"Earthen constructions" – towards creating a sustainable habitat by minimising the ecological footprint

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Abstract

Sustenance of the human race has put an immense pressure on our planet Earth in terms of sustainability of natural resources. The greenhouse effect and the ozone hole are the two most threatening effects of pollution. Constructions of buildings as well as materials contribute to a large percentage to this pollution. Again every material used in the building industry has its source in the Earth. In general the low energy materials will be least polluting. The conventionally used building materials like bricks, cement, steel, timber, plastics, glass etc. usually involve huge transportation costs and also manufacturing processes which are detrimental to the environment. On the other hand the demand for new buildings as well as the cost of building construction is growing a tremendous pace. We have to search for alternative materials which are energy efficient, environment friendly and economical like our traditional building materials - mud walls and thatch roofs. Of all the alternatives available to us which lead the way to sustainability, building with earth has been an ancient and accepted practice among communities all over the world. It is estimated that the construction and the operation of buildings is responsible for around half of all global CO2 emissions, thereby contributing the largest single source attributable to climate change. Earthen construction has been, is and will continue to be a reality. Stabilised rammed earth walls can be used as a building integrated source of passive cooling technique. A huge population in India lives in the rural areas where there has been a growing trend in shifting towards brick and concrete constructions in search for social status. Even a small percentage can lead to massive increase in global CO2 emissions if the trend is not checked at this point. This papers looks into the current scenario and hence the corresponding responsibility on architects, planners and policy makers to bring in technology reforms; *the green way of thinking'* which will see a better and safer tomorrow.

Keywords: sustainability, earth construction, ecological footprint

Introduction

United Nations World Commission on Environment Conference in 1986, chaired by the then Prime Minister of Norway GroHarlem, Brundtland, established the concept of sustainability, which it defines as, 'those paths of social, economic and political progress that meet the needs of the present without compromising the ability of future generations to meet their own needs' [Steele 19971]. Sustainability is the

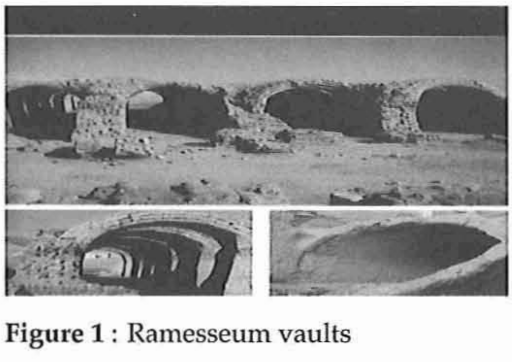


Figure 1 : Ramesseum vaults

moral imperative of the age of architects as said by the President of the Royal institute of British Architects (RIBA). At the beginning of the 21st century architects are expected to be ever more creative, while being mindful of the impact of their building designs on the ecological systems of the planet.

Earthen Construction

Next to food, water and air, shelter is man's most basic need. Earth has been the most basic building material since the dawn of man. To be sure, the earliest known kinds of earth construction were very crude by our standards today. Gradually man learned that some kinds of earth made better houses than others. Some of the best would last his entire lifetime. Rammed earth construction was first recorded by the Babylonians in 5000 B.C. The 1500 mile long Great Wall of China is the only man-made structure that can be seen from the moon with the naked eye. The wall was built around 300 B.C. and parts of the western portion are built of rammed earth. From there rammed earth migrated to India, over the Indian Ocean to Madagascar, across the continent of Africa, to Morocco, and then with Hannibal to Spain, the Pyrenees Mountains (where he built a string of watch towers, made from rammed earth, within eye sight of each other, many still standing), through the Alps, down into Italy (218-201 B.C., Hannibal introduced rammed earth to the Romans during the Second Punic War), then the Romans transported the idea to France and the lowland countries of Europe [http://webs.ashlandctc.org/jnapora/hum-faculty/syllabi/trad.html.]. The Kanuzi Nubians, faced with the challenge of a harsh, treeless environment and the problem of roofing over spaces without wood for beams or supporting members for centering, have perpetuated a building technique that has been used in Egypt since at least the 13th century BC, as in the Ramesseum, the mortuary complex of Ramses II. This method of construction

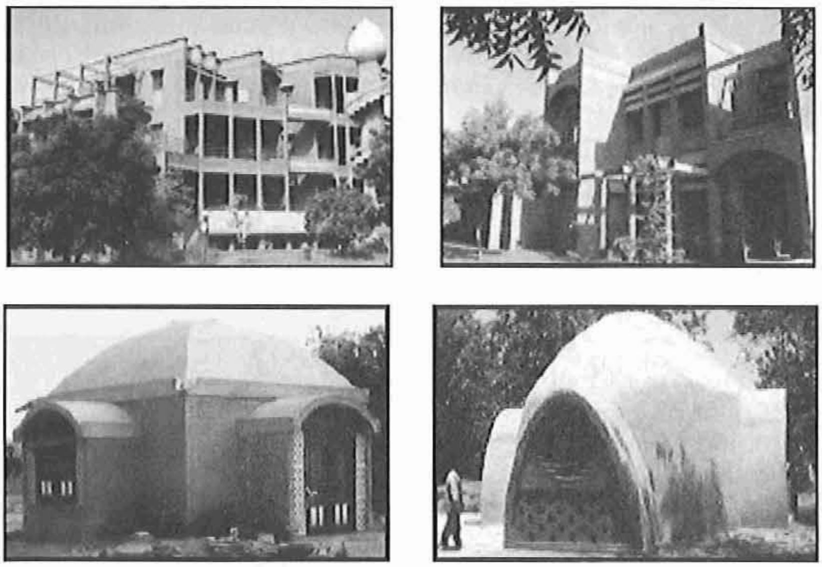


Figure 2: Vikas Community: Houses designed by the people of Auroville itself as well as architects. Photo Acknowledgements: 'Earthen Architecture and Stabilised earth techniques in Auroville', Satprem maini, 2007.

(Figure 1) shows a great understanding of the laws of statics. The vaults that form the basis of the system are made in a parabolic shape that will keep the material in compression only.

Earth construction exists in two formats today: the traditional mode which relies essentially on the use of unstabilised earth and the modern format often using stabilised earth. A majority of the modernizing societies tend to reject the traditional approach, with the possible exception of the use of adobe in certain parts of the world. With the addition of cement or cement and lime, earth acquires the strength and durability comparable to brick and is often accepted on that account. However, there are many societies which consider stabilised earth to be closely related to traditional unstabilised earth and prefer to use brick and concrete whose performance is never in question [Jagadish 20073]. The use of earth on the site as a building material saves cost, time, energy, and transportation. Buildings with earth has been an ancient and accepted practice amongst communities all over the world. It is estimated that the construction and the operation of buildings is responsible for around half of all global CO2 emissions, thereby contributing the single largest source attributable to climate change. Stabilised rammed earth (SRE) materials have low embodied energy content because approximately 95% of the raw materials are unfired and are locally available, thus minimising transportation. Recently, the use of crushed recycled aggregates (e.g. demolition waste from bricks, concrete or SRE itself) is increasingly used instead of virgin sub-soils. This offers the advantage of reducing landfill and converting on-site waste materials into a high quality product for new-build processes. Earthen architecture in Auroville shows a wide range of buildings: from houses to apartments and public buildings. The development of Vikas community showed that earth can be used for building a progressive and harmonious architecture up to 4 floors high. Compressed stabilised earth blocks (CSEB) are mostly used in Auroville and many stabilised earth technologies have been developed, from foundations to roofs and for disaster resistance.

Building technologies based on earth

Compressed Stabilised Earth Block (CSEB)

A wide range of equipment for building with earth, Auram, has been researched and developed from the very

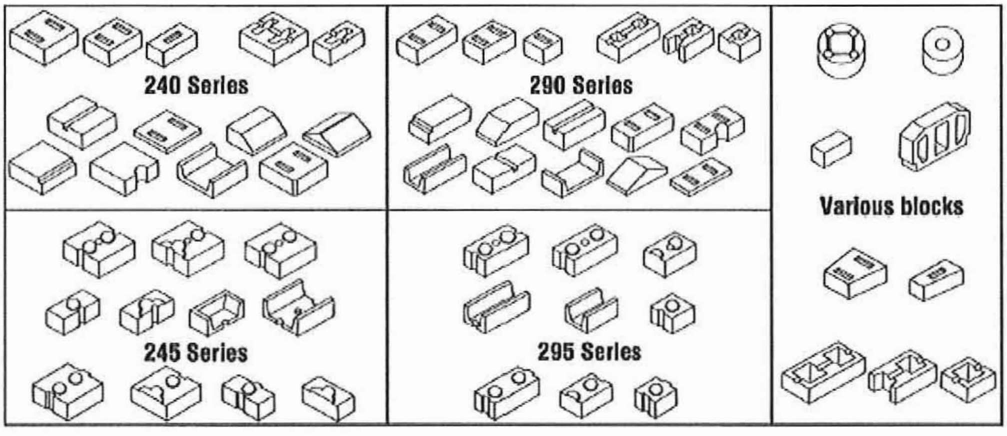


Figure 3 : Wide variety of compressed stabilised earth blocks, by the Auram press 3000.

onset by the Auroville Earth Institute. The press 3000 is today being sold worldwide. The Auram press 3000 as shown in the figues can fit 17 moulds on it, for producing about 75 different types of blocks, with various shapes and thicknesses. The figures below indicate the wide variety of compressed stabilised earth blocks produces by the Auram press.

SEB made in Auroville with 5% cement, have an average dry compressive crushing strength of 5MPa and a wet compressive crushing strength of 2.5MPa. The water absorption is around 10%. Country fired bricks have around 35 kg/ cm^2 for the dry compressive strength and 12% water absorption. The cost of CSEB walls (at Auroville) is 25.9 % cheaper than country fired bricks.

Stabilised Rammed Earth (SRE)

The soil is mixed with sand and stabilised with 5% cement. The mix is rammed by hand. Foundations are rammed directly in the trench. Walls are rammed in between formworks. Rammed earth walls are 45.3 % cheaper than country fired bricks.

Composite Basement and Plinth Beam

Basements are made with CSEB stabilised with 5% cement. The plinth beam is cast into a U shaped CSEB. Reinforced concrete is cast in the U shape blocks. This is a very neat and efficient way to do a plinth beam.

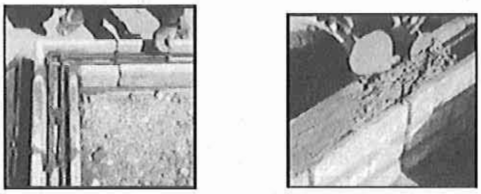
Composite Columns

Round hollow CSEB are reinforced with cement concrete. Reinforcements vary but the rod diameter cannot exceed 10 mm for the round blocks 290 (290 mm diameter) and 12 mm for the round blocks 240 (240 mm diameter).

Composite Beams and Lintels

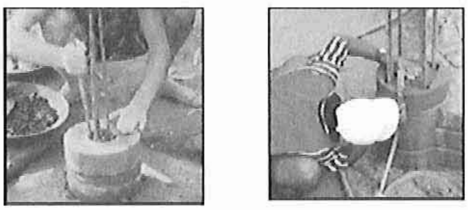
Reinforced cement concrete is cast in U shaped CSEB. The bottom part of the beam is precast in a reversed position on the ground. Once cured, it is lifted and the middle and top parts are built on it. Three different heights of beam are done, according to the span (see Figure 32) and the blocks are used as lost shuttering in all cases:

- Single height beams: up to 1.25 m span with 2 bars of 12 mm. U blocks also help in this case the compressive strength of the beam, as they are on top of the beam.
- Double height beams: up to 2 m span with 2 bottom bars of 12mm and 2 top bars of 8mm.
- Triple height beams: up to 3 m span with 2 bottom bars of 12mm and 2 top bars of 10mm.



a. Stabilised rammed earth foundation and wall

b. Reinforcements and casting



c. Composite columns

Figure 4 : Uses of solid rammed earth

Figure 5 : Segmental vault 10.35m span, 2.20m rise, 6m long, built in 18 days with 4 masons

Vaulted Structures

At the Auroville Earth Institute, the Nubian technique of vault construction has been further reasearched and new ways of building vaults and arches have been worked upon. The free spanning technique allows courses to be laid horizontally, which presents certain advantages compared to the Nubian technique which has vertical courses. Depending on the shape of vaults, structures are built either with horizontal courses, vertical ones or a combination of both. The Auroville Earth Institute has developed an optimisation method for calculating the stability of vaulted structures. This method has been especially developed for designing and building vaults without Centerings [Maïni Satprem 20074].

Building Process/ Weller Cob – Walling Technique

The most important technical progress in comparison to the traditional house is the introduction of a damp proof course, a brick foundation and mixing of loam with straw. The traditional building technique (where very wet loam is used) was replaced by the "Weller" technique that is quite similar to the traditional one. The 'Wellerbau' is a historical earth building technique. Loam is mixed with straw, which is a kind of reinforcement for the wall. Neither cement is added, nor any other supporting structure. The "Weller" – wall (550mm) is constructed in layers. Each layer is built approximately 70 cm high, dries up within 3 - 4 days and is trimmed on the sides with a spade to get the accurate shape (Figure 6). After a second drying period, another layer can be added. The building process is much faster in comparison to the traditional method: the layers can be much higher due to the straw "reinforcement" and the bearing strength is high enough after some days to step on the wall and to add another layer. Even sandy loam is suitable for this technique and fertile sticky soil can be saved for agriculture.

Figure 6 : Source, Anna Herringer, 2007. Weller construction: mixing; placing of first layer, trimming with the spade; 2nd layer (Herringer, 2007)

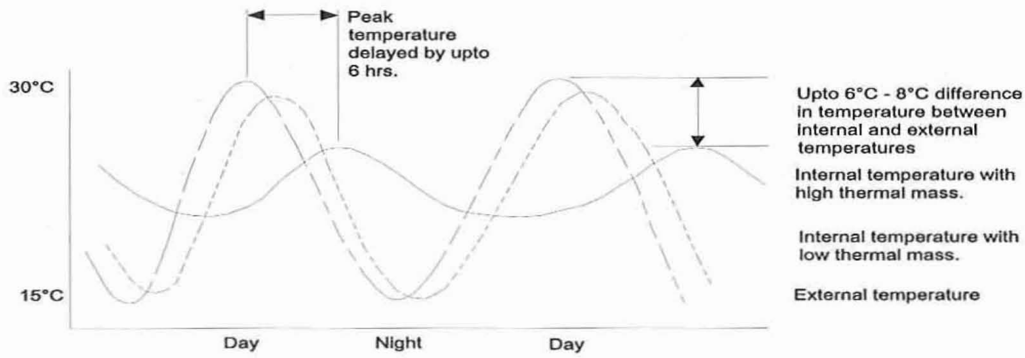


Figure 7 : Internal temperature stabilizing effect of thermal mass (de Saulles 2005).

Passive Air Conditioning Potential of SRE

The use of air conditioning to control the indoor thermal environment (temperatures and ieshumidity) of buildings, within comfortable levels for the occupants, is now commonplace. Stabilised rammed earth (SRE) walls can be used as a building integrated source of passive cooling technique..

SRE has a similar heat capacity to concrete and the additional advantage of being hygroscopic while offering a low carbon alternative to the high cement content of solid concrete. Today, building designers are increasingly becoming aware that SRE walls can be used in modern buildings for the combined functions of load-bearing structure, external envelope as well as for passive cooling technique.

Some of the row housing approaches in traditional rural India have built-in features which protect earth walls against rain. For instance, the side walls of row houses, which are perpendicular to the street, are never exposed to rain as the space between two walls is too narrow and is further protected by roof projections. The front walls of the house are also often protected by a sloping verandah (or cow shed) roof. The lighting is often provided by small courtyards and the mud walls are completely protected against rain erosion. The only threat to such mud walls is possible flow of water from leaking roofs which can locally damage the walls if it is not attended to in time [5Allinson D & Hall M 2007].

Alternative Specifications for Earth Walls

It is possible to consider a hierarchy of earth walling solutions wherein some

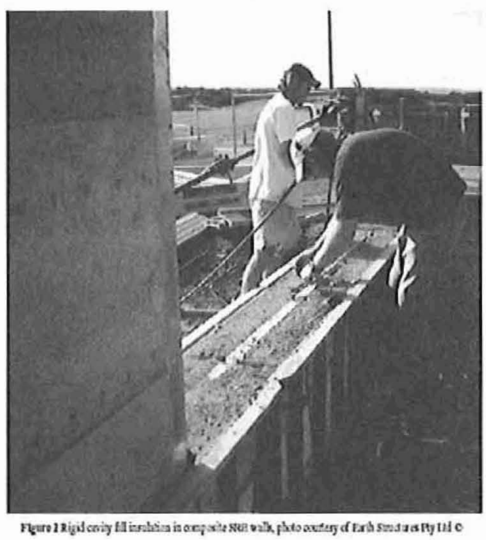


Figure 8 : Rigid cavity fill insulation in composite SRE walls. Photo courtesy of Earth Structures Private ltd

of the stringent performance criteria are progressively relaxed retaining some of the essential criteria.

The following hierarchy of solutions is suggested by the authorJagadish and Ullas, 2007 [6]

a. When unstabilised earth construction is used it is possible to consider walls which have satisfactory dry compressive strength (~3.0 MPa) and resistance to rain erosion. This is quite cost effective.
b. Partly stabilised earth can be consideredwhichhasdrycompressive strength (~3.0 MPa), resistance to rain erosion and retention of shape of earth block even after soaking in water for 24 hours although the saturated compressive strength is inadequate. This is moderately cost effective.
c. Fully stabilised earth construction will satisfy all the four criteria. Costlier than the earlier options, but favourable with brickwork and concrete block work.

Total Cost of house Rs.23000
Cost/sqft –Rs.107.62

Figure 9 : Circular Rammed Earth Structure Bhunga at Hodka, Kutch, Gujarat

Use in disaster resistant homes

There was a huge demand for houses to rehabilitate the earthquake affected families in Gujarat state after 2001 Kutch earthquake. Initially Compressed Stabilised Earth Block (CSEB) construction technology was used but as a variation of the CSEB technology, cement stabilised rammed earth techniques were adopted and developed to suit the various forms of houses include the traditional houses called Bhunga [Jagadish & Ullas 2007]. However, as societies come under the influence of 'Development' earth construction appears to be less attractive. Environmentalists are eloquent about the ecological benefits of earth construction but the poorer sections in developing countries are not impressed.

Future Research Aspects

There is a need to examine afresh the durability aspects of traditional earth constructions since many useful local practices are vanishing from our knowledge systems due to the perceived inferiority of earth construction. Such technologies are likely to spread in areas where entrepreneurs or entrepreneur NGOs are able to provide the technology delivery systems [Abey & Smallcombe 2007].

i. While it is energy efficient to use stabilised block technology instead of bricks, its accessibility to the poorer sections of society does not appear to be satisfactory.
ii. In terms of new materials, cob is a traditional building material in the South West of England. It is a mixture of subsoil, straw and water and is built with no shuttering. Cob has a real future in mainstream construction – it is sustainable, low environmental impact, versatile, durable and aesthetically pleasing.

iii. There have been a number of high profile examples of rammed earth construction in recent years, heavily influenced by the high quality contemporary work on continental Europe by Martin Rauch. In these projects earth construction acts as an emblem of 'green construction', though the walls are rarely used to their structural or environmental potential. Again the work tends to be slow and expensive, and where understanding or quality control is not good, the results can be somewhat disappointing.

iv. The high public profile and 'engineered' aesthetic quality of such contemporary earth building has served to dispel the 'mud hut' image of a material associated with hand-made buildings of low quality in dry climates, rather than a one suitable for contemporary UK construction projects. However, because of its expense, rammed earth will not become a common form of contemporary construction and remain in the niche of 'eco-buildings' special clients.

v. The improved image of earth construction brought about by such projects has coincided with a general increase in the importance of considering environmental impact in the U.K. construction industry. Driven as much by cultural aspiration as by changes in building regulation, there are increasing opportunities for new sustainable products and methods to break out of the green fringe into common use.

vi. Criteria for Mainstreaming: The niche of green building has allowed experimentation in a wide variety of 'alternative' construction materials over the last 15 years, but very few have broken into the mainstream of everyday buildings thereby making a significant difference to the environmental impact of the way we create and manage our built environment. Some are too expensive, some are difficult to use, some do not suit commercial construction processes and program and some are difficult to develop as commercial products. Ones that have mainstreamed, such as sheep's wool insulation, have been simple to use as substitutes for conventional, more environmentally damaging products, are not disproportionately more expensive, have a marketable image and could be brought to market with limited investment. In the family of earth construction techniques, only earth masonry fits these criteria in a U.K. context.

- It can be affordable and, in a climate of increasing energy costs, will become increasing low cost compared to competing products.
- It is easy to use and relates closely to existing common construction practices.
- There is a large, established manufacturing industry with excess capacity that could develop commercial products relatively quickly, at low initial investment.
- Given basic guidance, building designers could easily incorporate it into current building designs.
- In design terms, it would have multiple technical benefits and respond to a growing interest in the use of thermal and moisture mass to minimise energy consumption and improve building health.
- Clients have a track record of responding favourably to its use.

These credentials mean earth masonry has the ability to be turned, relatively quickly, into a new mass construction material. Investment by the brick industry is key to developing the image of an eco-friendly product of progress and building demand for these products in a market it knows well.

The effect of housing on Ecological Footprint

The Living Planet Report 2006, [9] (WWF, Institute of zoology, Global Footprint Network, 2006) declares India among the countries having smallest "ecological footprint" at less than 0.9 global hectares per person. In 2003 the footprint per Indian was reported as 0.8 global hectares (gha). In comparison, USA required equivalents of 9.6, China 1.6 and Germany 4.5 global hectares per person (as on 2003). However there is a change in this positive scenario if we look at the National ecological footprint in relation to the nationally available biocapacity. At a total bio-capacity of 0.4 gha per Indian there is a deficit of 0.4 gha per person. With a population of 10667 Million the sum of -0.4 ha/person causes a footprint which is more than100% larger than the bio-capacity of the country.

There is a crucial need to find strategies to improve this situation. But how? India is one of the developing countries. It is very clear: we must fight poverty in India and find strategies that improve life for each individual person.

At the same time we must avoid the increasing of the ecological deficit. This might sound presumptuous taking into account the situation of high-income countries that are causing much more damage to our planet than developing of the ecological deficit. This might sound presumptuous taking into account the situation of high-income countries that are causing much more damage to our planet than developing There is a crucial need to find strategies to improve this situation. But how? India is one of the developing countries. It is very clear: we must fight poverty in India and find strategies that improve life for each individual person. At the same time we must avoid the increasing of the ecological deficit. This might sound presumptuous taking into account the situation of high-income countries that are causing much more damage to our planet

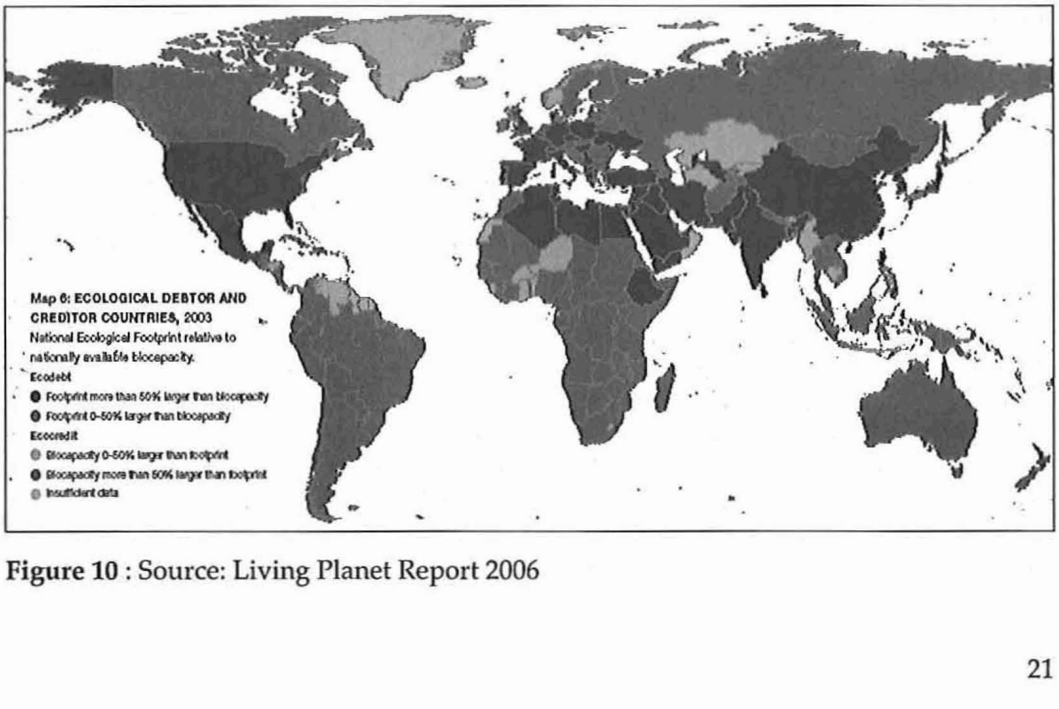


Figure 10 : Source: Living Planet Report 2006

than developing countries. But at present there is no country in this world that is released from the effort to save our planet. Sustainable development is a commitment to "improving the quality of human life while living within the carrying capacity of supporting ecosystems" (IUCN et al., 1991)[10]. What is the role of architecture in the process of development – in an improvement of living standard and a balanced eco system?

A survey of rRural architecture in India (Tobias Hagleitner et al., 2003) shows (Figure 7), that all expansion is happening onlyis mostly horizontal. In the survey area all with majority of the houses being houses were single storey. In addition to that wWealth causes two major effects on architecture and settlement pattern: It helps transforming settlement patterns from very dense and compact settlement to broader and expatiating households. Two hamlets with very low income families have for instance 41 where 200 people live on an area of 10 000 sq. m. and 17 families with 80 inhabitants on 5 500 sqm respectively. But on 5000 sqm only 8 households with 35 persons live in "Saha – para" which means "the hamlet of the rich". The other effect of financial capability according to the survey mentioned above is reflected in the building material. This is visible in the private temples and shrines. They all follow the unwritten law, which prescribes that all temples must be built in the most valuable material that is used in the homestead. The hierarchy is clear to see while walking through a Bengali village: Brick (best), loam (middle), bamboo and straw (last). To bring it to a point: All the expansion caused by the demographic development as well as financial ability is shown in capturing space and buying material instead of taking the (dirty) mud to one's feet. Not only comparatively "rich" people follow that pattern: also NGOs or public buildings from government do the same, which stand for development and improvement. What will be the consequence if this trend will continue?

Back to the concept of the ecological footprint and its respective components: The actual footprint of India due to the built-up land (meaning infrastructure including hydro power) in 2003 was 0.04 gha/person. More specific: the bio-capacity of cropland was 0.29, grazeland 0.00 and forest 0.02 gha/person. The total bio-capacity of the land is only 0.314 gha per inhabitant whereas the nearby country Myamar with similar climatic conditions has a biocapacity of 1.04 gha/person. (Living Planet Report, 2006) [*Living Planet Report, 20069*] The decisive difference is the population density. On an area of 1442973190.000 sqkm aand a a population of 1066 Million ([http://www.worldatlas.com/webimage/countrys/asia/in.htm#facts]. Wikipedia, 2006) Eevery square meter is vital to cultivate most important eatables, which is mainly rice, wheat and jute. Of course it is mainly a matter of agriculture to introduce a cultivation strategy to enhance the biocapacity. But it is a matter of architecture to care for the basic prerequisite, i.e. land. India must get out of poverty and seek to find a strategy to avoid an increasing footprint in the sector built-up land. The strategy is simple: a vertical extension of built-up land to save the precious land for a sustainable cultivation. "Population pressure continues to place a severe burden on productive capacity, creating a food deficit. Foreign assistance and commercial imports fill the gap. Underemployment remains a serious problem. Finding alternative sources of employment will continue to be a daunting problem for future governments, particularly with the increasing numbers of landless peasants who already account for about half the rural labour force." (Pearson Education, 2006)[Pearson Education 200612] As this quotation states, saving land is interlinked with many aspects such as economics, increasing debt, health/food, employment facilities and in a wider perspective – even with demographic changes in larger scale (migration), stabilised democracy and peace [Herringer 200713]..

Another crucial factor to measure India's footprint in future will be the country's CO2 emissions from fossil fuels. And architecture will have a major influence on that. Following article states the present trend: The Brick industry is worldwide constantly growing – Since 1990 the worldwide production of bricks is significantly increasing. The sales volume of that sector is estimated to be 26 million Euros at present. In China the brick production currently samples a vast boom. Now also the brick production in the Arabic countries of North-Africa, which up to now knew mainly handmade bricks is increasing. Globally seen bricks and roof tiles have reached a level of quality and sales quantity that let us look positive into the future (ARCHmatic, 2006).[ARCHmatic *2006* 14]. At present approximately 20 percent of the houses in rural area are built with bricks. The rest are bamboo/straw or loam buildings. What if India continues the present trend in its rural areas and follows the global model in investing in brick houses? This would cause a tremendous rising of the CO2 emission due to the coal, which is the energy source of the brickfields. The same would apply for steel instead of bamboo plus the energy consumption for the transport. In 2006 the total population of India was 1067 Million (Wikipedia, 2006),[15]. 75% of the total population) were settled in rural areas. Out of these 80% of; whichthat means over 80640 Million Indiansi live in houses built in loam or bamboo/straw. If these buildings will be replaced by houses built out of locally fabricated bricks, in brickfield that not even underlie the standards for filtering and reduction of emissions – the rising of CO2 emissions would increase in dramatic scale (in worst case about 20150 Million houses). CO2 in the atmosphere causes 80% of the global warming. The rising of the sea level would hit India as one of the first countries and 60 million people in Calcutta and Bangladesh would be homeless, the number and power of destroying floods (due to melting glaciers in the Himalaya) and cyclones (due to the water evaporation caused by higher temperature of the Indian Ocean) as well as a severe and permanent water crisis due to the drying-up of the river Ganges and Brahmaputra are predicted to be the immediate effects (Al Gore, 2006) [16]. That means building with loam is a valuable action against an increasing ecological footprint and it is even affordable for the poorest of a least developed country.

The Role of Architects and Planners

It is our responsibility as planners to support implementing bodies in terms of research in appropriate techniques, training and design. Policy making organisations, government and non-government organisations must set good examples through representative public buildings as well as through pilot projects for residential houses that can be multiplied by the villagers. For a real change towards a social and fair economic improvement we need to find ways to strengthen local identity and craftsmanship. Culture could be a possible way to succeed. There is a great example in Indian history of an effective protest against global industrialisation and for an independence through focussing on local production: Gandhi's philosophy of homespun, traditional clothes was a strategy to free from imported goods, to free from powerlessness against social and economic discrimination through self-production. Beside this it was a method to eliminate social differences fortified by the distinction between those who can afford buying prestigious English clothes and those who need to spin it by themselves. Isn't that situation very similar to the one of brick- and loam -buildings? The homespun "khadi" even became a kind of uniform for the Indian independence movement and was a symbol of independence as well as a deliberate return and appreciation of its own culture. (Nanda, 1958)[Rabindranath Tagore 193118]

Conclusion

Every man needs a shelter. In today's urban world, every man needs a house that is economic, durable as well as aesthetic. Right from the dawn of the 20th century, mass production of housing using industrial materials has been the only answer to cater to the growing demands. This has lead to large negative impacts on the existing environment. The man's day to day activities which are at par with the modern society has lead him to spend huge amount of energy in order to gain a certain level of comfortable living. However, with the present day trends, the future looks bleak with high carbon emissions, large ozone holes in the atmosphere and degraded human health. The time has come to rethink scientifically new ways of being more innovative and modern but less consumptive. The time has come when we need to give a serious thought as to how we can build upon the existing natural resources rather than unthinkingly deplete the existing ones. The famous Bengali philosopher Tagore describes beauty as "perfect harmony". And can that harmony exclude the elements of sustainability? How could something be beautiful if it is not sustainable? "When our universe is in harmony with man, the eternal, we know it as truth, we feel it as beauty. Beauty is in the ideal of perfect harmony, which is in the universal being." (Rabindranath Tagore, 1931).[Nanda 195817]. As architects we are in the service of beauty - it is on us to realise an architecture that is not a matter of self-infatuation but a trial to reach true harmony on all levels of the entire being. Earth as building material has the potentials to reach a high level of sustainability in all its social, economic and ecological aspects. But there is a surplus in building with earth: it is much more than just a building material: it is an essential element that touches our inner emotions. In every culture there are poems or songs about earth, but I have never heard one about concrete and steel. If we do not only find the right rhymes but also the appropriate architectural language I believe earth will no longer be the "material of the poor" - but the material of the future.

This paper has discussed the role of earth in construction of new buildings as a means of sustainable humane living. Some serious efforts on our parts can help us upgrade our lifestyles so that we can optimize our dependancy on the non-renewable energy sources.

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