What Characteristics Define Ecological Building Materials

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Abstract: - The impact of building activities on the environment is tremendous. It can be analyzed considering different topics: insulation, use of unconventional energy sources, solar devices, glass houses, photovoltaic systems etc. The paper focuses on the complex problem of healthy, ecological materials, analyzing what makes a building material ecological and what criteria should these meet. Some new ideas and technologies for the use of one of the oldest natural building materials, earth, are presented.

Key-Words: Ecology, Building, Materials, Health, Energy, Environment

1 Introduction

Ecology is nowadays an every day topic. The building sector is directly targeted, being, from the ecological point of view, one of the most damaging for the environment. The variety of new materials is tremendous, and so is the variety of new ideas. But what are the characteristics an ecological building material should have? These also are varied:

- They should be healthy for the users; natural materials are indicated
- They shouldn't consume energy for transportation, thus avoiding collateral pollution; local materials are indicated
- They shouldn't consume a great quantity of energy for fabrication; again, natural materials should be considered
- High insulation qualities are necessary, in order to avoid excessive energy consumption; natural materials rarely respond to these requirements without exaggerating their thickness
- Eventually the new materials and techniques should have beneficial effects on the environment; vegetation in buildings is indicated
- They should be recyclable
- They should be reusable at least once, or even several times
- They should reuse residues; the reuse of non ecological materials can be an ecological undertaking.

The paper will present examples in which some of the stated goals was targeted. Even traditional materials will be considered, when used in new, inventive ways.

The Finn architect Pirjo Kaltianen, teacher at the University of Oulu, proposed an ecological evaluation of building materials.

2 What are healthy materials?

The building materials should be healthy for the inhabitants/users. That means they should be:

- Without pollutants and toxic components
- Not causing unpleasant noises
- Secure as radioactivity
- Secure as electromagnetism (1).

If materials with high radioactivity should naturally be avoided, and so should asbestos (even if asbestos cement is not directly damaging in buildings, it becomes so at works of refurbishment or demolishment, reminding of the need to consider the full life cycle of any material), they are many other materials that are damaging. Some release for instance formaldehyde, incorporating certain solvents. Timber products are treated with chemicals, like insecticide, and composite materials incorporate certain resins. Some paints use toxic metals such as cadmium and lead (2).

3 Environmental impact of materials

Absolute rules can not be given for all situations or all the materials. One has to make choices. One of the questions is what would the environmental impact be and how can one assess it. When measuring the environmental impact several problems should be considered: energy use, resources supply, global warming, acid rain, toxins etc. The complexity of the topic has to be clearly stated.

3.1 Calculating the embodied energy

The embodied energy figures are often given without stating how they have been obtained, or even if primary energy has been considered or delivery energy (the efficiency of any energy transformation is under 100%, and differs for different primary sources, technologies etc.). It is also important to know where the boundary has been drawn. The used energy in a factory does not include all the history of the fabrication of a finished product (3).

Materials having very high energy requirements are: aluminum, plastics, copper and stainless steel (100 - 250 GJ/tone). Those with high energy requirements are: steel, lead, zinc, glass, cement (10 – 60 GJ/tone); with medium energy are lime, clay bricks and tiles, gypsum, timber (1 – 3.5 GJ/tone). The less demanding are sand, aggregate, volcanic ash and soil, with less than 0.5 GJ/tone.

These figures lead to a great range of energy costs. If one considers as unit the energy price for timber buildings, brick buildings will incorporate three times more energy, reinforced concrete 12 times and steel buildings 30 times (4).

3.2 Recycling and embodied energy

Refurbishment is a means of recycling existing buildings. But it is difficult to compare and decide if demolition and new build is more efficient energetically than refurbishment, because, in long term, a new building can be significantly more efficient than the older one over its life span, and will require less energy for its maintenance. From another point of view, demolition produces rubble that can also be damaging for the environment. In front of this dilemma, things should be attentively studies and every step of the proposed activities should be assessed.

Refurbishment has another characteristic: it seems to never end. An undertaking inevitably leads to another, and the costs are difficult to foresee.

3.3 Processing and embodied energy

The greater the number of processes a material undergoes the higher the embodied energy and waste quantities in production will be. As a result, the materials one should choose should be as close as possible to their natural state.

3.4 Transportation and embodied energy

The further a material has to travel, the greater the energy is used for transport. The weight of material will also be an important factor. Sometimes, the material travels several times. Granite for instance is quarried in very specific places. It is sometimes cut and polished even in a different country, and, at the end, can be used in a third very distant location. This process may make sense financially, but is unsustainable ecologically. Ecology and costs are sometimes difficult to harmonize.

3.4 Time and embodied energy

The embodied energy in building materials should be also related to the foreseen lifespan of the building, because the importance of the energy used for building material represents an important percentage for a building with a short life span, and is a small part of the whole energy used for a building that will last decades. The cradle-to-grave approach is called life cycle analysis. It is used to assess the total impact of a building and shows the importance of the life span. The longer a building will exist, the lower the impact of the energy consumption and pollution embodied in building materials and while erecting it will be. This embodied energy will be divided to the lifespan.

The International Standard Organization includes a methodology for life cycle analysis in ISO 14000, although this standard is not specifically related to buildings, but to environmental policies.

4 Earth - rediscovered building material

Earth is one of the oldest building material man has ever used. It is a natural material. Even if presenting different qualities, it can be found in all locations. It is a local material anywhere. It is considered healthy and needs little energy for production. It is not polluting.

How is earth used in contemporary buildings in addition to the traditional cob (having itself a significant come back)?

4.1 Earth sheltered buildings (ESB)

Earth sheltering is the architectural practice of using earth against building walls for external thermal mass, to reduce heat loss, and to easily maintain a steady indoor air temperature. Earth sheltering is popular in modern times among advocates of passive solar and sustainable architecture, but has been around (Figure1) for nearly as long as humans have been constructing their own shelter.

Figure 1: Traditional earth sheltered buildings

Earth sheltered building reappeared after the 1973 oil crisis, energy sources becoming scarce and significantly more expensive. Since then the price has become even higher, culminating with the 2008 peak.

The space heating is the primary energy consumer in most buildings. The two main causes of heat loss are infiltration and heat transfer by conduction. In earth sheltered buildings infiltration is minimized because its cause, wind, is separated from the structure by the covering. Without direct contact between walls and wind, outside air cannot force itself into the structure.

Conduction is also reduced, since the earth covering has a certain level of insulation capacity (although it can not take the place of the insulation (Figure 2).

Figure 2: Contemporary wood, steel and glass ESB

Earth has also many other advantages. Noise is muffled and most of the vibrations are not transmitted. It is fire resistant, and so are most of the materials used for the building structure, like concrete, stone or masonry. Storms do not affect such buildings.

Passive solar houses need to have a high thermal inertia, meaning important building material mass. For earth sheltered buildings, the necessary structure mass, reducing temperature fluctuation, is given by the earth. The exterior walls of a conventional building absorb in summer huge quantities of sunshine heat. But for earth sheltered buildings, the heat moves slowly through the wall. Each successive layer must first change temperature before passing excess thermal energy to next layer, and the slow process impedes the heat flow. The external temperature fluctuations influence scarcely the interior temperature, which remains relatively stable.

Earth sheltered buildings are naturally warmer in winter and cooler in summer, because under frost limits (50 to 100 cm below the surface) the temperature is more or les stable at 13 – 14 degrees Celsius.

The types of construction are:

- Earth piled up against exterior walls and packed, a slope descending from the house. The roof may or may not be fully earth covered. The building being above ground, moisture problems appear seldom and are easier to cope with.
- *In hill* constructions are set into a natural or artificial slope. In areas with varied reliefs, houses set into a slope or hill side were often erected. The ideal position is when the slope faces south (or north in the southern hemisphere).
- Underground, fully recessed constructions are built in excavated ground. For light and ventilation an atrium or inner courtyard are necessary.

If the benefits of earth sheltered buildings are numerous, the earth working as a thermal mass, potential problems also appear:

- Moisture can appear, due to water seepage. The waterproofing can be penetrated, generally around vents, which shouldn't be opening on the roof
- Indoor air quality is sometimes poor and internal condensation can appear. An adequate ventilation should be designed, using earth tubes (a kind of ventilation chimneys) or geothermal heat pump
- The building materials for earth sheltered construction tend to be non biodegradable, with plastics for waterproofing and concrete for the structure (Figure 3). Studies to find new, more environmentally friendly materials adequate to the use under the earth are under way
- The excavation of the site is also drastically time and labor consuming. The price of earth sheltered buildings is more or less similar to conventional ones, because they require minimum finishing and are economical in maintenance.

Figure 3: The use of concrete for ESB

The site planning for an earth sheltered building is an integral part of the design. Investigating the landscape of a site should consider many factors. Local topography can present flat land or differently oriented slopes.

The regional climate is also important. For cool and temperate climates the object consists in retaining heat in winter, avoiding infiltration, receiving winter sun, using thermal mass, avoiding winter winds etc. For summer shading and ventilation are the objectives.

Earth shelters are ideal for climates with extreme temperature (very hot in summer and very cold in winter). In humid climates extra care is needed in order to avoid condensation.

Earth sheltering is not an absolute either-or notion. All the buildings having a basement are at a certain level earth sheltered. The basement's situation is only le idea a bit further, protecting with soil more of the structure (Figure 4) and maximizing southern glass and minimizing all other openings (5).

Figure 4: A partial earth shelter

4.2 Green roofs

A green roof is a roof of a building that is partially or completely covered with vegetation and soil, planted over a waterproofing membrane (Figure 5). It may also include additional layers such as a root barrier and drainage and irrigation systems. Container gardens on roofs, where plants are in pots are not true green roofs, but rooftop ponds are a form of green roofs which are used to treat grey water. Green roofs are also called vegetated roofs, living roofs and eco-roofs.

Figure 5: A spectacular green roof

The benefits are varied:

- Grow fruits, vegetable and flowers (Figure 6)
- Reduce heating in winter by adding mass and thermal resistance value and cooling in summer by evaporation. The reduction in summer cooling and winter heat loss was evaluated in Canada to 26%
- Increase roof life span
- Retains storm water and reduces water run off
- Filters pollutants from the air and reduces carbon dioxide
- Filters pollutants from the rain water
- Increases sound insulation (the soil reduces low frequencies and plants reduce high frequencies)
- Increase wildlife habitat for birds (songbirds, migratory birds etc.) and insects in densely build areas that otherwise are drastically reduced
- Helps reducing air temperature in densely build areas (urban heat island effect), minimizing the heat accumulation on terrace roofs and increasing evaporation during sunny summer days. Studies have shown that if all buildings in a major city would have green roofs, the urban temperature could be reduced in summer by as much as 7 degrees Celsius.

Figure 6: Agriculture on a green roof

Green roofs can be *semi-intensive, intensive* or *extensive*, depending on the depth of planting and the maintenance needs. Roof planting requiring a fairly important depth of soil to grow large plants are *intensive*, because they require irrigation, feeding etc. These roofs are generally accessible to the public like other urban green areas.

Extensive green roofs are designed to be self sustaining and require minimum maintenance (once a year weeding and fertilizing for instance). They are only accessible for maintenance. They can be planted on very thin layer of soil or of varied materials.

Green roofs can be pitched or flat. Pitched green roofs are part of the traditional Scandinavian building techniques. The details can be very simple and can last, if well lead, up to 70 years without water penetration problems.

Modern green roofs made of a system of manufactured layers destined to support vegetation are a relatively new phenomenon. In some European countries actions has been initiated in order to promote green roofs. The city of Linz has been paying developers to install green roofs since 1983 and in Switzerland green roofs are encouraged by a federal law since the ’90-ties.

Industrial *brown field* sites represent a new and valuable idea. They are designed to become habitats supporting rare species of plants, animals and invertebrates. The flat roofs of new developments are covered with local material, in order to mitigate the loss of habitat the intervention brought. They thus become valuable ecosystems.

4.3 Living walls

A green wall is a wall, free standing or part of a building, partially or completely covered with vegetation, soil and vegetation. They are also called vertical gardens. The paper does not refer here to the use of climbing plants growing directly on the wall or on supporting structures, having their roots in the ground (*green facades*). The topic being earth as building material, the subject will be the *living walls* (Figure 7), which have both the roots and the shoots attached to the wall. The modular panels are often comprised of polypropylene plastic containers, geo textiles, irrigation systems, a growing medium and vegetation. There are two kinds of living walls: active and passive.

Figure 7: A living wall for a commercial building

Passive living walls have no means to move the air into the root system where pollutants can be degraded. Their benefits are equivalent to those brought by vegetation in any planted area.

Active living walls represent a new concept, by which the wall is integrated into the building’s air circulation system. By bio filtration and phyto remediation, the quality of the air is improved. The active living wall harnesses nature’s cleansing power by drawing air through the root system, where beneficial microbes degrade the pollutants and bring in interiors fresh air.

Living walls are also means for water reuse. The plants may purify slightly polluted water (grey water) by absorbing the dissolved nutrients. Bacteria mineralize the organic components from the water, to make them available to plants.

Living walls are particularly adequate in dry climates, because the water circulation on a vertical wall is less likely to evaporate.

Living walls can become works of environmental art (Figure 8).

Figure 8: Living wall as an artistic gesture

4.4 Earth bag constructions

Earth bag construction is an inexpensive method to create structures which are both strong and can be quickly built. It is a natural building technique that evolved from historic military bunker construction techniques and temporary flood-control dike building methods. The technique requires very basic construction materials: sturdy sacks, filled with inorganic material usually available on site (such as sand, gravel, clay or crushed volcanic). Walls are gradually built up by laying the bags in courses — forming a staggered pattern similar to bricklaying. The walls are almost always curved (Figure 9) to provide improved lateral stability, forming round rooms and domed ceilings like an igloo. To improve rigidity between each row of bags barbed wire is often placed between the courses. Twine is also sometimes wrapped around the bags to tie one course to the next, serving to hold the in-progress structure together and add strength. The structure is typically finished with plaster, stucco or adobe (Figure 10) both to shed water and to prevent any degradation from solar radiation. This construction technique can be used for emergency shelters, temporary or permanent housing and barns, or most conceivable small-to-medium-sized structures.


Figure 9: The igloo form of an earth bag house


Figure 10: Interior finishing of an earth bag house

4.5 Earth and recycled materials

Earth and recycled materials form an ecological, affordable and inexpensive combination, easy to realize all over the globe.

An example is the so called *Earthship* initiative, dating back to 1970 and founded by the architect Mike Reynolds. His vision for a sustainable home, using indigenous and recycled material took the form of a U-shaped earth filled tire home (Figure 11). Originally, tires were not the specifically considered (Figure 12), but it became the most common design, because tires are accessible to the average person. The walls build with earth filled tires present high structural capacities and are resistant to fire. The filling must be done on the site, because a tire filled with compact earth is very heavy.


Figure 11: Car tires for an earthship wall


Figure 12: Bottles for an earthship wall

The mass of the material gives the thick walls a high thermal inertia, a necessary quality for environmentally sustainable buildings.

5 Conclusion

New ideas for ecological materials are emerging at a high rate. The topic of this paper was focused on one single traditional, local, available, inexpensive, healthy material. But this very old material can be used in new, innovative forms.

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