# Sustainable and Ecological Designs of the Built Environment

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***Abstract*— This paper reviews designs of the built environment from a sustainability perspective, emphasizing their importance in achieving ecological and sustainable economic objectives. The built environment has traditionally resulted in loss of biodiversity, extinction of some species, climate change, excessive water use, land degradation, space depletion, waste accumulation, energy consumption and environmental pollution. Materials used like plastics, metals, bricks, concrete, cement, natural aggregates, glass and plaster have wreaked havoc on the earth´s resources, since they have high levels of embodied energy hence not sustainable. Additional resources are consumed during use and disposal phases. Proposed designs for sustainability solutions include: ecological sanitation and eco-efficiency systems that ensure social, economic, environmental and technical sustainability. Renewable materials and energy systems, passive cooling and heating systems and material and energy reduction, reuse and recycling can improve the sector. These ideas are intended to inform the field of ecological design of the built environment.

***Keywords*—**Ecological and sustainability designs, environmental degradation, ecological sanitation, energy use efficiency

## I. Introduction

ECOLOGICAL designs are designs that minimise environmentally destructive impacts by integrating itself with natural living processes [1]. For example these are applied in sustainable construction/ green construction, which are defined as the creation of a healthy built environment achieved by using resource-efficient methods and ecologically based principles [2]. The holistic management approach adopted by ecological designs can promote species diversity, sustainable resource utilisation and balanced circular flow of nutrients and water. The designs can result in an adaptable habitat, whose quality is a prerequisite for human and ecosystem integrity and health. [1]. Ecological designs can also assist to redress the environmental impacts of the existing built environment by focusing on architectural designs and construction. Environmental damage and ecosystem degradation can be reversed through reorganising landscapes, buildings, cities, and systems of energy, water, food, manufacturing and waste systems.

Ecological designs aim to mimic natural ecosystem integrity, ecological structure and processes. This includes the arrangement and connection of design elements within the local and global environment. The objective is to have ecosystem and environmental stabilisation on a micro and macro scale [1]-[3]. This is consistent with permaculture design principles. Permaculture integrates and forms relationships among, animals, buildings, and infrastructure in a reorganised landscape [4]. The aim is to create systems that are ecologically-sound and economically viable, which provide for their own needs, do not exploit or pollute and are therefore sustainable in the long run. Ecological designs should thus aim to create systems which mutually coexist on earth. It can utilise naturally available renewable energy which is environmentally friendly and use locally available resources in way that reduces or avoids the destruction of life on earth. The value of ecological designs is the integration of human objectives with natural systems, processes and patterns to provide architectural solutions thyat enable human landscapes to link with the environment [3].

The planning, design and management of the conventional built environment is mostly inefficient and unsustainable. This inefficiency can result in waste accumulation, resource depletion, human ill health, crime, disaffection, economic loss and environmental and atmospheric pollution [5]-[6]-[7]. The design of the built environment often reflects avoidable socioeconomic and environmental costs [5] and [7]. The construction of the built environment consumes approximately 16% of available fresh water, 30-40% of total generated energy and 50% of raw materials extracted from the environment by weight [7] and [8]. In addition the construction process is responsible for 40-50% of waste generated in landfills and 20-30% of greenhouse gas emissions. The processing and manufacturing of building materials in United Kingdom is responsible for 10% energy consumption and 10% $CO_2$ emissions [9]. Interior temperature regulation through heating and cooling in commercial buildings of South Africa account for 47% of total energy consumed while 26% is through lighting [6]. 10% of the global economy finances the constructing, operating and equipping of homes and offices globally [2].

Development including the construction of the built environment causes depletion of natural resources and environmental degradation. Since development is necessary, its effects must be compensated by investing the proceeds from the exploitation and depletion of the earth’s non-renewable resources into other forms of social or human made capital. The assumption is that this will maintain the productive capacity to meet the needs of the future generations [10]. The weakness of this argument is that natural capital cannot be substituted with any other form of capital. This is because of the multi-functionality and complexity of natural capital in

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supporting vital ecological processes for all forms of life. There is growing evidence and appreciation of the intrinsic value of natural resources and impacts of unsustainable development on the quality of life [5]. The flow of material resources, energy and wastes within the environment must be within assimilative and regeneration levels which do not compromise the life support systems [7]. It is logical to recognise that environmental degradation and depletion of natural resources is not always due to population growth or development. It is also as a result of the designs we implement to consume and manage resources. This can escalate the flow of materials. Ecological designs have the potential to reverse the unsustainable flow of resources and environmental degradation and can result in improved human ecological health, resilience and viability, leading to positive development, reducing waste and environmental degradation.

## II. ENVIRONMENTAL IMPACTS ASSOCIATED WITH THE CONSTRUCTION OF THE BUILT ENVIRONMENT

The human activities which cause the most significant environmental degradation are linked to construction [8]. The construction of the built environment causes depletion of natural resources and environmental degradation due to its high consumption of materials resources and intense waste production and pollution. Positive development is being advocated for. This is a concept which goes beyond minimising damage to being able to reverse ecological damage and make the best use of recycled materials and renewable resources.

**Biodiversity loss and species extinction:** The construction of the built environment on sensitive and vulnerable ecosystems such as wetlands or marshlands destroys ecosystems integrity and the natural habitats for a diverse of life species. Harvesting of the natural tropical hardwood for use as building materials is going on at unsustainable rates [8] and there have been alarming rates of species extinction rates of 5000 to 15000 per year [10]. The tropical rainforests are home to more than half of the world's biota yet about 17 million hectares of tropical rainforests are lost annually. This rampant loss of trees due to deforestation can be linked to the demand of materials for the built environment. Ecological designs therefor aim to work with nature rather than against nature. The idea is that the built environment becomes part of the ecosystem and forms beneficial relationships with nature.

**Climate change, $CO_2$ emissions and water use:** The production of building materials mainly cement and steel are only surpassed by the use of fuel in emission of greenhouse gases. Cement production releases a lot of nitrogen oxides and 1,1tonnes of $CO_2$ per tonne of cement. The embodied energy for cement is further increased due to transportation and the extraction of raw materials. The use of cement and steel in reinforced concrete further increases total embodied energy of buildings. Production of iron and steel is water and energy intensive accounting for about 41% of global energy consumption. Table 2: shows associated water use and $CO_2$ emissions during the production of conventional building materials [8].

**Table 1: Water use and $CO_2$ emissions of conventional building materials**

| *Material* | *$CO_2$ Emissions* | *Water use* |
|---|---|---|
| Cement | 1,1tonnes $CO_2$/ tonne of cement | 3,6tonnes of water/ tonne of dry cement |
| Clay bricks | 0,25 tonnes $CO_2$/ tonne of brick | 0,5tonnes of water/ tonne of clay brick product |
| Glass | 2 tonnes $CO_2$/tonne of glass | -- - |
| Steel | 1,2 1tonnes $CO_2$/ tonne of steel | 300tonnes of water/ tonne of steel |

The built environment consumes electricity for lighting, heating and warming. Over 50% of electrical power produced globally is through the combustion of fossil fuels, which are the greatest source of $CO_2$ emissions [8]. The built environment restricts underground water replenishment and contributes to pollution of water bodies. It is estimated that more than 1.8 billion people will have no access to safe drinking water by 2060 [11]. It is suggested that in order to reduce $CO_2$ emissions and total embodied energy of buildings ecologically designed structures should use locally available materials. These materials can be treated with natural processes for example sun drying of adobe bricks and use of wood which is naturally dried and harvested locally.

**Space utilisation and land degradation:** 37% of all used land is degraded [12]. It has been noted that the built environment contributes significantly to the distortion of the natural environment. The creation of structures including buildings and pavements which compact the soil surface also contributes to land degradation. Urban growth, road construction, mining and industry has caused massive land degradation and has affected about 19,5 million hectares. Although urban areas occupy 1% of the earth's land area they tend to be located on fertile land and their activities impact negatively on arable land. In the United States of America 400 000 hectares are lost annually and China lost more than 5 million hectares in the last two decades due to urbanisation [2]. In general soil erosion and loss of arable land is mainly is mainly attributed to:

- Sprawling of single storey buildings.
- Strip mining of aggregates and unsustainable harvesting of timber used in construction.
- Site clearance and development prior to construction causing erosion and compaction.

Ecological designs aim for maximum and efficient utilisation of space through creation of double storey buildings and utilisation of roof space. Land degradation can be avoided by use of products from sustainably managed sources. Environmental damage is also restored through mutual relationships of whole ecosystem components.

**Waste accumulation and environmental pollution:** Globally construction and demolition of buildings contribute about 40 and 50% of the waste that is going to the landfills. Illegal waste dumping creates breeding places for mosquitoes. Local authorities also incur additional expenditure in trying to rehabilitate the illegal dump sites [8]. As a result the urban population is exposed to pollution levels above those recommended by the World Health Organisation. The production of building materials like iron, non-ferrous metals, steel, glass and bricks, releases about 20% of dioxins into the atmosphere. Incineration of municipal and construction waste, for example, treated waste wood, floor coverings and electrical wires, is responsible for 69% of dioxin released into the atmosphere. Waste accumulation is minimised in ecological designs through waste trading, reuse and recycling. Pollution can also be minimised through the preferential use of environmentally friendly finishers.

## III. ENERGY CONSUMPTION OF THE CONVENTIONAL BUILT ENVIRONMENT

The environmental impact of the built environment is directly linked to the choice of building materials used. Processing of raw materials to produce building materials is energy intensive and releases waste. In the United Kingdom about 10% waste emissions are directly linked to the manufacture and processing of building materials [9]. The choice and quality of building materials in ecological designs can be determined by:

- Energy consumption during the manufacture of the building material.
- The amount of $CO_2$ emissions due to the manufacturing process.
- Environmental impacts due to the extraction process.
- Chemical properties and toxic levels of the material.
- Energy and fuel consumption to site delivery.
- Pollution levels at the end of the life cycle.

In ecological designs there is preferential use of building materials with low embodied energy. Table 2: shows the embodied energy for different materials [9].

**Table 2: Embodied energy of building materials**

| *Material* | *Density (kgm-$^3$)* | *Low value GJtonne-$^1$* | *GJm-$^3$* | *High value; GJ tonne$^1$* | *GJm-$^3$* |
|---|---|---|---|---|---|
| Natural aggregates | 1500 | 0.030 | 0.05 | 0.12 | 0.93 |
| Cement | 1500 | 4.3 | 6.5 | 7.8 | 11.7 |
| Bricks | ~1700 | 1.0 | 1.7 | 9.4 | 16.0 |
| Timber (prepared soft wood) | ~500 | 0.52 | 0.26 | 7.1 | 3.6 |
| Glass | 2600 | 13.0 | 34.0 | 31.0 | 81.0 |
| Steel (steel sections) | 7800 | 24.0 | 190.0 | 59.0 | 460.0 |
| Plaster | ~1200 | 1.1 | 1.3 | 6.7 | 8.0 |

The main source of energy is mostly non-renewable and contributes to environmental degradation which results in the emission of greenhouse gases which cause global warming [9]. In some cases to construct a house with low embodied energy may not be justified when compared to refurbishment, provided there are no extensive demolitions. In ecological designs there is preferential use of materials close to their natural states. For example the use of softwood window frames are preferred to aluminium window frames. Organic and water based paints with natural pigments or waxes are preferred to synthetic paints. Transportation and weight of materials contributes to embodied energy of materials. Under such situations there is need to analyse total distance travelled and energy used for transportation within the whole life cycle of the building materials. This is important in order to assess the impact and importance of the building's lifespan. The longer a house can last the lower the impact of the energy and pollution resulting from the manufacture of its materials. Conventional building materials like steel, concrete, timber, bricks, cement, aggregates, glass and plaster account for most of the mass of buildings. These materials contribute significantly to the embodied energy of buildings. The designer should specify materials in a way that offsets embodied energy [9].

**Building materials and embodied energy:** This is the total amount of energy used to manufacture a material. It sums up the energy used for the extraction of raw materials, transportation to processing plants, energy used for manufacture, transportation to site and energy used to fit the material.

**Plastics:** While plastics have high embodied energy they are a waste product from the petroleum industry. The argument for plastics is that they reduce waste accumulation. The argument against their use is that they promote an unsustainable industry which emits large quantities of $CO_2$ and 50% of toxic materials into the environment. During their life cycle plastics release harmful volatile organic compounds (VOCs) into the atmosphere. VOCs are present in synthetic compounds in carpets and oil based synthetic paints. Polyvinyl chloride plastics are always avoided because they cannot be disposed in an ecologically safe way although they can be recycled [9].

**Metals:** All materials from the metal group have high embodied energy. The manufacturing processes of these materials results in a lot of harmful emissions. The recycling of metal wastes is energy intensive and releases toxic dioxins due to the presence of chlorine in metals. Therefor the use of metals in the built environment must always be minimised.

Although stainless steel and aluminium are recyclable, they are not ecologically suitable. This is because their first manufacturing and processing has high environmental impacts [9].

**Timber:** The use of timber as a building material is considered to accrue environmental benefits. Timber is a renewable resource which contributes to $CO_2$ sequestration throughout its life cycle. The use of timber is discouraged when it is transported over long distances or when it is harvested from unsustainable forests. When timber is being considered as a building material, there is therefore a need to search for locally available sources. When timber is used on the exterior it must be treated with environmentally friendly compounds like borax. Another alternative is the use of timber which has been traditional harvested. Timber harvested in this way is durable and resist cracking or insect attack [9].

## IV. MITIGATION OF IMPACTS ASSOCIATED WITH CONVENTIONAL DESIGNS

Globally electrical energy drives the day to day activities of the built environment. In residential buildings energy is used for cooking, lighting, warming and cooling. South African poor households spend a fortune for energy services [13]. The use of fuels like coal and wood for space heating causes indoor pollution and can result in ill health and deaths. The extraction of materials, production processes and life cycle of finished goods consume large quantities of energy. The commercial built environment of South Africa consumes about 15,800 gigawatt-hours of electricity per annum [6]. The breakdown is shown in Figure 1.

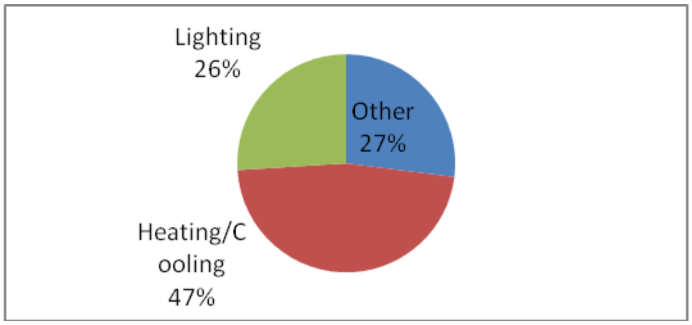


**Figure 1: Breakdown of energy use in South African commercial buildings**

The South African economy is about two to five times as energy intensive as the economies of the Organisation of Economic Cooperation and Development nations. It is the world's third highest emitter of greenhouse gases per unit of gross domestic product (GDP) in the world. Energy generation in South Africa alone emits more than 15 million metric tonnes of carbon dioxide per annum. The inefficient use of energy in South Africa's built environment compromises environmental quality [6].

**Improving energy efficiency and sustainability through eco-designs:** Figure 2 shows typically expected energy and cost savings from improved efficiency [5]. The amount of energy used to keep the interior and exterior surroundings of the built environment comfortable and healthier can be reduced by adopting ecologically designed structures [13]. The benefits of eco-designs hence extend beyond reduced expenditure for space heating. Cost effective measures can be used to reduce energy consumption in the built environment by 25%. The added benefits are improved ventilation and reduction of $CO_2$ emissions. Therefore eco-designs can achieve positive development through mitigating causes of climate change and global warming. [5]

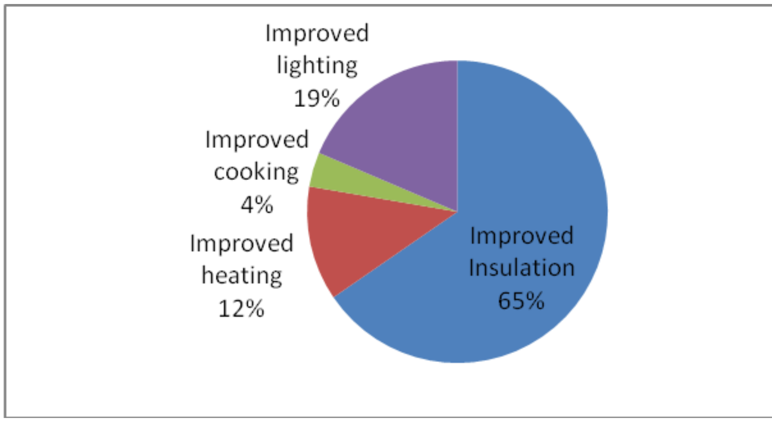


**Figure 2: Energy consumption reduction by cost effective efficiency**

**Passive solar designs in ecological designs:** Passive solar designs in ecological buildings aim to achieve thermal comfort with minimum input of conventional energy. This is achieved through the application of energy flow principles and regional climatic characteristics in the design, construction and management of houses. The orientation of houses influences the energy requirements and their ability to optimise and capture solar radiation for heat gain and heat loss minimisation. Houses in the southern hemisphere must be inclined at $\pm$ $15^0$ N. This will minimise the amount of energy for warming in winter and for cooling in summer. The concept of roof overhangs must be combined with orientation of houses. To maximise utilisation of heat energy from the sun there is need to use building materials with high thermal mass. The benefit derived is maximum heat storage during daylight and gradual release of heat during night periods [13].

Positioning and extend of glazing determines heat gain in summer and heat loss during winter. In order to have minimum heat gain in summer and minimum heat loss in winter the total glazed area should be 20% of total floor area. Double glazing achieves high thermal efficiency and can be used in areas with long and cold winters. There is also advantage of using materials with high thermal efficiency for flooring to maximise trapping of radiation. Houses with ceilings regulate heat inflow and outflow to achieve better thermal efficiency. This ensures maintenance of near constant temperature during cold and warm periods without the intensive use of conventional energy. The application of double walled houses for insulation is also recommended [13].

**Solar Photovoltaic cells:** Solar photovoltaic panels can be used as roofing material. The installation of solar roofs mitigate the environmental impacts of buildings significantly. The high embodied energy during the manufacturing process of photovoltaic cells can be offset by the energy generated during the life cycle. Two solar roofs have been found to generate a about 5kwh which can be fed directly to the grid. This can result in reduced demand of about 40%-50% on conventional energy from the grid depending on location, reducing $CO_2$ emissions and mitigating climate change causes at a local level [13].

**Ecological sanitation:** Nearly 4 million people die as a result of water pollution related diseases annually [14]. Black water (waters from toilets) if collected separately allows for conversion to organic fertiliser. This offers an opportunity to replace the use of chemical fertilisers and halt the spread of pathogens and water borne diseases. Grey water (waters from kitchen, shower and washing) offer scope for new sanitation concepts to produce fertiliser and reuse water. Yellow water or urine contains soluble agricultural nutrients NPK. Ecological sanitation can achieve positive development with close to zero emissions and 100% reuse of waste material. It can create a production unit which provides reusable water, organic fertilisers, soil conditioning material and bio waste. A system can be created, which separates black water and grey water linked to a composting chamber or a biogas digester. Figure 3 shows the components of such a sanitation system [14].

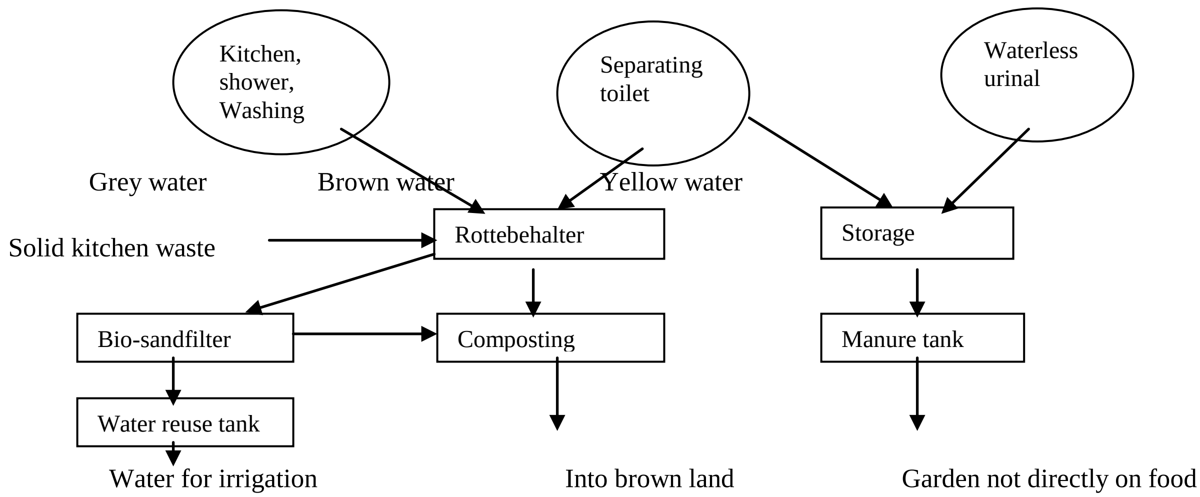


**Figure 3: Components of ecological sanitation with composting chamber**

The system can be linked with sustainable agriculture for positive development of black water, yellow water and grey water to eliminate waste emissions.

## V. THE SUSTAINABILITY OF ECOLOGICAL DESIGNS

Unsustainable and excess urban ecological footprint is causing unsustainable built environments. Urbanisation is on the increase in the developing countries where 50% of the population in urban areas lack proper sanitation and 25% has no access to clean water [7]. Sustainability can be achieved through an ecologically based redesign of infrastructure, services and the built environment [1]-[7]. This can result in improved sustainable livelihoods, employment creation and economic and social benefits with a positive rebound effect. Retrofitting the built environment can increase productivity through a reduction in operating costs, improved worker health, efficient energy utilisation and sustainable use of renewable materials [7].

Ecological designs can incorporate conservation, regeneration, and stewardship. Conservation retards the depletion of scarce natural resources. This encompasses reusing and recycling resources, creating communities with dense populations to preserve space and energy efficiency through insulation and use of efficient vehicles. The weakness of the conservation strategy is that it at best allows minimum damage. This will accumulate to an annual deficit in natural capital. Mathematically it is proven that the cumulative increment of minima can result in the attainment of maxima. Regeneration and restoration add to natural capital by actively restoring the capacity of degraded ecosystems and communities. It heals and renews systems to harmonise with nature. Regeneration goes further than preservation and protection to rejuvenation of collapsed systems [1].

Stewardship entails care to living systems and the built environment. It maintains natural capital by spending frugally and investing wisely. Ecological designs should take a holistic approach on conservation, regeneration and stewardship. Conservation spends natural capital gradually while regeneration adds natural capital and stewardship involves wise allocation of renewable resources and protecting natural capital. Ecological designs have thus the potential to reduce energy consumption and total material outflow, integrating human communities with the global ecosystem. Toxic composition of wastes can also be positively manipulated to levels within the assimilative capacity of the ecosystem the sink [1]

## VI. THE SUSTAINABILITY OF ECOLOGICAL SYSTEMS

**Environmental sustainability:** The extraction of natural resources for material use and emission of waste substances must not exceed the regeneration and assimilative capacity of the natural ecosystems for sustainability. The aim is to maintain and phase out the diminishing of biodiversity productivity. The aim is to reduce environmental degradation and depletion of natural resources. Energy optimisation and overall sustainability can be achieved by using renewable forms of energy like solar, wind, hydro and passive thermal designs. Strategies for water savings include roof water harvesting, low-flow showers and tap aerators and landscaping with drought tolerant indigenous plants [2].

Maximum and efficient recycling and reuse of material resources lengthens the life cycle of landfill sites, reduces space utilisation for landfills and reduces the consumption of resources. This can allow the regeneration of resources by the global ecosystem and restrict resource depletion. For effective reuse of buildings, the construction of buildings must be highly adaptable. This will make it easy for reuse, renovations, modifications or refurbishments. The overall aim is to make maximum use of the built structure intact as possible or recycle unusable materials as much as possible in another project. Recycling differs from reusing in that the old materials are used as raw materials in the manufacture for new materials or designs. In order to avoid depletion of non-renewable resources attention must be paid to the 3Rs, Reduce, Reuse, Recycle. Resource life cycle can be extended by using a product more than once, recycling after the usable life and adopting the use of renewable alternative when feasible. There should be preferential use of renewable energy and materials from sustainably managed sources to non-renewable energy and materials [2].

Minimisation of waste and emissions can be achieved through minimised air, land and water pollution, at every stage of the life cycle of construction projects. At global levels it calls for the reduction in greenhouse gas emissions and ozone depleting substances. At a local level this requires implementation and monitoring management plans for noise, dust, odour, vibration, chemical and particulate emissions, and solid and sanitary waste during construction. A healthy and non-toxic environment can be created by eliminating or through proper use of hazardous products. These products can release formaldehyde and volatile organic compounds into the air compromising the health of occupants [2].

There is need for the maintenance and restoration of biodiversity to enhance the ecological processes. Ecological designs can achieve positive development and maintenance of ecological diversity through:

- Conservation of life support systems which regulate climatic conditions recycles nutrients, create and regenerate soil and renew ecosystems.
- Maintenance of biodiversity and ecosystem integrity.
- Use of natural and renewable resources such as soil, forests, ranches, crop fields, water and animals.
- Reversal of damage due to human activities on ecological processes. There should be promotion of activities which improve environmental stability.

**Social sustainability:** Ecological designs aim to improve the quality of life and meet the basic needs of human life. This is achieved through conditions which eliminate poverty. The management of the construction processes must aim to reduce accidents and eliminate the use of substances which affect human health. Development planning must therefore cater for self-determination and cultural diversity. The designs of the built environment must ensure that they are compatible with human institutions and technology. Capacity building must empower disadvantaged local people with skills which lead to self-sustenance and sustainability at local level. The local people must be given the opportunity to participate fully in the project. This is important for human development in the area and ensures sustainability as the skills are passed from generation to generation. Social costs must be fairly or equitably distributed. If equal distribution is not achieved there must be fair compensation of those extremely affected by the construction up of the built environment. Benefits arising during the construction process must be optimised and enjoyed by the locally disadvantaged. There must be intergenerational and intra-generational equality. Social, biophysical and financial costs of the current construction must not be transferred to future generations. To achieve this there is need to respect the source and sink limits of the environment and change energy and material consumption patterns [2].

**Economic sustainability:** Communities or targeted populations must afford the cost of the construction process and materials needed. This can be achieved by removing the overreliance on technical sustainability. The construction process must create employment for the locally disadvantaged individuals. This will also mean circulation of benefits arising from the construction of the built environment within the community. The construction of the built environment must be cost effective and use resources efficiently. This is achieved by using full cost accounting and real cost pricing to indicate social and biophysical costs [2] Ecological designs must be competitive in market places. Hence they need to be adaptable to policies and conditions which favour sustainability. Construction processes must aim to use of materials from sustainable sources which demonstrate environmental consciousness. To achieve sustainability proceeds from the use non-renewable must be invested in substitutes, social and human made capital.

**Technical sustainability:** Ecologically designed buildings must be durable, reliable and functional. The design must ensure that the structural strength of the buildings can resist natural destructive forces. The first priority of eco-designs is to lengthen the life cycle of built structures. Durable buildings contribute to energy savings and reduced solid waste accumulation. Durability of the built structures must not be enhanced above its useful life as this can be a waste of resources. Ecological architecture must focus more on good function rather than style. Ecological buildings must be adaptable to alterations as necessary. Eco-designs must be of good quality and be able to meet desired needs and functions. This ensures sustainability because cherished structures are cared for and maintained while dehumanising structures are prone to vandalism. [2]

The principle of serviceability of buildings recognises that each part of a building is characterised by its own decay curve. The life cycle of each part can be extended by its serviceability which can be through renovation or replacement. The serviceability of the building structure also considers future upgrading requirements. The serviceability approach considers the whole life cycle from the pre-design period up to decommissioning. Complex buildings must be designed in a way which allows individuals to adjust their inside environments. This can be achieved through use of thin buildings which optimizes contact with nature, opening windows and advanced distributed user controlled, environmental conditioning and networking systems. Ecological designs can revitalise urban infrastructure through integration of buildings for housing, retail place and workplace. This principle is necessary to enhance working, living and leisure environments. [2]

## VII. SOCIAL AND ECONOMIC IMPACTS OF ECODESIGNS

Ecological designs can be cheaper, cleaner and more equitable. The design of some ecological houses may incorporate energy production and saving strategies at little or no extra costs [7]. Financial returns on extra costs incurred for energy savings on buildings can be achieved within eight to ten years [15]. There is a misconception that ecological buildings always entail additional costs. Sustainable construction can respect the connection between the environment, society and the economy to reverse unsustainable trends as shown in Figure 3 [5].

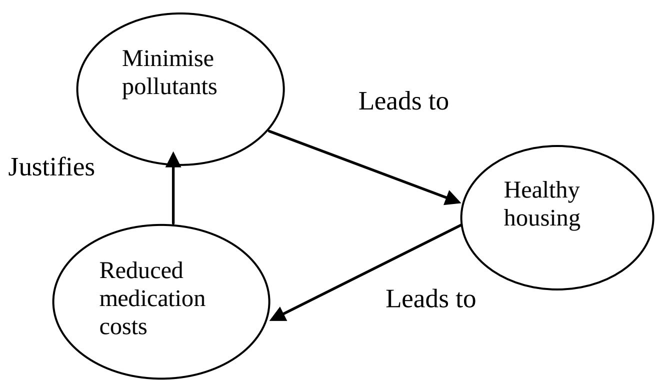


**Figure 4: Benefits of sustainable construction**

There are economic benefits from ecological buildings besides energy and maintenance. These include health, productivity and performance. The beneficial elements of ecological designs may involve little or no extra costs. These include site selection, proper layout, form and window orientation, eliminating over sizing and pre thinking staffing and security issues. Environmental designs which improve air quality and lighting contribute to operational efficiency and simultaneously to improving the performance of people and processes within the buildings. Research indicates that productivity and performance can be enhanced by good air quality, personal environmental control, daylight, and a connection to plant features. There is overwhelming evidence on the influence of the built environment in schools and students performance. A good environment promotes the chances for pupils to do better and allows teachers to do their job well creating a better sense of community [5].

## VIII. CONCLUSIONS

An ecological design which seeks more social and environmental value for less resources and energy can reduce many of the effects if not some of the causes of inequitable wealth transfers. [7] Ecological designs redress the environmental impacts and ecosystem degradation of architectural designs and construction through reorganising landscapes, buildings, cities, and systems of energy, water, food, manufacturing and wastes. They create systems which mutually coexist on earth utilising naturally available renewable resources.

Currently, the planning, design and management of the conventional built environment is inefficient and unsustainable. This inefficiency results in waste accumulation, resource depletion, human ill health, crime, and disaffection, and economic loss, environmental and atmospheric pollution. It is logical to recognise that environmental degradation and depletion of natural resources is not only due to population growth or development. It is also as a result of the designs implemented that to consume resources unnecessarily. Excessive flow of materials also escalates without control. Ecological designs can reverse some of the unsustainable flows of resources and the environmental degradation which results. This can improve human and ecological health, resilience and viability

Ecological designs differ from conventional designs in a number of ways. These include materials and energy use patterns, ecological sensitivity and environmental compliance, design considerations, socioeconomic and ecological factors and participation and learning by ordinary people in the design process. For human basic needs to be attained within sustainable limits of the environmental carrying capacity there is need to reduce energy and material resource consumption and reverse the cumulative environmental degradation and depletion of natural capital to result in positive development. This can be achieved through an ecologically based redesign of infrastructure, services and the built environment. The choice of building materials used is very important. Conventional building materials like steel, concrete, timber, bricks, cement, aggregates, glass and plaster account for the bigger mass of buildings and contribute significantly to the embodied energy of buildings.

The design and construction of the built environment influences the fair sharing of resources. It also determines the social and economic sustainability of communities [8]. There is need to change the current mentality and image of the built environment to ensure sustainability. This must start with the choices people make, materials used and the energy sources. There must also be a paradigm shift in the whole value system in shaping human settlements. The limit to growth requires a change of most design fields. Design for sustainability needs to be based on a global perspective which values simplicity, frugality, durability, reparability, distributive justice, smallness of scale, avoidance of luxurious and affluent styles and easy maintenance.

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