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Sustainable Material: Challenges and Prospect

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ABSTRACT

Today, the new valuation of sustainable materials in light of their ability to fulfill the requirements of sustainable development has raised the bar. The economic growth will result in increased material throughput as well as solid and hazardous waste generation. Understanding the life-cycle of materials management and monitoring materials consumption trends will provide the information in determination of how we can satisfy our materials needs at acceptable economic and environmental costs to assist both regionally and globally. This paper reviews the challenges for sustainable development from material aspect and the future prospect of the utilization of sustainable materials in construction industry. Policy designs together with steering mechanisms are required to facilitate and support further mainstream sustainability transitions. Besides the price system, regulatory framework and technical information, human mindsets must work together to enable and encourage life-cycle of materials management. Further research and development will not only provide innovative solutions to existing problems but will in particular offer new opportunities through the development of innovative materials to improve the quality of life.

Keywords:
Environment, life-cycle of materials, sustainable material

1. Introduction

Environmental issues originate from the large consumption of materials and energy in the whole world. Materials have supported human life with advantages and conveniences unfortunately they also impose a wide variety of burdens on the environment through each and every step of production. According to Dave Fagan *et al.*, [1], extracting, producing, and using ever-increasing volumes of material resources-most of which are finite will inevitably have important environmental consequences. The implications of current patterns of economy, our continued existence with materials used which unsustainable to the environment, had influenced the potential of climate change.

The crises raise the bar for new materials solution. Today, sustainable material is believed to be solution for an integrated approach toward managing material life cycles to achieve both economic efficiency and environment viability. The properties, performance and content of these materials make a significant contribution to reduced environmental impact, from lowering carbon emissions to maximizing use of the earth's limited resources. According to Lauren Heine [2], sustainable

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materials is a material that fits within the constraints of a sustainable materials system where in order to be sustainable, the material must be appropriate for the system and the system must be appropriate for the material. This view is supported by Koichi and Kohmei [3] who write that materials support the basis of technology and systems; therefore, it is important to consider how the materials development should contribute to the construction of a sustainable society.

Materials are derived from resources that are classified as either renewable or nonrenewable. Since the capacity of the earth is finite, the minimizations use of resources, are important for sustainable development in our world. The definition of sustainable development is produced by the World Commission on Economic Development (WCED) is most generally accepted. Sustainable Development was defined as the development that meets the needs of the present without compromising the ability of future generations to meet their own needs [4]. It was understood to bring together the development needs of humanity, protection and conservation of the natural environment and maintaining the ability of future generations to meet their own needs. Sustainability requires the reconciliation of environmental, social equity and economic demands. The Department of Economic and Social Affairs, United Nation (UN), in its World Population Prospect, foresees the world population of 7.2 billion in mid-2013 is projected to increase by almost one billion people within the next twelve years, reaching 8.1 billion in 2025, and to further increase to 9.6 billion in 2050 and 10.9 billion by 2100 [5]. The estimates increase of world population has raise the critical issue that this situation will lead to less sustainability with more and more environmental impact.

Currently, the crucial materials issue we are facing is the ability of the earth; air, water and land as well as many types of environmental problems caused by our current patterns and rates of resource used. There are no possibilities to reduce all environmental impacts to zero. There are number of threats to sustainable development, including environmental degradation in many parts of the world. Thus, this paper provide a review on the challenges of materials and shows the future prospect through utilization of sustainable materials for sustainable development.

2. Materials Towards Sustainable

Materials include all those extracted or derived from natural resources, which may be either inorganic or organic substances, at all points throughout their life-cycles. Wood, metal, polymer, composite, minerals, fuels, chemicals, soil, rock are all material. Increasing material flows in volume, diversity and distance transported, had contribute too many of the world's environmental and economic problems. Our world is threatened by environment impacts from the production of materials including potential scarcity in the continued availability of natural resources both regionally and globally. Even though the world has not recently faced significant disruptive crises in the supply of materials largely because new discoveries and technologies have delayed predictions of shortages, it was acknowledged that technologies will have other unforeseen impact and we need to take responsibility for how they are used. Joseph Fiksel [6] address that the environmental impacts of non-renewable resource consumption due to technology will likely outweigh concerns about resource scarcity for the foreseeable future.

Pressures to our environment caused by our current patterns and rates of resource and material used are not new. Since 1987, party leader of WCED, Gro Harlem Brundtland declared that "Many critical survival issues are related to uneven development, poverty, and population growth. They all place unprecedented pressures on the planet's lands, waters, forests, and other natural resources, not least in the developing countries" [4]. Afterwards, in 1992, world leaders United Nations, participating in the Earth Summit declared that "a principal cause of the continued deterioration of the global environment is the steady increase in materials production, consumption and disposal"

[7]. Since that, the governments around the world, including developed and developing countries, have acknowledged the purpose of sustainable material use. Sustainability is a critical environmental, economic, and quality of life issue. As our natural resources is finite, the tolerence from each country in managing the materials and resources will reduce the environmental impact and enhance our capacity for future needs and generations.

3. The Challenges

Developing and maintaining low carbon, zero-waste cities and infrastructure for improving our ecosystems i m.faugee@gmail.com s not an easy way. Scientists believe we use more materials and resources which produce more damaging greenhouse gasses, toxics and non-degradable waste than our planet capability. These manmade processes and activities will create pressures on the ecosystem and our future generation needs. The main problems with materials and resources used are the environmental impact generated by our current patterns rate. Challenges in sustainable materials use can be focus on natural resources and raw materials, relationship between production and consumption patterns, designing for sustainable product, production of waste and emissions and current focus on energy and tranportation efficiency. The framework of sustainable material management (SMM) is part of the challenges as well. The future framework for SMM lies in our ability to combine design, nature and technology with the environment.

3.1 Natural Resources Limitation

Future pressures on natural resources may become severe. Materials are derived from natural resources that are classified as either renewable or nonrenewable. Resources constitute a “limited infinity”, although they may be provided for infinite time, their productivity is limited [8]. The prediction on depletion of renewable resources is serious, as human society is embedded within the biosphere and depends on ecosystems for a steady supply of the basic requirements such as water, energy, minerals and agricultural land for life. As the world’s population increases and the global economy continues to expand, it is relatively safe to assume that worldwide demand for basic resources will also continue to increase. The demand in supplies commodities/materials; also create market pressures to develop substitute materials and/or products. At the same time, extraction of many non-renewable resources is already reaching or near a peak [9].

Industrial manufacturing and the consumption of technical products have led to a dramatic prediction of depletion of natural resources. Rapid technical developments during the last centuries have caused serious environmental impact, such as over-consumption, resource utilization and pollution which can be regarded as an unsustainable life style [4]. The use of material today for energy, packaging and the products themselves has increased at least 20-fold per capita in many highly industrialized countries from the end of the 19th century until today [10,11]. More components and more mixed materials in various products, which demand transportation, in combination with generally higher energy consumption, are only examples of over-consumption. Figure 1 lists the raw materials put into use annually in the United States from 1900 through 2010.

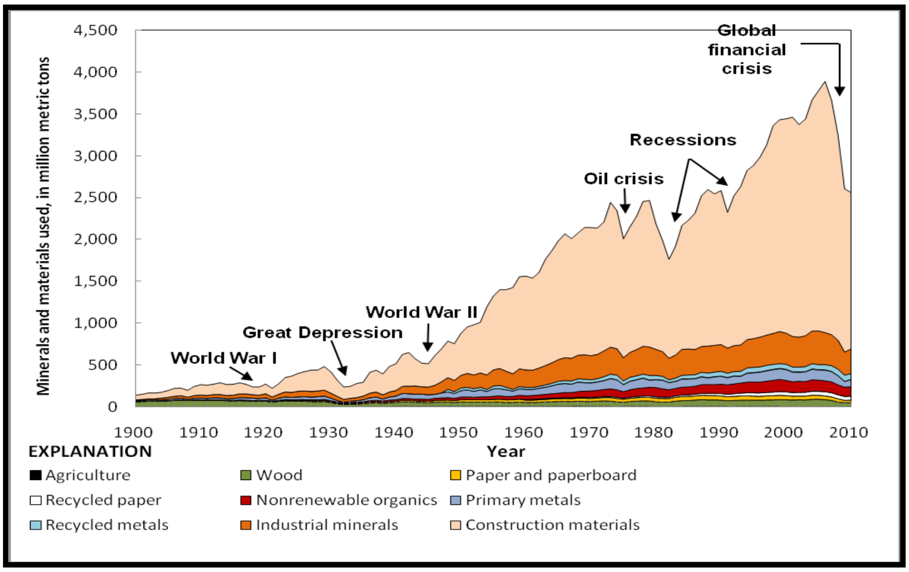

Fig. 1. U.S. raw materials put into use annually from 1900 through 2010. Source: [12]

The graphs show the contractions in raw materials usage have been coincident with major economic and military events from the past 11 decades such as World War I, the Great Depression of the 1930s, World War II, the post-World War II expansion, the oil crisis of the 1970s, the recessions of the 1980s and early 1990s, the extended period of economic prosperity and technological growth at the end of the 20th century and the global financial crisis that began in 2007 [12]. Based from the graph, the raw materials consumed in the United States have grown substantially since the beginning of the 20th century due to public demand, population growth, and industrialization. This graph shows the demand for basic resources continue to increase.

3.2 The Right Design Challenges

Some evaluation indicators should be considered when selecting materials for sustainable products [13]. A sustainable product is a product which results as little impact on the environment as possible during its life-cycle. The sustainable aspects of products include extraction of raw materials, production, use and final recycling. The energy consumption of materials in the forming process (e.g. forging and casting), the final treatment process (e.g. heat treatment and surface treatment) and the economic cost are also included [14]. The material selection and specification are the most important part to investigate before any materials to be used in order to avoid non-toxic or non-durable materials. According to Ljungberg and Edward [15], sustainable material selection methodology should compare a set of candidate materials and through the aggregation of the three indicators (social, economic and environmental) to identify the best material domains. Material selection is one of the main phases of product design process that has great impact on the manufacturing of sustainable products. Selection of material is traditionally made by technical demands like price, strength of material, temperature stability, density, hardness, etc. [16]. The technical demands are not enough for sustainable product. Therefore, Dehghan Manshadi et. al. [17] address that sustainable material selection can be regarded as a multi objective problem, being the optimal selection and the best match found between the available materials profiles and the requirements of the design. Chiner [18] found that the selection of the sustainable materials is a difficult process that demands the management of a great amount of information about the materials properties and there are often several solutions for a particular application.

A variety of methods are used to assess material selection for designing sustainable product from different researcher. Ashby [19] methodology takes environmental factors into account as shown in Figure 2. Scopes of his work is screening the proposed materials using environmental constraints and eliminates ones that are not compatible with environmental regulations and continue research the material family history for the top candidates before final selection for the best material.

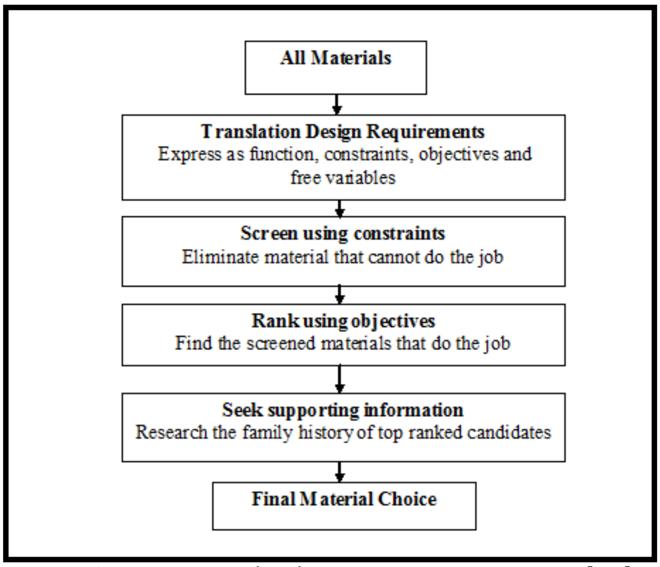

Fig. 2. Material Selection Process. Source: [19]

Beside Ashby, Weaver et al. [20] also developed environmental materials selection charts. Chen et. al. [21] developed a systematic methodology while Feng [22] developed a methodology with toxic impact concern based on the result of Thurston et al. [23]. Although comprehensive methodology is recommended by the researchers, Ribeiro et. al. [24] point out materials is believes to perform differently regarding different aspect of analysis for example the impact of life cycle costs and environmental profile of material candidates over their life-cycle. One of the best approaches of material selection for sustainable products is life-cycle engineering (LCE) but Hosein et al. [25] found that LCE is a costly and cumbersome task and it is not economic to perform for a large number of proposed materials in order to choose the most suitable one for sustainable product. Further research and development need to be explore for finding the right design aimed at material selection.

3.2 Hazardous Material and Production

Manufacturing of products typically involves chemical substances like blending of the products, interfacial interaction of the two chemical substances, cutting fluids during machining, cleaning aids and paint. Building materials, interior furnishings, surface treatments, paints, coatings and consumer products have been shown to emit volatile organic compounds (VOCs) and result in the presence of indoor air contaminants [26] [27]. As we spend more and more time inside buildings we are confronted with the indoor air quality and its health consequences, which are directly linked to the materials we use.

Beside the hazardous materials in manufacturing, Howarth and Hadfield [28] address that production of steel, glass, aluminum and paper require high electricity usage, generating carbon dioxide (CO_2) which includes increasing global warming. The changing weather patterns, impact of climate change, increasing sea level and flooding will not mainly affect the agricultural industry, but will also cause more disease and ill health to human. World Resources Institute (WRI) [29] found that total global CO_2 emissions grew 12.7% from 2000 to 2005, an average of 2.4% a year. The total global

CO_2 emissions grew higher is believed may contribute for higher greenhouse gas emissions and associated consequences, such as sea level rise. Ahmad et. al. [30] address that globally averaged sea levels is predicted to rise 0.09 to 0.88 meters by 2100 due to the increase of CO_2 emission.

In coming years from now, predictable advances in chemistry and other fields will create more new chemical compounds that contribute to the production of dangerous waste materials as well. Levin [31] identify that information on potential hazards of these chemicals prior to specification, purchase or use of these products, is limited, in spite of a notable increase in relevant activity during the past two decades. While many of these products may represent important improvements, undoubtedly, some of these new substances may have the potential to cause harm to human health and ecological systems. The increased materials consumption presents a threat to the sustainability of renewable resources such as forests, as well as the quality of land and fresh water. For example the release of some elements into soil and water leads to accumulation of toxic substances in food chains.

3.4 Life-cycles of Materials

Addressing the development needs of billions of people, enabling education and economic developing radically more eco-efficient solutions, lifestyles and behavior. Many companies now recognize the fact that they can make cost savings by encapsulating critical technical processes and handling problem materials more economically. Today, this development is leading to a rediscovery of the product life-cycle. Applying a life cycle perspective can help identify opportunities and lead to sustainable solutions to reduce the environment impact.

Life-cycle of materials includes all activities related to materials such as extraction, transportation, production, consumption, product use, reuse, recycling and disposal. All these stages will give a certain environmental impact, which is mainly caused by the materials involved in the different stages [32]. Extraction activities increase local demand for water and electricity and cause contamination of surface and ground waters, moreover, mining often causes mobilizing of elements which are released from soil and rocks or from the minerals themselves to the environment (e.g. release of sulfur containing substances in brown-coal mining, causing e.g. acidification of ground water) [33]. The life-cycle of materials illustrates this clearly; after materials are extracted or harvested from natural resources, it will go to the materials production and product manufacture stage which include design process, before produce a product that is use, and at the end of its life discarded as waste which released to landfill, air as well as water or recycle and reuse the product as per Figure 3.

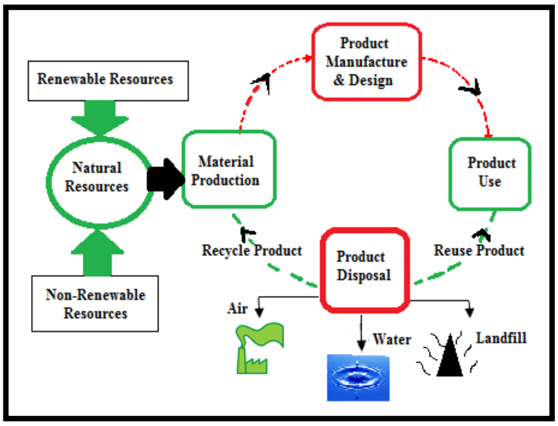

Fig. 3. Life-cycles of Materials

From the life-cycle of materials, energy and materials are consumed at each stage, generating heat and solid waste, liquid and gaseous emissions. For example, throughout the material flow, materials and products require transport. Transportation used to distribute material and products, generate greenhouse gasses (GHG) emissions from the fuel of those vehicles and higher energy consumption and thus contribute to the product's environmental footprint. Hence, the life-cycle of material flow contributes to a wide range of global environmental impacts. Many of today's most urgent environmental problems arise from increasing volumes of worldwide production and consumption as well as the associated use of natural resources, including renewable and non-renewable raw materials, energy, water and land. These trends make the shift to SMM critical to design for environment and accomplishment in next generation of sustainable materials. Mingdong and Jiann [34] address that the high demand for next generation sustainable materials such as high-temperature aerospace materials, bio-degradable polymers, bio-plastics, polymeric material, biometrics and smart materials, requires inter-disciplinary breakthroughs in both materials synthesis and processing. Specific methodology and facility has to be developed to resolve a new age of high-added value products. In order to arrive at a broader perspective, the approach to apply a life-cycle perspective is called Life Cycle Assessment (LCA). LCA is a way to analyze the inputs and outputs of materials and energy and the environmental impacts that are directly attributable to a product, a process, or a service. There are typically six important steps involved in an LCA evaluation [32]:

i. Extract from material
ii. Manufacturing with, e.g., ennobling and refinement
iii. Packaging stage
iv. Transportation of, e.g., material and the ready product
v. Product user stage
vi. Product disposal stage

There are many ways by which life-cycle of materials can be accomplished. Beside the price system, regulatory framework and technical information, human mindsets must work together to enable and encourage life-cycle of materials management.

4. Future Prospect

In 1987, global warming emissions and environment degradation, has shaped by the trends we did not recognize [4]. Prediction our life future, based on what we have done previously, shall give us a chance to change, if we want to shape it positively. Some predict that our world will be better, due to what we are currently doing. Much has been written about sustainability and how to apply it to different areas and sector as well as finding the solutions to overcome the complex problems. All countries pulling together to formulate an interdisciplinary and integrate global approach concerns for our future in economic, social and environment. Therefore, it was not surprise that in future years, our world will establish secure from chemical environment and reach the sustainability.

Future prospect by the systematic efforts through governments with all part of society and the advancement of information, will enabled more participatory approach for making environmental decisions. As the public becomes more aware of hazardous risks and the environmental impact, the changes in consumer values have prompted shifts the industrial sector, to manufacture the products based on managing resources efficiently. Advanced technology innovation system (expert system) used in finding sustainable materials for designing products, will contribute much more sustainable products. Technology advanced on natural resources and related technologies innovations have the potential to improve our quality of life. Hence, materials and products will be less toxic and natural resources will be used more efficiently. Furthermore, manufactures of sustainable products which designed to last longer also will decrease the released of solid and hazardous waste to land, air and water, as well as reduce the generation of waste. Besides, small volumes of wastes that actually need disposal will be carefully managed under an efficient and environmentally protective system. Materials that were once considered wastes, will be recognized as a resource, continually reused and recycled. Recycling and reuse has benefits the environment by diverting waste away from landfill, thereby reducing pollutant emissions. It's also helps meet the material demands of economic production, curtailing the need for extraction of virgin materials, generally minimizing the amount of resources involved and all the associated environmental impacts.

4.1 Sustainable Materials in Construction Industry

Construction industry is a major sector that needed on the agenda for sustainability in its development. Construction activities and operations always requires large amount consumption of materials and resources, energy, water as well as create a significant amount of waste, resulting in pollution and the destruction of the global ecosystem. Pacheco-Torgal [35] address that the construction industry is responsible for the consumption of a relevant part of all produced materials, however, only recently has this industry started to worry about its environmental impacts. The approach to the selection of materials and construction methods to eco-friendly can give a low level impact on the natural environment. This view supported by Ding [36] who points out that the selection and use of sustainable building materials play an important role in the design and construction of green building.

Today, the demand for the use of sustainable construction materials in order to meet the needs of sustainable development was raised in all countries. Sustainable construction begins with the use of sustainable products and building materials during the construction works and in the building. Sustainable construction methods require less use of natural resources and improve the function of the materials and products. Nowadays, there is various sustainable building materials have started being used in the construction industry. The materials involved were eco-concrete, double glaze glass, rubber, steel, wood and composite materials. These materials have new green criteria and improve the function of the materials which different with the conventional construction materials. The use of recycled materials for finishes materials that have a green label such as the use of carpets, bod plaster, wood finishes and internal furnishings is another example of sustainable materials. Recycling and reuse of products has provided many benefits to the natural environment as well as save the earth from the waste. Besides, the usages of local materials are also encouraged. The use of local materials can reduce the hauling of construction materials over long distances, thus reducing the greenhouse gas emissions associated with transporting such materials [37].

Sustainable construction begins with planning and design. The role of developers and consultants is essential at an early stage because sustainable construction involves the selection of materials and important products as well as environmentally friendly construction methods. Architects and consultants can specify materials that reduce the use of natural resources such as sand and aggregates. When involved in need materials such as sand and aggregates, the selection of materials that can be recycled or reused should be selected whenever possible. An alternative in using such as recycled crushed concrete as hard core for construction of road is the best selection instead of using new aggregates. Tom and Stuart Wilmot [38] urged the road construction industry turns its mind to reduce consumption of non-renewable resources and maximising its use of insitu stabilization. Reuse excess concrete for the construction of other structures components for example concrete barrier, wheel stopper, wall dividers, road kerb and paving blocks can help save a lot of waste concrete. To enhance sustainability in construction industry, waste can be turned into resources to reduce the disposal problem. Besides the waste from concrete, Mangesh et. al. [39] found that the application of agro-waste also suitable for sustainable construction materials. This application is seen effectively and economically. Raut et. al [40] reviews various waste materials in different compositions to develop waste-create bricks (WCB) while Primov Pavsic et. al. [41] determines how best the sewage sludge and biomass ash become composite material for sustainable construction materials. Munoz Velasco et. al. [42] also found that the reuse of waste in brick production implies an enhancement of the bricks properties for sustainability in construction materials. From the point of view of sustainable development, this kind of waste management presents an optimum zero waste solution while preserving natural resources and reducing CO_2 emissions.

The selection of products from composite material is also a sustainable product. The use of composite materials is highly recommended due the materials consume little natural resources or not directly. Liang and Hota [43] found fibre-reinforced polymer (FRP) composite materials have potential to be selected as a material of choice toward a sustainable built environment. Meira Castro et. al [44] also identifies a promising waste management solution for glass fibre reinforced polymer (GFRP) waste materials by developing a cost-effective end-use application for the recirculates, thus contributing to a more sustainable fibre-reinforced polymer composites industry. To encourage more sustainable use of materials, the concept of Industrialised Building Systems (IBS) has been applied in the design of construction. Riduan and Jay Yang [45] recognized IBS as the potential of promoting sustainability deliverables by better control of production environment, minimising construction waste, using efficient building material energy, and stabilising work conditions. Faiz et. al [46] highlight the sustainability principles in IBS have always maintained the balance between environment and construction, improve human self-respect and encourage economic development to strive for a better quality of life. Most of the bridge sections including tubular steel piles, precast spun piles, reinforcement caging, precast shell and segmental box girder are IBS components that are prefabricated on land to reduce the amount of time spent at the bridging line and help speed up construction processes as well as reduce waste. This view supported by Ali Khan [47] which addresses those ready-made bridges by using prefabrication methods are for speedy construction. Zhengdao Li et. al. [48] found that as a sustainable construction method, prefabricated construction is increasingly being adopted worldwide to enhance productivity and to alleviate the adverse environmental and social effects. Other prefabricated non-concrete components such as prefabricated staircase, bathroom, steel roof, metal parapet, cladding and glass facade also a good choice of sustainable products for building construction. One important aspect of this perspective is the influence of prefabrication on construction waste reduction and the subsequent waste handling activities, including waste sorting, reuse, recycle, and disposal [49]. Glass facades, curtain walls and cladding can be used to replace the traditional masonry and concrete walls. These facade systems offer new dimensions in architectural designs. Coatings on the glass panels can enhance the thermal insulation of curtain walls. Sheweka and Mohamed [50] address vertical facade greening can provide a cooling potential on the building surface, which is very important in hot climates. Sabrina and Kenneth [51] also found the guidelines established for the design of naturally ventilated buildings indicated potential application of double skin façade for improving the indoor thermal comfort even in warmer regions. The use of double glazing not only further enhances the thermal insulation of curtain walls, but also their acoustic performance. Curtain wall is a lightweight external wall system that is hung on the building structure. It is characterized by grids of in filled material such as glass, metal and granite. Its flexibility allows architects to create striking designs for new buildings and refurbishment of old buildings. The use of modular and standardized panel sizes would speed fabrication and can incorporate architectural and solar control elements such as shading and lighting.

The drive towards more sustainable construction is achievable only when all the stakeholders in the industry, including developers, designers, builders and suppliers recognize and appreciate its importance. All parties are needed to make a conscious decision to adopt the use of sustainable materials in their building projects. We also need to educate and raise awareness of consumers on sustainable construction materials since after all it is consumers demand. Policy designs together with steering mechanisms are required to facilitate and support further mainstream sustainability transitions by applying implementation as following:

i. Innovation beyond production efficiency
• Further research and development in the application of production processes that gear the design, use, and reuse capabilities to minimize raw material inputs and maximize products recycling for further productive use.

ii. Innovation in advanced technology
• Further research and development in developing advanced technology (expert system) with affordable cost for sustainable materials selection.

iii. Life-cycle thinking and design for environment
• Full life-cycle approach and use sustainable materials for designing sustainable product that have capabilities to reduce the cost of raw materials, extend product life spans, reuse, recycle, refurbish and disposal as a safe material that no harm to the human and ecosystem.

iv. Implementation of sustainable materials in design
• Fully use sustainable material (non-toxic) in product design. Move towards natural and industrial systems. (e.g.: eco-design, industrial ecology, etc.)

v. Adopt new business models
• Innovations and integrate SMM with product and service in the strategy and operations of business.

vi. Innovation in technology
• Further research and development in developing advanced technology with affordable cost for measuring and managing chemical risk in materials or products.

5. Conclusion

Understanding the meaning of sustainable materials and using the life-cycle of materials approach wisely can lead to improvements in product design, technological innovation that increases the efficiency of resource use for better waste management practices and more effective policies. Monitoring materials consumption trends and get used to life-cycle of materials management provide the information in determining how we can satisfy our material needs at acceptable economic and environmental costs. Overall, the more efficient sustainable materials used in products, can minimize hazardous waste generation and protect the ecosystem thus reduce resources used as well as improve recycling and reuse rates.

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