Urban Heat Island: Cause for microclimate variations

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Learning about ways to mitigate the effect of Urban Heat Island on our environment.

Urbanization has a dynamic relationship with the physical environment Urban and rural environments differ substantially in their microclimate. These climatic differences are primarily caused by the alteration on the surface of earth by human constructions and the release of artificially created energy into the environment. Inadvertent climate changes induced by urbanization are well documented. Such changes, are epitomized by the concept of `Urban Heat Island`(UHI) India is increasingly becoming urban. According to the 2001 Census, 27.8% of the urban population resides in cities, compared with 25.5% in 1990. The Urban population is expected to rise to around 40% by 2020.City growth and urban development are inevitable phenomenon of the 21st century, hence there is a need to explore the causes and peculiarities of the Urban Heat Island Effect and propose solutions to .the problem. This paper is a step towards proposing some solutions to the problem.

IMPACT OF URBANIZATION

The phenomenon of city- induced environmental change has been known for many centuries. The ancient Indian architectural manual ' Silpa Sastra'(translated by Acharya, 1979) laid out rules for siting of villages, towns and forts based on prevailing wind directions and solar orientation. Building and street layout, and massing, were prescribed so as to enhance street- level shade, air-pollution dispersal and storm-water drainage. Vitruvius'Book I of the Ten Books on Architecture (trans.Morgan, 1960) also considered city layout in relation to local environmental conditions.

Urbanization has a significant impact on all elements of the atmosphere. Replacing natural vegetation with artificial surfaces alters the heat balance and hydrology of the local environment. Urban canyons affect wind speed and increased particulate content enhances precipitation down wind of a city.

This paper explores the cause, and characteristics of Urban Heat Island Effect and proposes some solutions to the problem.

THE PHENOMENON OF URBAN HEAT ISLAND

The term "heat island" refers to urban air and surface temperatures that are higher than nearby rural areas. Many U.S. cities and suburbs have air temperatures up to 10°F (5.6°C) warmer than the surrounding natural land cover.

The heat island sketch pictured here shows a city's heat island profile. It demonstrates how urban temperature's are typically lower at the urban-rural border than in dense downtown areas.

The concentration of human activities in urban areas creates an "island" of heat surrounded by a "sea" of cooler rural areas called the "urban heat island". Heat is added to the urban atmosphere by industry, transportation, exhaust heat, and air conditioning among other things. Artificial surfaces with low albedo absorb much insolation, heating the surface more than if it were a natural surface like grass. The additional heat can create differences in air temperature between the city and countryside of 10° C (18°F) or more. Consequently, snow disappears earlier and vegetation bloom earlier in the city. Sunlight is trapped within the "urban canyon" by reflective surfaces. Building materials like brick and asphalt have high heat conductivity. Heat loss in the evening can compensate for that which has been gained during the day.

The EPA says: *Heat islands form as vegetation is replaced by asphalt and concrete for roads, buildings, and other structures necessary to accommodate growing populations. These surfaces absorb - rather than reflect - the sun's heat, causing surface temperatures and overall ambient temperatures to rise.*

THE URBAN CLIMATE

Urbanization, due to its increased thermal capacity, lack of water for evapotranspiration, and the canyon effect, tends to aggravate the negative effects of climate. The presence of buildings and roads

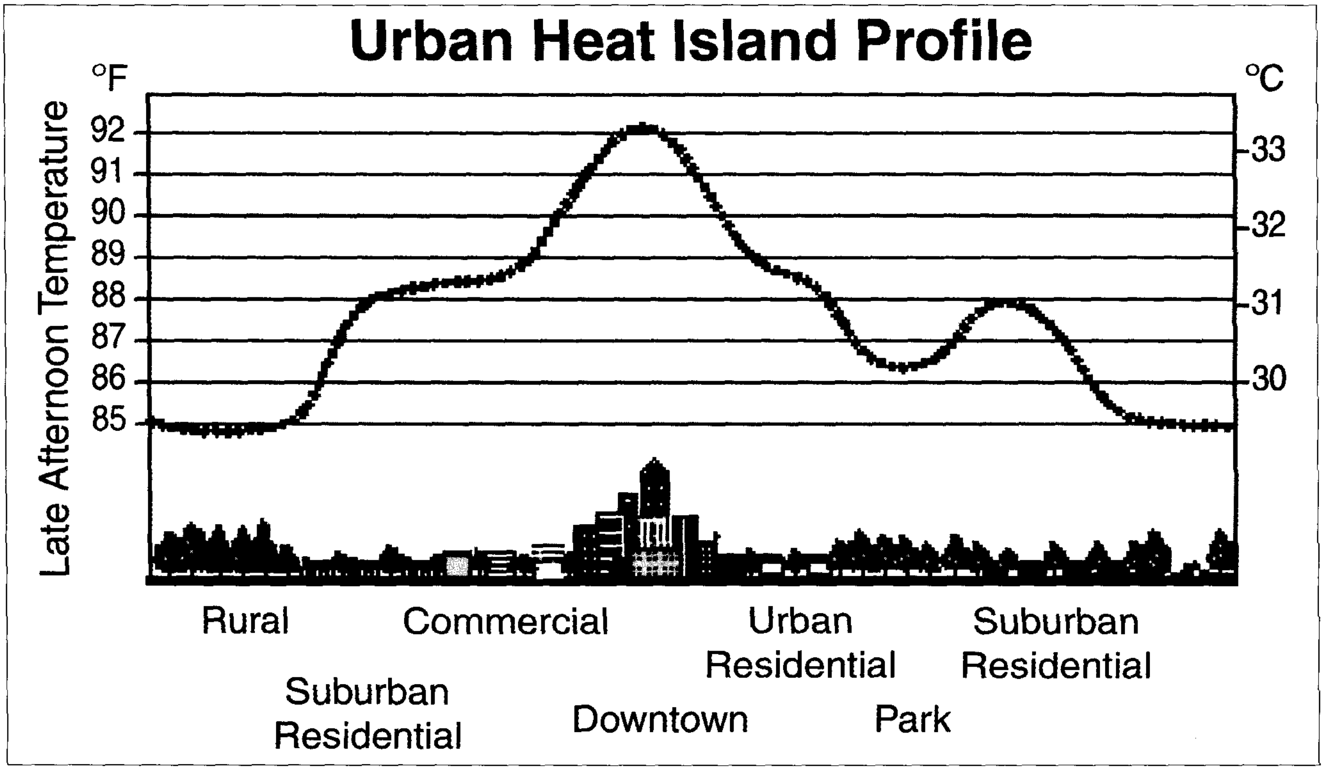

Fig. 1 Urban Heat Island Profile, Source: Heat Island Group

affects the radiation, heat and water balance of an area. This means that the local climate in a city is different to that in the surrounding countryside. There are large differences in solar radiation and heat and water balances between urban and non-urban areas.

Urban climates are the result of the interaction of many natural and anthropogenic factors. Air pollution, building materials, emission of heat from human activity, together with natural factors, cause climatic differences between cities and non-urban areas. The climate of a particular city is controlled by many natural factors, both at the macro-scale(e.g. the latitude) and at the meso-scale (e.g. the topography, the presence of water bodies).

The climate of a city is controlled by many anthropogenic factors also. The important factors are-

- the release (and reflection) of heat from industrial and domestic buildings;
- the absorption by concrete, brick and tarmac of heat during the day, and its release into the lower atmosphere at night;
- the reflection of solar radiation by glass buildings and windows. The central business districts of some urban areas can therefore have quite high albedo rates (proportion of light reflected);
- the emission of hygroscopic pollutants from cars and heavy industry act as condensation nuclei, leading to the formation of cloud and smog, which can trap radiation. In some cases, a pollution dome can also build up;
- Recent research on London's heat island has shown that the pollution domes can also filter incoming solar radiation, thereby reducing the build up of heat during the day. At night, the dome may trap some of the heat from the day, so these domes might be reducing the sharp differences between urban and rural areas;
- the relative absence of water in urban areas means that less energy is used for evapotranspiration and more is available to heat the lower atmosphere.

THE URBAN GEOMETRY HEAT ISLAND EFFECTS

The form of a city tends to trap radiation near the surface. The Figure no.2 shows the Sky View Factor (SVF) within a city, a major cause of store of energy within a city built mass. The sky view factor is reduced by the urban built-up. The maximum value of the SVF is 1 which occurs for open areas, without any trees, houses etc.(Oke, 1987). This means a lot of energy is stored in the city during the daytime and this is then gradually lost during the night. This slows down the night-time cooling of a city compared to non-urban areas.

The explanation for the night-time maximum is that the principal cause of UHI is blocking of "sky view" during cooling: surfaces lose heat at night principally by radiation to the (comparatively cold) sky, and this is blocked by the buildings in an urban area.

The size and spatial structure of a city also governs the extent of the Urban Heat Island (UHI). Urban areas with low-rise buildings spread among

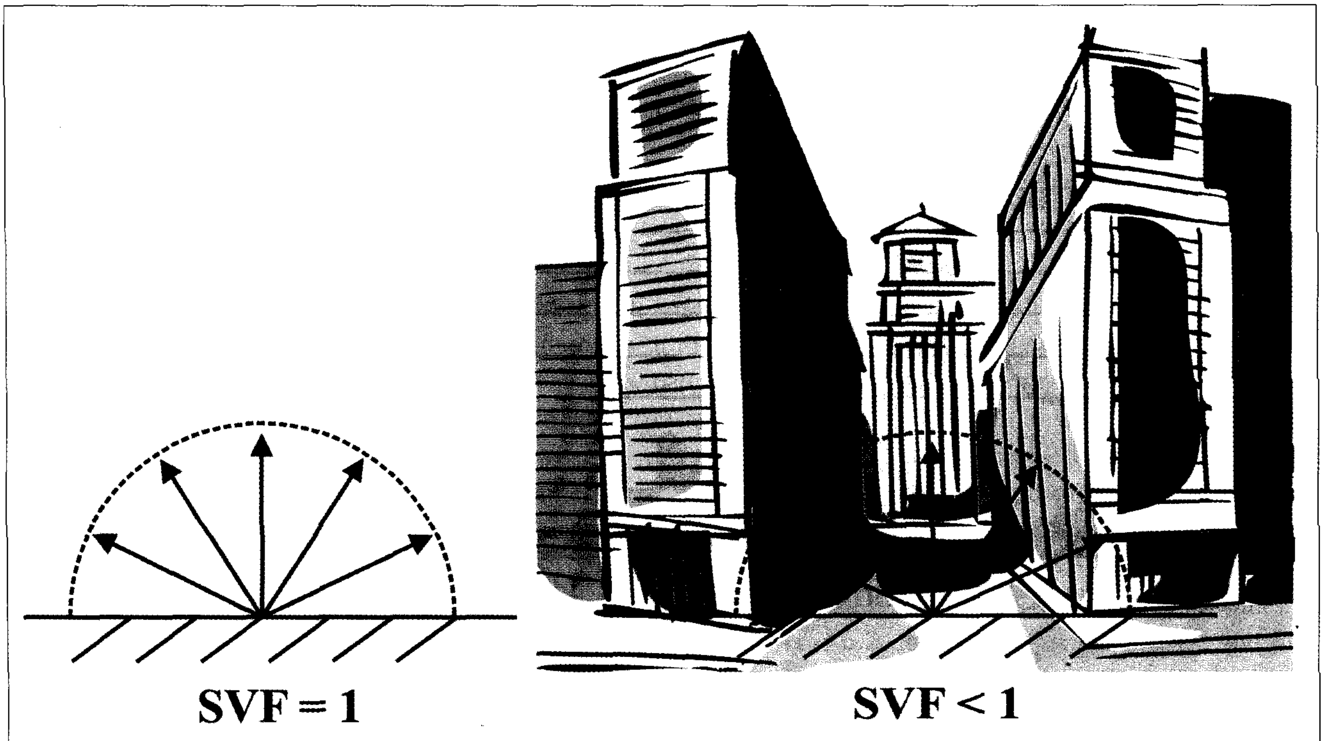

Fig. 2 Sky View Factor, Source: http://www.atmosphere.mpg.de

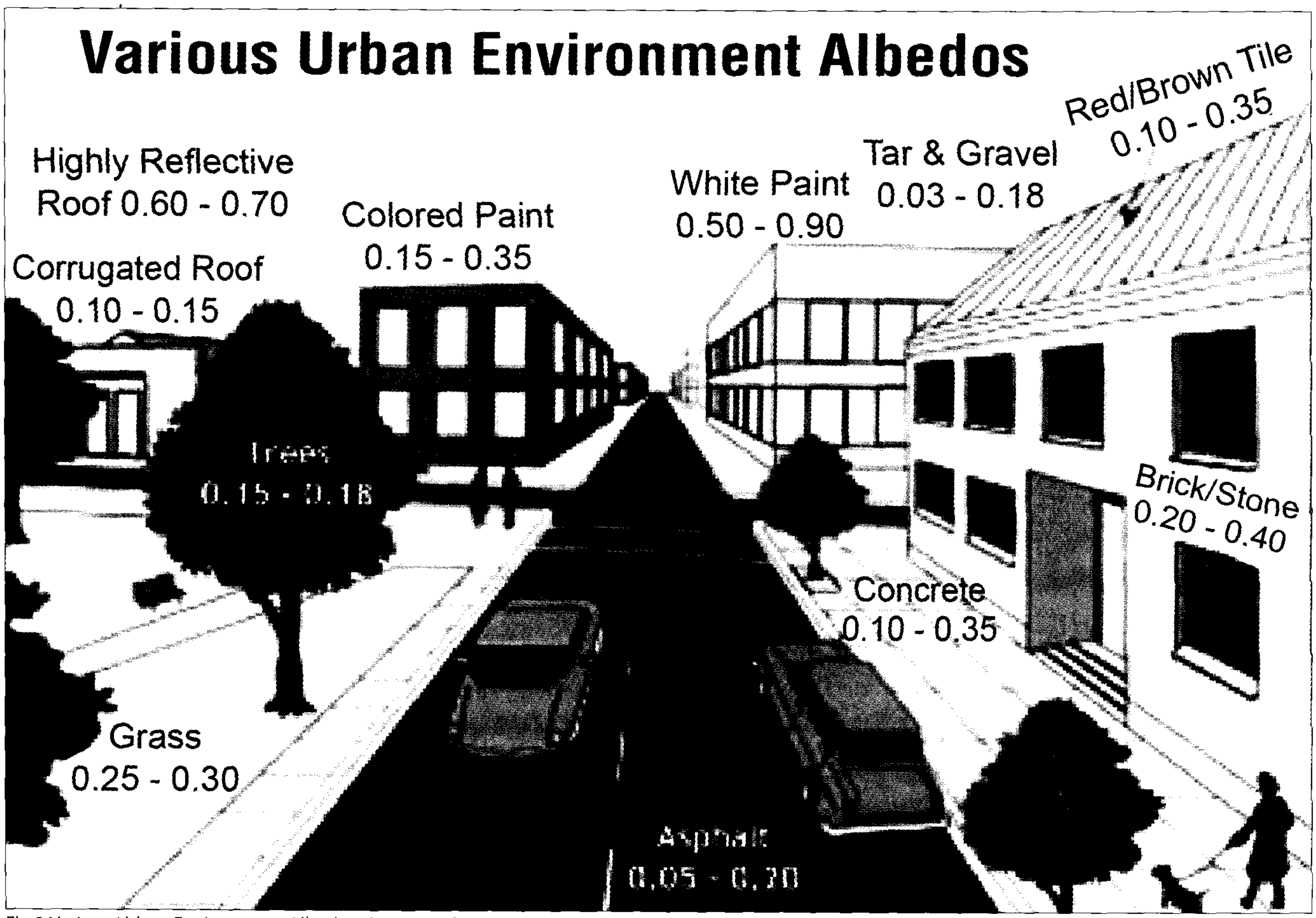

Fig.3 Various Urban Environment Albedos, Source: U.S.Environmental Protection agency, Source: http:Yosemite.epa.gov/oar/globalwarming.nsf/content

green areas do not form typical urban heat islands. The modern world high-rise structure produces the urban canyon effect, which traps the heat increasing the effective UHI effect.

Other causes of a UHI due to geometric effects is that the tall buildings within many urban areas provide multiple surfaces for the reflection and absorption of sunlight, increasing the efficiency with which urban areas are heated. This is called the "canyon effect". Another effect of buildings is the blocking of wind, which also inhibits cooling by convection.

The amount of solar radiation received by an urban canyon as a whole depends on the height of the buildings and on the orientation of the canyon.

ALBEDO AND THE HEAT ISLAND EFFECT

As a city grows and develops, new factors modify the local climate of a city and therefore, have a complex character consisting of a mosaic of different surface materials. Each surface material has a different albedo, a measure of the amount of solar radiation reflected back into space. For a city as a whole, the albedo can be as low as 10-15%, which means that a lot of the incoming solar radiation is absorbed by the city. Additionally, most of the building materials used in the construction are characterized by a high heat capacity and high heat conductivity. The Figure given above gives the albedo in urban environment.

CAN HEAT ISLANDS ALTER LOCAL CLIMATE?

Every house, building, and road changes the microclimate around it, contributing to the urban heat islands of our cities. The intensity of a heat island will depend upon its topography, its proximity to water bodies, and local climate. Urban heat islands also can impact local weather, altering local wind patterns, spurring the development of clouds and fog, increasing the number of lightning strikes, and influencing the rates of precipitation.

Increased heat enhances photochemical reactions, which increases the particles in the air and thus contributes to the formation of smog and clouds. London receives approximately 270 fewer hours of sunlight than the surrounding countryside due to clouds and smog. Urban heat islands also increase precipitation in cities and areas downwind of cities.

Our stone-like cities only slowly loose heat at night, thus causing the greatest temperature differences between city and countryside to take place at night.

CAN HEAT ISLANDS CONTRIBUTE TO GLOBAL WARMING AND AFFECT HUMAN HEALTH?

Although urban heat islands are distinctly different from the phenomenon of climate change, during the summer months they can contribute to global warming. The increased use of air conditioning and refrigeration needed to cool indoor spaces in a heat-island city, for example, results in the release of more of the heat-trapping greenhouse gases that cause global warming. Furthermore, the poor air quality that results from this increased energy usage can affect our health, aggravating asthma and promoting other respiratory illnesses.

The buildings, concrete, asphalt, and the human and industrial activity of urban areas have caused cities to maintain higher temperatures than their surrounding countryside. This increased heat is known as an "Urban Heat Island." The air in an urban heat island can be as much as 20°F (11°C) higher than rural areas surrounding the city.

The increased heat of our cities increases discomfort for everyone, requires an increase in the amount of energy used for cooling purposes, and increases pollution. Each city's urban heat island varies based on the city structure and thus the range of temperatures within the island varies as well. Parks and greenbelts reduce temperatures while the Central Business Districts (CBD), commercial areas, and even suburban housing tracts are areas of warmer temperatures.

Every house, building, and road changes the microclimate around it, contributing to the urban heat islands of our cities.

MITIGATION OF HEAT ISLAND EFFECT

Various environmental and governmental agencies are working to decrease the temperatures of urban heat islands. This can be accomplished in several ways; the most prominent are -

- **Switching dark surfaces to light reflective surfaces**

  The heat island effect can be counteracted slightly by using white or reflective materials to build houses, pavements, and roads, thus increasing the overall albedo of the city. This is a long established practice in many countries.

  Dark surfaces, such as black roofs on buildings, absorb much more heat than light surfaces, which reflect sunlight. Black surfaces can be up to 70°F (21°C) hotter than light surfaces and that excess heat is transferred to the building itself, creating an increased need for cooling. By switching to light colored roofs, buildings use 40% less energy.

- **Planting trees**

  Trees affect urban microclimate at two levels: human comfort and building energy budget (Parker, 1983: Miller,1988). Planting trees not only helps to shade cities from incoming solar radiation, they also increase evapotranspiration, which decreases the air temperature. Trees can reduce energy costs by 10-20% (Oke,1989). The concrete and asphalt of our cities increases runoff, which decreases the evaporation rate and thus also increases temperature.

  The main proponent of this theme is the Heat Island Research Group of the Lawrence Berkeley national Laboratory (LBL), Berkeley, California. Its simulation of summertime UHI suggests that planting trees will lead to 15-35% reductions in building cooling energy costs (Akbari et al.,1992).

- **Manipulating Urban geometry**

  This strategy has the greatest potential for comfort enhancement at the neighbourhood scale. Oke (1988b) was one of the first to suggest that improvement to urban geometry at street level needs to (a) reduce UHI in summer, (b) retain heat during winter, and facilitate adequate air change for comfort and pollution dispersal. In order to achieve these three objectives, Oke suggested a building height to street width (H: W) ratio of 0.4 : 0.6.

  Another research (Swaid, 1992) proposes an adjustable vertical shading device attached to the top of a canyon wall. This in turn increases the street canyon depth at daytime and when this device is retracted at night, the nighttime SVF remains unchanged.

- **Public awareness and representation**

  Committees formed to address urban heat mitigation should include representatives from the citizens. Policies should be made so as to suit the needs based on stakeholder input, and must be effectively communicated to the public. Enhancing the quality and character of the neighbourhoods can be easily accomplished by working together.

CONCLUSION

"Heat Island Effect" needs to be looked into seriously and its very important to gain the ability to control its negative impact. These factors not only affect the local climate but also the environment of the planet as a whole.

Approximately half of the world's population lives in cities, and this value is expected to increase to 61% by 2030. Heat islands form as vegetation is replaced by asphalt and concrete for roads, buildings, and other structures necessary to accommodate growing populations. City growth and urban development are inevitable; this means more number of people will be exposed to consequences resulting from heat islands in the future.

The need of the hour is derive design strategies for the mitigation of the negative effects and must be implemented seriously. These must be made mandatory by the local authorites and defaulters must be fined heavily.

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Photographs: Courtesy the Author.

ARCHITECTURE TRIVIA QUIZ

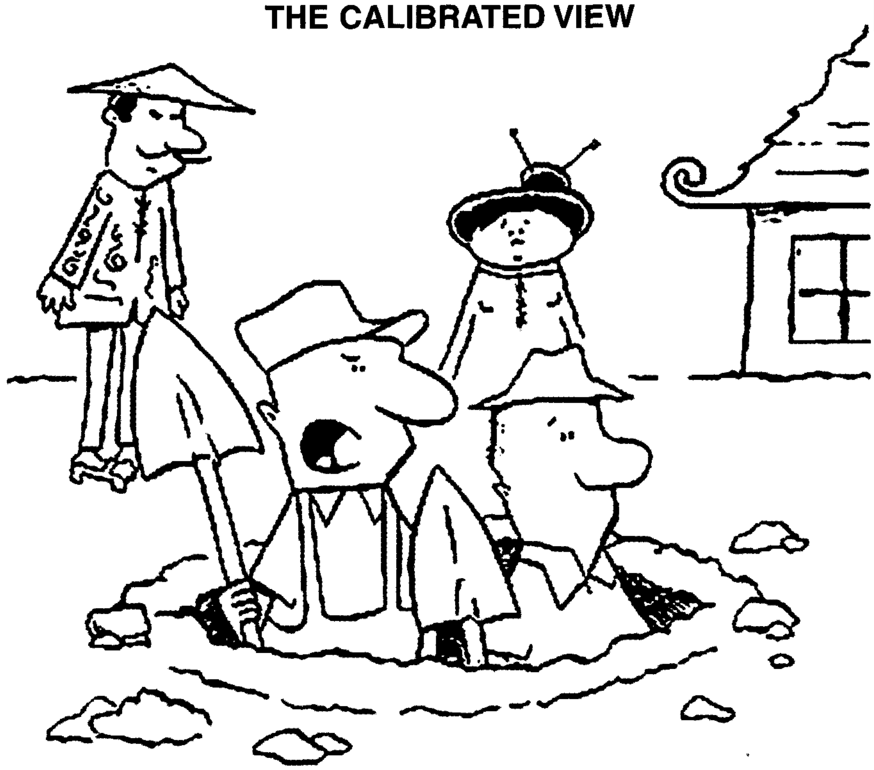
1. **Which architect designed the Sangrada Familia, Barcelona, Spain?**
   - Antoni Gaudi
   - Aldo Rossi
   - Tullio Inglese
   - William Chamber

2. **Which architect designed the Bank of China?**
   - Norman Foster
   - I.M.Pie
   - Frank Lloyd Wright
   - Arata Isozaki

3. **Which is the world's tallest hotel?**
   - Grand Lisboa, Macao
   - Burj Al Arab, Dubai
   - Detroit Marriott, Detroit
   - Rose Tower, Dubai

1. Antoni Gaudi 2. I.M. Pie 3.Rose Tower, Dubai

THE CALIBRATED VIEW



I think this is deep enough for the foundations!