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Methods and Technologies in Sustainable Architecture: An Overview

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ABSTRACT: In the last decades, “sustainable architecture” has emerged as a movement in architectural design towards the sustainability of the built environment. Associated with its development are also many disputes on the meaning and implications of this new concept. There has been no agreement amongst scientists and architects in defining the term and on how it should be implemented in practice. Some other terms such as “green building” and “ecological design” have also been used in parallel with “sustainable architecture”. It can be interpreted as an approach to architectural design that minimizes resource consumption, utilizes natural energy, mitigates environmental damages, and improves human health. More importantly, it should also be considered as a tool for raising people’s awareness of environmental protection or in other words a response to mother nature, who always coexists and supports mankind. However, the agreement that has been reach among the scientists is the identification of eight areas that sustainable architecture needs to deal with, namely i) site selection and building orientation, ii) energy consumption, iii) material selection, iv) indoor environmental quality, v) water consumption, vi) waste disposal, vii) construction methodology, and viii) life-cycle costs. This paper will review the methods and technologies in each of these eight areas that should be employed to create the sustainability of the built environment. The review will discuss the contents as well as the advantages and disadvantages of each method and technology. The paper will also conclude with discussions on other technologies beyond the mentioned ones and on the obstacles that should be removed on the way toward a real architectural sustainability.

Keywords: energy, material, consumption, waste, environment

1. Introduction

In the last decades, “sustainable architecture” has emerged as a movement in architectural design towards the sustainability of the built environment. Associated with its development are also many disputes on the meaning and implications of this new concept. There has been no agreement amongst scientists and architects in defining the term and on how it should be implemented in practice. Some other terms such as “green building” and “ecological design” have also been used in parallel with “sustainable architecture” in order to clarify or more specifically express its implications. Several scientists define “sustainable architecture” as “the social and cultural shift in the world order, patterns and styles of living” (Kremers 1995) and others consider it as “environmentally friendly modes of design, construction and operation geared towards producing healthy enduring communities” (Zachariah, Kennedy, and Pressnail 2002).

Some of them have also attempted to relate the term to the Second Law of Thermodynamics in order to argue that sustainable architecture is an impossible goal. Steven Strong stated: “the term is intellectually dishonest...” and moreover, Dick Levine argued that “sustainable architecture is an oxymoron” (Kremers 1995). However, sustainable architecture should be understood in a broader meaning rather than in the meaning of words. It can be interpreted as an approach to architectural design that minimizes resource consumption, utilizes natural energy, mitigates environmental damages, and improves human health. More importantly, it should also be considered as a tool for raising people’s awareness of environmental protection or in other words a response to mother nature, who always coexists and supports mankind.

Despite the controversial discussions regarding the term definition, the agreement that has been reach among the scientists is the identification of eight areas that sustainable architecture needs to deal with, namely i) site selection and building orientation, ii) energy consumption, iii) material selection, iv) indoor environmental quality, v) water consumption, vi) waste disposal, vii) construction methodology, and viii) life-cycle costs. These areas cover most of the issues that contribute towards sustainable architecture. This paper is going to make a review on methods and technologies employed to create the sustainability in the built environment. The paper is structured following the above areas and in each area, popular methods and technologies will be discussed.

2. Review of Methods and Technologies

2.1. Energy Consumption

Energy consumption is one of the issues that have been mentioned most often in sustainable architectural design. Since the main contributor to the "greenhouse effect" is carbon dioxide, energy and how it is used is the key environmental issue and should be at the forefront of priorities for all those in the construction industry. There have been three main ways to reduce energy use in buildings: promoting energy efficiency, utilizing natural energy, and using renewable energy. It is necessary noting that due to the broad meaning of the word "efficiency", a lot of literature on sustainable architecture uses the term "energy efficiency" to cover all these three ways. In this paper, the term should be merely understood as good energy management, effective energy design, and well control of mechanical systems.

2.1.1. Promoting energy efficiency

The first factor that contributes to increasing energy efficiency in buildings is the way that buildings are designed. Several basic design methods used are: providing maximum areas of shade or reducing the external surface area; well sealing to reduce the infiltration of air from outside; providing insulated masonry such as using thick brick wall and reinforced concrete and expanded polystyrene insulation for external cladding (Brenda and Robert 1991); using reflective or suspended ceilings; and minimizing the height of storeys to save energy consumption for air conditioning. Some of these basic rules in architectural design were employed even before the concept of sustainable architecture appears.

The good management and control of mechanical and electrical systems is also an important component in green buildings. The energy efficiency can be achieved only when these systems are appropriately and effectively designed. A number of methods used in this field are the followings: integrating systems, commissioning the building, using intelligent controls for electric systems, designing systems for appropriate use patterns and locating in areas accessible for maintenan-
se of noise pollution and frequency band discomfort. Several methods to increase natural daylight are:

ce and service, and allowing varied light levels for different tasks (Dawn, 2002). Such methods are not a difficult goal with today's technology.

The energy saving is not limited to only the building fabric. Since the occupants of modern buildings rely heavily on appliances installed in them, the use of low-energy appliances is a significant factor in achieving high energy efficiency. Low-energy computer, photocopier that employs a cold process, purpose-built fridge and freezer that are much better insulated than normal models, passive drier using solar heat to dry clothes, and heat exchange unit for removing moist air are several types of appliances that significantly save energy. These special appliances can save electricity consumption from 60 to 90 per cent less than an average conventional version (Brenda and Robert 1991).

2.1.2. Utilizing natural energy

Due to the overlapping between two terms "natural energy" and "renewable energy", "utilizing natural energy" in this paper is considered as a concept that refers to natural ventilation, lighting, heating, and cooling or in other words the direct uses of passive solar energy whereas "using renewable energy" is used to describe indirect uses of natural energy converted by artificial technologies.

Smith (2001) explained natural ventilation as a "part of reaction against the heavily engineered sealed glass box of offices has been the drive to explore the possibilities of creating an acceptable internal climate by natural means." Natural ventilation is enabled based on a basic rule that warm air is lighter than cold air and therefore will tend to rise in relation to cold air. There are a number of methods used to encourage natural ventilation as the followings: opening windows on opposite walls rather than on adjacent walls in order to allow better cross-ventilation; providing enough opening areas to provide sufficient flow; providing windows that are able to control air flow; and incorporating vertical towers into the design to allow the stack effect to draw air through the building. However, one disadvantage of natural ventilation is that it may draw polluted air into building. In order to overcome this, two methods are employed. First, drawing fresh air into the building at only high level, above the diesel particulate matter zone. Second, using terminal design which rotates according to the direction of the wind, thereby it is ensured that fresh air is always drawn in from the windward side and exhaust air is expelled on the leeward side (Smith 2001).

Although natural daylight always exists as a present of mother nature, it did not receive significant attention in building design until recently. In addition, the development of the fluorescent tube lamp facilitates makes people neglect it even at the expen-
thermal systems convert direct solar radiation into

designing large atrium to introduce natural daylight for adjacent spaces; installing light shelves which serve dual purpose of providing shade and reflected light; using prismatic glazing to produce more diffuse distribution of incoming light; providing light pipes for gathering sunlight and then transmitting to building interiors; using holographic glazing which is basically the same with prismatic glazing but it is more advantageous in terms of enabling to produce particular internal light patterns; and providing controlled solar shading combined with triple glazing in order to achieve various levels of light (Guzowski 2000).

Natural heating or passive solar energy use is a process that involves the three following stages: collection - to collect solar energy, storage - to store sun's energy, and distribution – heat stored is slowly released. The most common types of passive solar system for heating are direct gain, indirect gain, and isolated gain. The direct gain system utilizes windows to allow solar radiation to directly enter zones to be heated. Windows should be double or triple glazed with low emissivity glass. The floor is of a high thermal mass to absorb energy and reduce temperature fluctuations (Smith 2001). The indirect gain system uses heavy materials that help the building absorb more solar radiation for thermal storage. Then the collected solar energy is gradually released at night for heating the building. This system often has a wall placed behind glazing facing the sun in order to control the heat into the building. The isolated system is the use of an attached sunspace, which is also known as solar greenhouse or conservatory, to collect energy and pre-warm ventilation air for the main building. Another attractive use in passive solar buildings is the use of rock bed. It is often located beneath the source of hot air, therefore, natural convection is impossible to transfer the heat (Roaf 2001). This method calls for the use of fans which consume a lot of energy contradicting to the goal of natural heating.

The most primitive method, but by no means ineffective, in natural cooling is perhaps the use of vegetation and trees. They can provide both shade and evaporative cooling through moisture expiration of leaves. The use of water features such as pools, fountains, and sprays is also effective. Green roof and vertical garden are also known as new and significantly effective methods of natural cooling and ventilation. Several more active methods employed are: chilled ceilings, embedding pipes in concrete floors carrying cooling water. However, these methods are not really natural cooling due to their requirements of energy.

2.1.3. Using renewable energy

In contrast with passive solar energy is active solar energy. The distinction between two kinds is that active
2.2. Water Consumption

The second issue that is often mentioned in literature on sustainable architecture is water consumption. As

another form of energy with the help of technologies and equipments. Flat-plate collectors are typically used to collect energy for hot water and space heating. The plates transfer heat to a fluid-usually air or water-circulating. This system is often associated with the use of advanced glazing such as heat reflecting, heat absorbing glazing and photochromic, thermochromic, electrochoromic glass (Zeiher 1996). It is called "active" because the system needs auxiliary equipments such as fans or pumps to transfer the fluid.

One of the most promising technologies in using renewable energy is photovoltaic technology. The technology is operated based on the rule that photovoltaic materials can generate direct electrical current when exposed to light (Smith 2001). The most dominant photovoltaic material used today is silicon. However, silicon is still expensive and photovoltaic cells have not yet been able to be applied in large scale.

The term "biomass energy" is often referred to the concept of using energy converted from plants and waste. Biomass energy is an attractive alternative because it is available and renewable. Biomass energy technologies include direct combustion, biogas production, waste-to-energy conversion, conversion to liquid fuel, gasification and pyrolysis, and ethanol fermentation (Zeiher 1996).

Geothermal energy industry uses natural hot water as a source for geothermal power station. However, the efficiency of natural hot water' conversion to energy is low, ranging from 5 to 20% only (Smith 2001). Besides, geothermal power stations pose significant pollution to air and water environment. They extract a large amount of steam and hot water, dissolved salts, and toxic substances such as arsenic, boron, lead, and mercury into the environment (Zeiher 1996).

Hydroelectric energy is seen as the fuel of the future. Once the technology enables it to completely replace fossil fuels, the environmental benefits are enormous. The reason for its considerable benefits is that the only product of the process creating energy is water vapor (Ayres and Frankl 1998). Moreover, it is non-polluting, has a reasonable calorific value, and can be safely stored (Smith 2001). However, the question arisen is that when would the technology allow the production of hydrogen to be in a large scale?

Another product of solar power is wind energy. It has been exploited as an energy source as early as 5,000 years ago. It is also non-polluting and abundant. Yet there are some disadvantages associated with wind energy production as the followings: the sites are often located very far from cities or centers of population; causing noise pollution, and the output is unpredictable.
(Edwards 1999). Although the wastewater resource is large, this technology has some disadvantages with respect to maintenance and operating costs.

2.3. Material Selection

technologies and industries develop dramatically as well as living style, demand for water tends to exceed supply. There are many reasons for this and some of the major causes are: the increase in water consumption of households, greater ownership of water consuming appliances, increased crop watering due to the effects of global warming, growing water use by industries, and changing patterns of rainfall (Edwards 1999). This imbalance calls for water conservation programs in many nations in various regions all over the world. To contribute to address the problem of water purity and supply as well as to achieve the sustainable development, architects, environmentalists, and the construction industry have employed a number of methods and technologies under the two following headings: reducing the amount of water used by appliances and grey water systems.

Technologies used to reduce water consuming of appliances include modification to existing sanitary ware and application of novel systems. The modification to existing sanitary ware is basically a method to improve and optimize water usage of sanitary ware units such as taps, water closets, and urinals. Several measures employed are inserting a spray nozzle into the outlet of the existing tap to convert the tap discharge from a flow to a spray thereby reducing the flow rate up to 70% compared to a standard tap, inserting rubber blocks into the cistern to save flushing water, and installing hydraulic or detector/solenoid systems to existing urinals to restrict flushing. Some of the technologies used in terms of application of novel systems are the followings: providing waterless urinals that completely eliminate water usage by using chemical mixture; installing vacuum toilets which carry waste by air pressure instead of relying on a large volume of water as the conventional types do; and using composting toilets which are operated based on the composting process encouraging aerobic digestion (Edwards 1999).

Grey water systems refer to systems that utilize rainwater and recovered wastewater for the purpose of supplying non-potable water. The first method applied to grey water systems is collection and utilization of rainwater. The basic process of this method is to collect rainwater from a downspout draining the roof, then transfer to the inside of the building for storage, and from here rainwater is distributed to sanitary ware units. This method is quite simple in terms of technology, however, it requires periodical maintenance and electrical supply. The second technology employed is recycling of domestic wastewater. These systems collect discharged wastewater from baths, showers, sinks, dishwashers, and washing machines and filter and disinfect it by using chemicals such as chlorine, ozone or by ultraviolet light before being stored for reuse

significant. They can cause a number of diseases that have been known as “sick building syndrome”. These diseases include asthma, skin cancer (Roaf 2001), and Legionnaire’s disease (Edwards 1999).

To achieve a better indoor environment, many methods have been employed as the followings: using natural

The third key issue contributing towards sustainable architecture is material selection in construction of buildings. The choice of building materials has potential impacts on the environment and health of occupants. In order to estimate the environmental impacts of buildings, the concept of “embodied energy” has been introduced as an effective tool. “Embodied energy” in construction industry describes the amount of energy used to produce building materials. Embodied energy is often categorized into two kinds: delivered energy and primary energy. The former refers to the actual quantity of energy delivered to the site. The latter refers to the amount of energy used to produce a quantity of delivered energy (Roaf 2001). To calculate embodied energy, a few factors need to be taken into account such as recycling, processing, transportation, time, and used materials. Each building material has its own embodied energy, therefore, knowing embodied energy of different materials is important and crucial in selecting materials for the building.

A number of methods and technologies employed to achieve better materials performance are the followings: reuse or refurbish an existing building, manage construction waste to minimize waste disposal in landfill, design for standard sizes, design for disassembly at the end of the building’s life, provide composting facilities, design for occupant recycling program (Dawn 2002), use products that reduce material use, salvaged products, products with high recycled content, natural products, products that prevent pollution, and materials that reduce heating and cooling loads (Zachariah, Kennedy, and Pressnail 2002).

2.4. Indoor Environmental Quality

As people tend to spend most of their time indoor nowadays, indoor environmental quality has become a high priority in design of buildings. A study conducted by the U.S. Environmental Protection Agency showed that “indoor air can be a hundred times more polluted than outdoor air” (Rocky Mountain 1998). Further more, Rocky Mountain (1998) also identified some major factors that negatively affect the quality of indoor environment as the selection of building materials and finishes, activities like smoking and open combustion of gas or wood appliances, high moisture levels, and the amount and quality of fresh air circulated through ventilation systems. Adverse effects posed by a bad indoor environment to human health are relatively

Waste has recently no longer been considered as refuse. It is also a kind of resources if waste management is carried out properly. The amount of waste generated in construction industry is even more than that in other production activities if taking into account all wastes discharged into environment from many building materials manufactories. Waste minimization can be effectively dealt with at both the design and construction stage. There are many rather than man-made materials; utilizing natural lighting and ventilation; periodically maintaining ventilation and air conditioning systems to supply clean and fresh air for the building; locating the building at high external air quality areas; design to avoid interior condensation (Edwards 1999); completely avoid using asbestos material; using products that block or remove indoor pollutants; providing permanent entryways that prevent external contaminants; and restricting smoking (Zachariah, Kennedy, and Pressnail 2002).

2.5. Site Selection and Building Orientation

Site selection and building orientation is the first and important stage in any green design. It directly and strongly affects the environment. Moreover, building siting influences even local society, landscape, and ecological systems. The key step in site selection is to fully understand and thoroughly assess characteristics of the existing site. The basic idea of this process is to identify what is already there; therefore, the impacts that a new building will have on the local environment can be estimated. Some specific methods used are the followings:

- Protecting existing features of the site including native landscape, natural vegetation, historical and cultural elements, and hydrogeology characteristics.
- Restoring damaged sites: this method refers to the concept of restoring sites that have been damaged by previous building or industrial activities. It includes cleaning up site contamination and restoring original landscape features.
- Landscaping for low-impact management practice. This method basically involves with planting climatically appropriate vegetation. It can help reduce irrigation and maintenance costs.
- Fostering a sense of community and culture: this is also known as planning and designing for a good social and cultural environment. Several specific ways of this method is designing more pedestrian walkways, trails, common spaces, bikeways, and green spaces for community activities.
- Public hearing and participation.

(Rocky Mountain 1998)

- Reusing existing building (also known as recycling).
- Developing in an already built up area to reduce negative transportation impacts.
- Reducing habitat disturbance.
- Efficient building orientation.

(Zachariah, Kennedy, and Pressnail 2002)

2.6. Waste Management

the construction stage and the building itself may have on ecosystems as well as on workers and occupants health. Some of the methods often applied are follows:

- Managing sites carefully for protecting trees, vegetation, and soils. This method includes careful selection of excavation contractors with clear specifications on protective measures, identifying

advantages of a good waste management system such as conserving natural resources, saving energy in production and transport, reducing pollution, minimizing the amount of waste disposed in landfills, producing cheaper products by using recycled materials or by using energy from waste (Edwards 1999).

3-R rule: reuse, recycling, and recovery, which is quite common in municipal solid waste management strategies, can also be applied to construction waste management as an effective tool. The use of recycled materials from other industries to produce construction products has become a good method in waste management. This includes wood alternatives based on recycled tyres and plastics, flooring made from reconstituted wooden pallets, straw-based walling systems, combination of wood waste and cement to create insulating boards, aluminium roofing shingles made from recycled drink cans, recycled wool fibres from the clothing industry made into insulating felts, recycled paper-based insulation boards, and paints made from recycled household hazardous waste (Edwards 1999). On the contrary, recycling construction waste for use in other industries can reduce significant amount of waste that needs to be disposed of in landfills, thereby achieving considerable benefits in terms of both economic saving and environmental impact reduction. Another method that has been employed and known for a long time is the use of pre-manufactured components. This manner can help reduce over 70% of waste compared to conventional practice (Zachariah, Kennedy, and Pressnail 2002). Providing on-site biological wastewater treatment systems, which has also been known as “living machine”, has recently been employed in a number of green buildings. These systems were first invented by Todd and Todd and considered by them as the key for a sustainable development.

2.7. Construction Methodology

Sustainable construction is an associated and parallel element of sustainable design and these two components together partially constitute sustainable development. In order to achieve sustainable architecture, adopting construction methodology in building practice is an important factor and should be carefully planned taking into account all impacts that

Apart from the many methods and technologies contributing towards sustainable architecture discussed above, there are also others that have not been mentioned in this paper such as tidal energy, nuclear power, and energy from space. The reason for not discussing those is that some are not directly related to sustainable architecture; several of them are still new and in process of technological experiments; and others need further studies or are still in discussion of whether or not they really contribute to sustainable development. Besides, a couple of new concepts such as “healing

construction vehicle parking and staging areas away from trees, conducting an inventory of trees and selecting those to be protected; erecting fencing around selected trees; and minimizing changes in grade on the building site.
- Minimizing the impact of heavy machinery.
- Maximizing the use of equipments that conserve energy.
- Avoiding the use of toxic or dangerous materials.
- Implementing careful construction practices.
- Employing sequencing construction activities to minimize contaminant "sinks" such as the emission of volatile organic compounds from fabric panels, carpets, ceiling tiles, furniture, and partitions. This can help to protect air quality of the building.
- Protecting occupant health from airborne contamination by blocking ducts, installing plastic sheeting around the active area, and depressurizing the work area.

(Rocky Mountain 1998)

2.8. Life Cycle Costs

One of effective tools in estimating environmental burdens posed by production activities, that is becoming commonly used is life cycle assessment. Environmental Protection Agency (1995) defined environmental life cycle assessment as "a process aimed at identifying, evaluating and minimizing environmental impacts associated with products, manufacturing, processes or systems" (Korol and Caron 1997). One of life cycle assessment' objectives is to estimate life cycle costs associated with the product. In order to estimate this, all costs involving with every stage of product's life cycle need to be taken into account. The more life cycle costs of a product are, the more the environment incurs impacts posed by that product. Buildings are a product created by humans involving many stages of construction process. To reduce life cycle costs of a building, an effective method being used is employing recycling programs. This method was discussed in the previous part of this paper (6. Waste Management). Some other methods are: adopting integrated life cycle cost plan where savings from one system are used to subsidize the cost of more expensive systems, and implementing thorough decommissioning plan (Zachariah, Kennedy, and Pressnail 2002).

3. Conclusion

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buildings" and their applications to achieving the sustainability of architecture through using roof-top gardens or building materials that can remedy or neutralize environmental damages, have not been deeply discussed because they have not yet been proven feasible in practice or the issues that they encompass are beyond the scope of this paper. However, no matter what these methods and technologies differ from those being used today, they are all developed aiming at the three essential targets: conserving natural resource, reducing environmental degradation, and increasing human health. To achieve these targets, there are two greatest barriers that need to be overcome: economics and technology. Even if these obstacles could be removed in the future, other elements such as society, history, and culture should not be ignored in design and construction towards sustainable architecture. More specifically, awareness and community's concern on environmental issues plays an important role in achieving sustainable architecture as well as sustainable development in general. Zachariah, Kennedy, and Pressnail (2002) are extremely right when stating that "truly green buildings will only come from green people."

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