private houses, 4.) often with "badghirs" to keep water fresh.

3.

4.

Esfahan

"Qanats" pour their water into a network of "djubbs," nourishing and cleaning the city like blood vessels and capillaries do within the body. They are the secret for turning deserts into green cities, air conditioned by rich foliage. Urban trees are not desert plants (because a cactus would do nothing to change local climate) – their leaves moisten the air and cool the environment by evapo-transpiration. A healthy tree transpires 500 l a day, withdrawing 300.000 Kcal of heat, sometimes noticeable directly by a slightly cool breeze. These trees follow the principle, "head in fire and foot in water."

The "djubbs" water the root system in pulses, so wetting and aerating alternate. Iranians and Arabs were world champions in desert gardening.

Djubb in Tehran

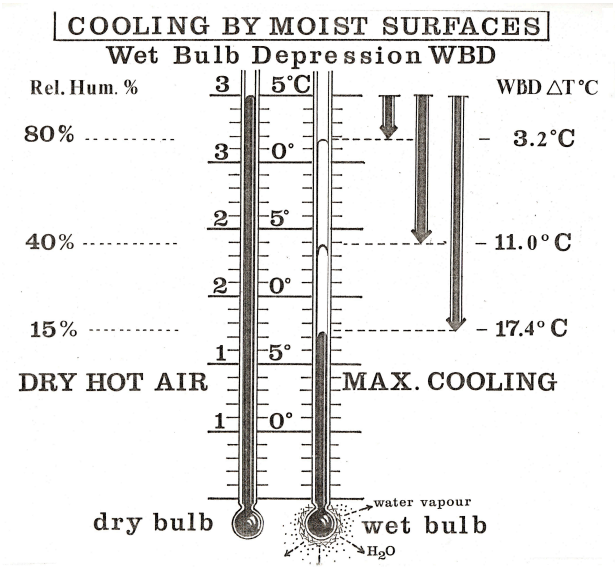
Mahan Garden, Kerman

Rule 11: Take Advantage of the Climate Extremes You Have to Overcome

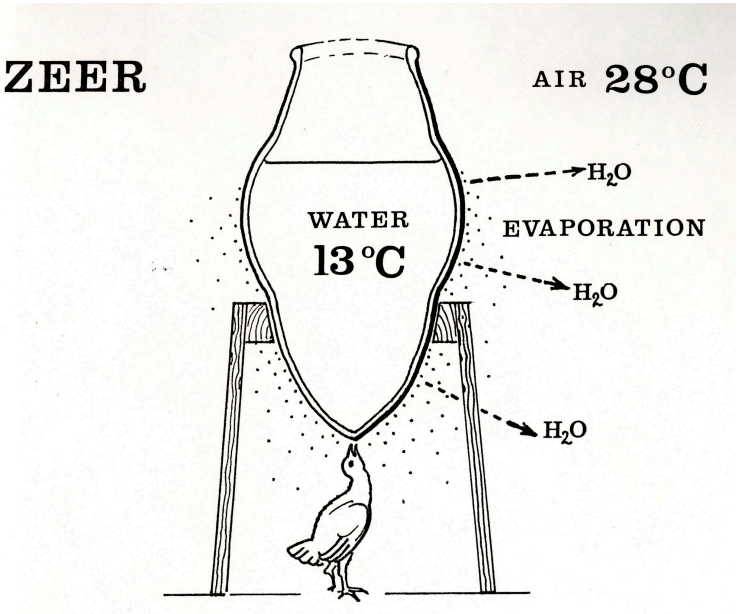
The desert climate in Iran is extremely dry. Evaporation in dry air has the highest cooling effect as to be demonstrated by the "wet bulb depression," observing the temperature difference between a dry and a moist thermometer in environments of different air humidities, e.g., lowering temperature by 17,4° in 15% relative humidity.

The desert climate has extreme differences between hot days and cold nights, especially in altitudes over 1000 meters. Courtyard houses store cold night air for the next day. Before electric cooling, generally all opportunities should be provided by planners to fill any building with cool night air (night ventilation). The pitiless Iranian sun offers an unrivaled source of sustainable energy first for hot water, later for cooling by solar heat following the absorption principle and finally converting sunlight to electricity, splitting water to store sun energy in the form of pure hydrogen, the fuel of the future – driving cars or producing electricity by fuel cells with high efficiency (60% of hydrogen energy converted to electric current).

Comments:
Iran may develop a wealth of energy even without oil or nuclear power. Increasingly, precious oil should just help to finance soft alternatives for the future. Nuclear power (only 4-5% of world energy production) creates more problems than it would solve.



With high relative air humidity at 80%, the evaporation cooling effect is only 3,2°C. Given 40% relative air humidity the effect is a remarkable 11°C and at 15% it is even as much as 17,4°C.



In these porous water jugs, which are known as "Zeers," in the Nile Valley, we have measured a water temperature of 13°C whilst the surrounding temperature was 28°C. Even the few drops on the outside were not lost—serving as a water source for domestic pets.

Rule 12: Respecting Grown Structures

Preserving structures that are grown culturally as well as grown naturally – especially those representing unmistakably unique elements – give a town individual character which makes it lovable for citizens and for visitors.

Comments:

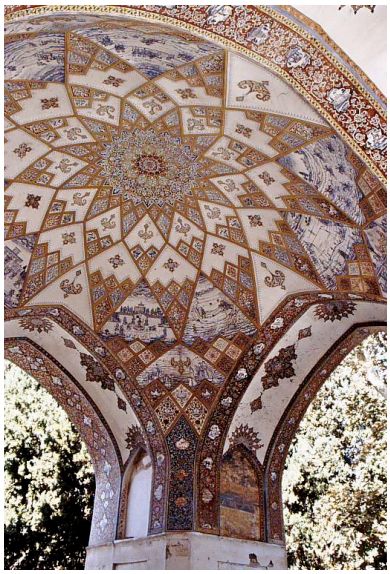
– Reusing (repairing and sensitively modifying) old buildings in most cases turns out to be much better than demolishing.

– This is also a question of energy – recycling an existing structure conserves considerable amounts of energy, contained in basic wall material (1/3 of the energy necessary for erecting a new building) and saves transport- and landfill costs.

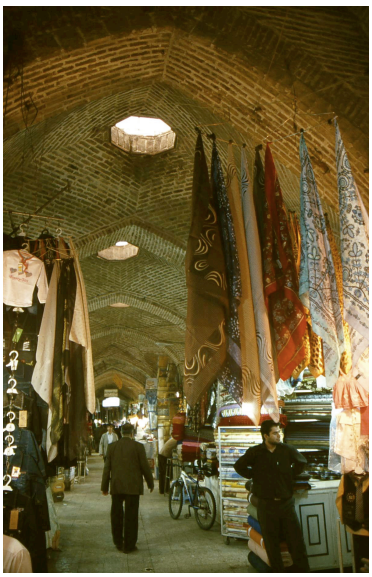
– Recycling a building may also maintain charm and character of a place.

– Old trees are often points of reference for orientation. A rock, towering a city, may well make it unique, such as in Edinburgh or Salzburg. "What a city may become in the future depends on what it has been in the past."

Yazd

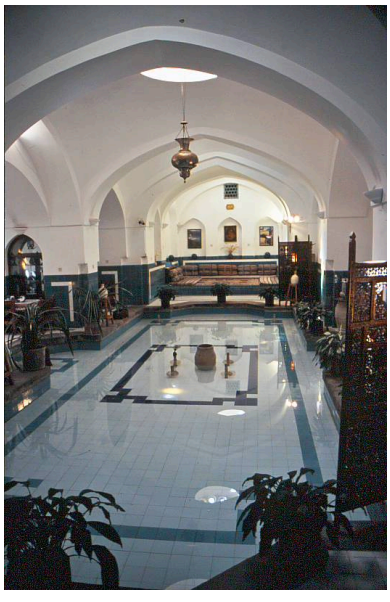


Bagh-e-fin

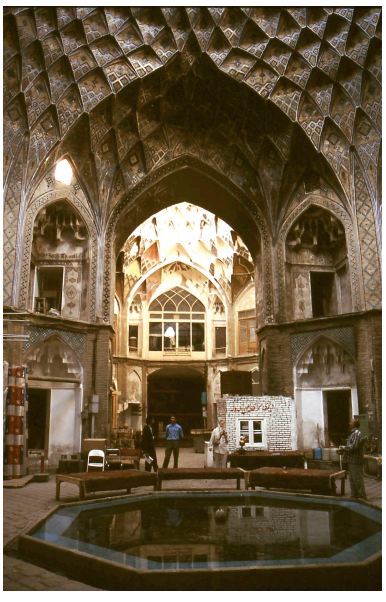


Qasvin Bazaar

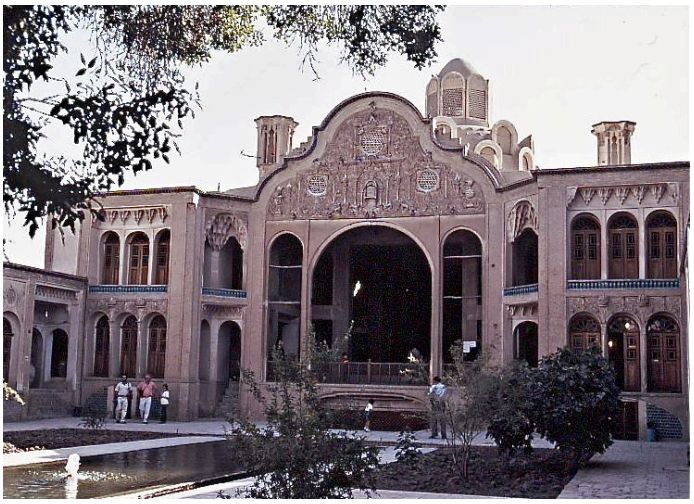
Bagh-e-fin

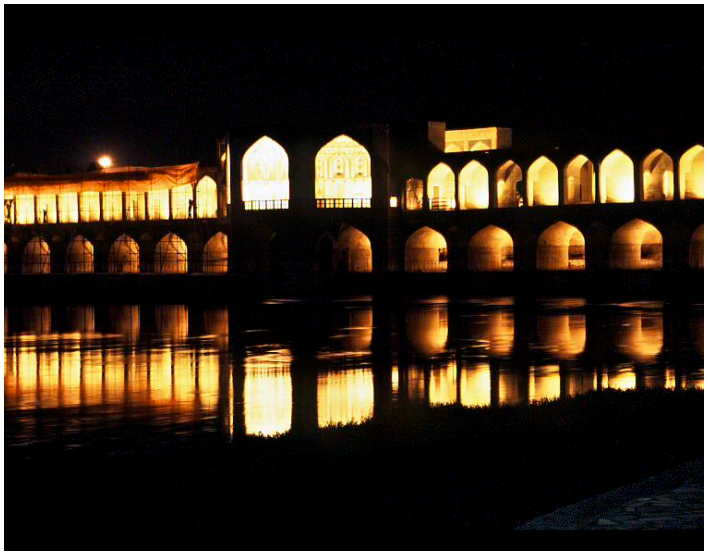


Yazd Hamam



Keshan





Conclusion

There were valid reasons the ancient cities and buildings of the desert were designed as they were and the wisdom behind these decisions are as beneficial today as they were centuries ago. Contemporary city leaders, planners and builders can learn from the agreeable structures of the past, for efficient use of energy and to preserve the cultural identity of a place.

Builders can protect inhabitants against the heat of the sun by the insulating properties of thick walls, the passive ventilation of vaults and domes, wind towers ("badghirs" in Iran or "malkafs" in Arabic countries), the shade from narrow lanes and arcades, as well as by the trees and other greenery in courtyards. Together with access to one's own balcony or roof garden in "low rise high density" residential districts situated in a maze of little alleys, dead-end streets and small squares--these are the conditions of quality of life found in traditional desert cities from Asia, the Middle and Near East and the Mediterranean.

Ancient ideas of channeling water and storing it for cooling and irrigation are ingenious conservation technologies that can be used today.

The proven advantages of the accumulated wisdom of hundreds of generations and the wise adaptations to local traditions will ensure functionality, comfort, efficiency and charm in today's desert cities. Future eco-technology can be easily combined with this spirit.

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