From path to process – transitioning from green to sustainable materials use

Naa Lamkai Ampofo-Anti

Building Science and Technology Competence Area, CSIR Built Environment, Pretoria, nampofoanti@csir.co.za

Introduction

Building and construction activities consume more raw materials by weight than any other industry sector – about 50% of all the materials extracted from the Earth's crust annually are transformed into building and construction materials and components (Koroneos and Dompros, 2005). Extraction, manufacturing and transportation effects represent a contribution that each building material or component makes to the overall environmental burden of a building. Once a building is occupied, it is the constituent materials which determine contributions to the outdoor environmental effects listed in Table 1B and to indoor environmental quality. At the end of service life (EOSL) a building material may be disposed of at a landfill, leading to wastage of materials and embodied energy and contribution to toxic loading in the environment. A fundamental objective of sustainable construction is to use resource[1] efficiency strategies and ecological principles to sharply reduce and even reverse these environmentally harmful effects of building materials use.

Table 1: Green versus sustainable measures

1A: Examples of "green" material measures	1B: Examples of sustainable material measures
Recycled content	Energy use
Resource re-use	Material use
Rapidly renewable materials	Water use
Local / regional materials	Acidification potential
	Global warming potential
	Toxicity potential

However, resource efficiency and ecological principles are not easily understood by the green building community (Cole, 1999). Hence, as is the case with other economic sectors, significant efforts are being expended to replace conventional materials with "green" materials in the belief that any industry efforts aimed at environmental improvement is a contribution to sustainability. However, there are important differences between "green" and "sustainable" measures. There are also different ways to measure industry contributions to sustainability. In the last two decades the question of how to measure sustainability has received much attention from researchers and thinkers alike. While their proposals vary from theoretical to practical, together they articulate two main approaches - relative and absolute measures. Both approaches are informed by systems thinking. This chapter aims to articulate to the green building community the value and importance of transitioning the measures for materials selection from "green" to "sustainable".

This chapter is divided into four sections. Section one clarifies the difference between the terms "green" and "sustainable". Sections two and three briefly present the principles and methods of the two approaches to measuring industry contributions to sustainability and examine their short comings and limitations. Section four discusses the findings and proposes a future direction for sustainable materials use. The basis of the chapter is a study of the published literature. The scope of the chapter is environmental sustainability and therefore the term sustainable is used mostly in reference to this pillar of sustainable development.

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[1] Resource means energy and materials

The difference between green and sustainable and why it matters

“Green” is an approach that has the potential of making the world less unsustainable, but does not make the world sustainable (Yanarella and Levine, 2008). “Green” attempts to measure environmental improvements relative to current typical practice or requirements. Similarly, the guidelines that offer direction on how to improve upon current practices only implicitly acknowledge sustainability as a goal (Cole, 1999; Yanarella and Levine, 2008). For example, a product[2] in a certain category might be identified as the “greenest” not because it is environmentally benign but simply because the available alternatives are much more environmentally destructive.

“Green” aims for quick wins or to “pick the low hanging fruit”. The product of concern is marketed on the basis of a single environmental attribute, typically, energy efficiency, thereby painting it as “greener” than a full environmental analysis would do. For example, the concept of the net zero energy building (NZEB) is lauded for reducing the operational energy of buildings to zero but the proponents are silent on the embodied effects[3] of (i) materials used in the various building life cycle stages and (ii) the life cycle stages (making, using, maintaining and disposal) of the novel technologies that deliver renewable energy. In a market survey of more than 1000 “green” consumer products this “sin” of the hidden trade-off was the most frequently committed, accounting for 57% of the results (TerraChoice, 2007).

By contrast, a notion central to the concept of sustainability is that human well-being must be stabilised within the carrying capacity of the earth without leaving present or future generations worse of (Figge and Hahn, 2003). Thus social and economic development needs to take place within planetary boundaries that define the safe limits outside of which the earth system cannot continue to function in the stable Holocene-like state conducive to human development. The boundaries are tightly coupled – if one is transgressed, the others are also under threat. Indications are that several of these boundaries have already been exceeded (Rockstrom et al, 2009). The mass flow of building materials through our industrialised society is an important contributing factor (Kibert et al, 2000). It follows that (i) a reduction in the *absolute* resource use of a product would be an indication of a positive contribution to sustainability (ii) physical indicators describing and quantifying resource flows must logically form the basis of any method claiming to measure sustainability (Cole, 1999) (iii) all three dimensions of sustainability ought to be assessed in a comprehensive manner (Yanarella et al, 2009; Cole,1999).

Given that economic activities such as building and construction do not create or destroy matter, but merely changes its location, form and value (Hawken et al, 2010) two positions on the prerequisites for sustainability have emerged – weak and strong (Malovics et al, 2008). Weak sustainability adherents argue that even if the quantity of natural capital[4] is decreasing by creating man-made capital, total capital can be maintained, which would be enough to fulfil the criteria of sustainability. The advocates of strong sustainability on the other hand are less permissive, arguing that natural capital cannot (or only to a limited extent) be substituted by man-made capital[5] and may suffer irreversible harm, so that it is necessary to maintain not only the aggregate but also the amount of available natural capital.

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[2] Product means building material or building component

[3] Embodied effects are all the inputs from nature (e.g. fossil fuels, raw materials, water) and releases to nature (e.g. GHG emissions, water effluents, solid waste) attributable to the product life cycle.

[4] Natural capital means both non-renewable (e.g. fossil fuel, metal ore) and renewable (forests, grasslands) resources. Natural capital provides services that technology may never be able to replicate on the scale required to sustain life, e.g. converting carbon dioxide into oxygen.

[5] Buildings and other physical infrastructure

Based on the two interpretations of sustainability, two approaches to measuring industry contributions to sustainability have emerged – relative and absolute. Both approaches adopt the strong sustainability position. The first measure investigates efficiency while the second focusses on effectiveness. The following sections describe the two industry routes to sustainability and also investigate their shortcomings and limitations.

The eco-efficient route to sustainability

According to the proponents of relative measures, eco-efficiency, which relies on technological innovations to reduce the material content of products without reducing their utility (Dobers and Wollf, 1999), is the only means to bridge the gap between a finite supply of resources and sinks on the other hand; and an ever growing demand for resources on the other hand.

The eco-efficiency concept was developed academically by Schaltegger and Sturm (Kicherer et al, 2007). Thereafter, the concept was promoted prominently in *Changing Course* (1992), written by Stephan Schmidheiny in collaboration with the WBCSD[6], as the strategic path for business to follow to contribute to sustainable development. According to *Changing Course*, “Eco-efficiency is reached by the delivery of competitively priced goods and services that satisfy human needs and bring quality of life while progressively reducing environmental impacts of goods and resource intensity throughout the whole life cycle to a level at least in line with the earth’s carrying capacity.” Eco-efficiency may also be viewed as “Adding maximum value with minimum resource use and minimum pollution” (Dobers and Wollf, 1999).

Eco-efficiency is concerned with two dimensions of sustainability – environmental and economic. There is a strong focus on technological solutions whereby innovative technologies are developed to reduce the resource intensity of products and abate overall life cycle environmental impacts while maximising business profits hence it is frequently referred to as “doing more for less”. To measure eco-efficiency, two key sustainability assessment tools, namely, Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) are combined to ensure that both dimensions of sustainability are covered in the analysis.

Much of the published literature on eco-efficiency has focused on dematerialisation as an important means of achieving eco-efficiency (Dobers and Wolff, 1999). Dematerialisation focuses on the input side of material flows and the use of products, rather than on disposal options, the rational being that the reduction of total material throughput of any product also limits the full range of embodied effects– associated with the product life cycle. The extent to which dematerialisation must take place (or alternatively, eco-efficiency must be increased) for the environmental impact of the global economy to remain below the Earth’s carrying capacity has received much attention from environmental scientists. A factor of ten, reflecting a tenfold reduction of material flow per unit of service to be realised over a period of 30-50 years, is promoted in the 1994 *Carnoules Declaration*. Other researchers anticipate that more radical long-term reductions in material flows, that is, a factor of 50, may be necessary to accelerate the global shift towards a steady state economy (Reijnders, 1998). However, in the 1998 book *The Factor Four*: *Doubling Wealth, halving resource use,* Hawken et al (2010) suggests that society could aim for the more moderate Factor 4 target as a short to medium term measure. The variations in the Factor X reflect different projections of the key variables, differences in the interpretation of carrying capacity, different assessment contexts, and different time perspectives (Anders and Hauschild, 2011). In the worst case scenario, future products and systems may need to be improved to the point where they provide the same services as today, but at 2% the resource use and emission rate of current technologies.

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[6] World Business Council for Sustainable Development (WBCSD)

To be successful, dematerialisation entails appropriate action by the key product value chain actors at all levels of society, that is, production, consumption and regulation:

- To stem the flows of virgin raw materials, government subsidies need to be withdrawn so that the costs can be internalised by the extractive industries.
- Manufacturers need to apply resource efficient and cleaner production (RECP) methods in their production processes and integrate extended producer responsibility (EPR) considerations into the product value chain. RECP is a company-level approach to using resources efficiently and reducing environmental pollution while saving costs. EPR is mainly implemented through environmental regulation which imposes a duty on manufacturers to internalise costs by taking back post-consumer products. EPR is currently included in South African waste policy. The main benefit of EPR is that it transforms the conventional cradle-to-grave industrial model into an innovative closed loop model that diverts EOSL products away from waste disposal into either direct re-use or a range of product recovery management[7] (PRM) options.
- The consumer's role is to create an enabling environment for resource use to be optimised and for wastes to be minimised. This is achieved by creating a demand for services instead of capital goods.
- Building designers would need to "plan for the funeral at the birth", that is, buildings and building components would need to be deliberately designed for ease of disassembly at EOSL.

Shortcomings and limitations of eco-efficiency

Eco-efficiency has no direct relationship with absolute sustainability

In using LCA to quantify eco-efficiency, the actual effects of human interactions with ecosystems are not fully reflected in the assessment because ecosystems are generally not included in the system boundary, but rather treated as a source of resources and a sink for waste (Bjorn and Hauschild 2012). Furthermore, an assessment based on LCA measures potential – not actual – environmental impact, thus the result of an assessment can only show that a product has improved, but how much closer that improvement brings the product to the goal of absolute sustainability remains unknown. (Bjorn and Hauschild, 2012; Figge and Hahn, 2004).

Eco-efficiency may contribute to unsustainability

The advocates of the eco-efficient route to sustainability presuppose that growth will always be accompanied by technological innovations that favour dematerialisation. However, the total environmental impact of economic activity is not only dependent on technological advancements but also on population size and the level of per capita consumption (Huesemann, 2004). The relationship between environmental impacts (I), population (P), affluence (A) and eco-efficiency / technology (T) is expressed through the equation I = PAT, also known as the IPAT identity (Huesemann, 2004; Ehrenfeld, 2005; Reijnders, 2008; Bjørn and Hauschild, 2012). Since affluence (A) and population (P) are on the rise globally, impacts (I) may exceed (or may have already exceeded) a defined sustainability level leading to a diminished ability of ecosystems to supply resources and provide sinks for pollution (Bjørn and Hauschild, 2012). Despite this, the overarching aim of eco-efficiency is to

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[7] PRM options are processed on the product level – they include repair, refurbishing, remanufacturing and cannibalisation, all of which are aimed at preserving the identity and functionality of used products on a high standard. Recycling is processed on the material level and results in the loss of identity of a product therefore it only comes into operation when PRM options have been exhausted (Schultmann and Sunke, 2007).

improve production technology (T) to the furthest extent possible without addressing the consumption aspects (P and A).

However, according to the Second Law of Thermodynamics, the environmental impact of a given technology (T) can never be reduced to zero, hence there is a lower limit beyond which it is impossible to improve eco-efficiency (or reduce resource use) further. Besides, the historical evidence indicates that improvements in technology will often have the opposite effect from that originally intended (Huesemann, 2004). In some cases, a product may move further away from the goal of sustainability if the growth in volumes consumed out-weighs the efficiency gains (Huesemann, 2004; Bjørn and Hauschild, 2012). For example, when the energy source for heating private homes was switched to cleaner fuels, the building occupants generally chose a higher indoor temperature (Bjørn and Hauschild, 2012). Better eco-efficiency might therefore lead to growth and thus to an increased use of environmental resources (Figge and Hahn, 2004). This effect has been observed in many different contexts and is known as the "the rebound effect" (Huesemann, 2004; Bjørn and Hauschild, 2012; Reijnders, 2008). Thus in the absence of restraints on consumption (P and A) eco-efficiency interventions merely exacerbate unsustainability.

The eco-effective route to sustainability

According to the proponents of absolute sustainability, *effective* as opposed to *efficient* measures are the primary guarantors of sustainability. As a strategy for sustainable design of products the eco-effectiveness concept was first promoted as an alternative to eco-efficiency through the book *Cradle-to-cradle: changing the way we make things* by William McDonough and Michael Braungart (2002). The overarching philosophy behind cradle-to-cradle (C2C) is to achieve absolute environmental sustainability by increasing the positive impacts of products through eco-effectiveness.

Eco-effectiveness is fundamentally different from eco-efficiency in that it is modelled on the successful interdependence and regenerative productivity of natural systems (Braungart, et al, 2006). It uses systems thinking in a new, cyclical approach that transforms the product life cycle into a closed loop in which there is no longer a "grave" because the waste from old products are "metabolized" to become "food" (resources) for new products. While eco-efficiency seeks to reduce the negative environmental impact of doing business, eco-effectiveness is premised on the belief that business solutions ought to be life sustaining, restorative and regenerative in addition to being effective (Young and Tilley, 2006). Other similar approaches and philosophies that use or call for the use of natural systems functioning as a basis for sustainable product design include but are not limited to *The Natural Step* and *Biomimicry*.

The C2C product design and development process is founded on three key principles, namely, waste equals food, use current solar income and celebrate diversity. Waste equals food shifts the design mentality from one of creating waste that has to be thrown away to one which turns end-of-service-life (EOSL) products into "nutrients" for making new products. To operationalize this principle, materials should either be defined as technical or biological "nutrients" – mixing the two results in a product that can only be downcycled[8] at EOSL. Technical "nutrients" should be designed for industrial recycling, while biological "nutrients" are designed to be recycled by living systems. This is illustrated in Figure 1. This first principle works hand in hand with Product Service Systems (PSS) a voluntary business model which applies principles similar to EPR whereby manufacturers retain ownership of products thus the business focus is to sell services and functions instead of capital goods. The second principle, use current solar income, suggests that as long as the energy required to fuel

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[8] Downcylcing is the process by which used materials are recycled into lesser quality products with lower market value. White writing paper, for example, is often downcycled into cardboard and once downcycled to this new form it cannot be used as white paper again.

manufacturing processes, including continuous loop recycling, is derived from renewable sources, then there are no quantitative constraints on the amount of energy used throughout the product life cycle. The purpose of the third principle, celebrate diversity, is to encourage designs which respect and enhance local cultures and protect the environment.

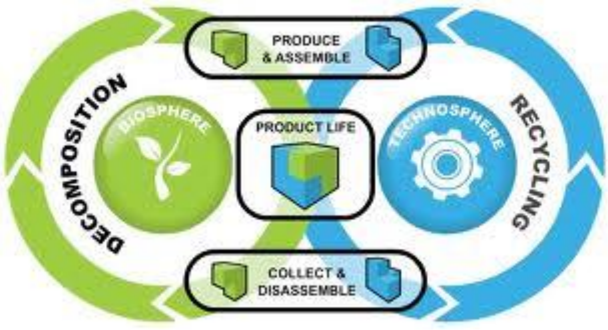

Figure 1: The eco-effectiveness concept

In practice, the stepwise strategy set out in Box 1 is implemented to transform conventional products into eco-effective products (Braungart, et al, 2006). The stepwise strategy serves as a design aid at two distinctive levels. At the material level, an in-depth analysis, and possibly reformulation of all materials that go into the making of an eco-effective product is required to ensure that they can fall into one of two categories – technical or biological nutrient. At the product level, the strategy stimulates service life planning. Hence, if the intention is to re-use, repair or re-manufacture the product at EOSL then it has to be appropriately designed – for example, for ease of disassembly. Table 2 sets out a practical interpretation of the “five steps to eco-effectiveness”. Certification is now available from the Cradle-to-cradle Products Innovation Institute. Four levels of certification are available, namely, basic, silver, gold and plantinum

Table 2: Five steps to eco-effectiveness Source: Kibert, 2006

Step	Requirements
1	Free ourselves from the need to use harmful substances (e.g. PVC, lead, cadmium and mercury)
2	Begin making informed design choices (e.g. materials and processes that are ecologically intelligent , respectful of all stakeholders, and which provide pleasure or delight)
3	Introduce substance triage (a) phase out known and suspected toxins (b) search for alternatives to problematic substances, and (c) substitute for them “known positive” substances
4	Begin comprehensive redesigns to use only “known positives”, separate materials into biological and technical, and ensure zero waste in all processes and products
5	Reinvent entire processes and industries to produce “net positives”, that is, products that actually improve the environment

Shortcomings and limitations of eco-effectiveness

Continuous loop recycling has hidden trade-offs

Continuous loop recycling is inherently energy intensive. Hence, a future C2C society may minimise virgin raw materials extractions but increase the overall energy demands of our industrialised society (Bjørn and Hauschild, 2012). Furthermore, zero waste systems are not possible due to the Second Law of Thermodynamics whereby materials are dissipated in use just as energy is, so complete recycling is impossible (Kibert, 2006). Simply put, materials will be lost in recycling processes and due to entropy, will naturally seek to return to background concentrations for natural materials and very low concentrations for synthetic materials. C2C and other similar approaches do not address this potentially difficult issue when suggesting that recycling of technical materials is desirable.

Eco-effectiveness may entail phasing out of many existing materials and may hamper the development of novel materials

C2C presumes that at end-of-service-life (EOSL) a technical “nutrient” can be separated easily into the original pure, material fractions for purposes of recycling. In reality, this may amount to phasing out many existing materials and also restricting innovation. For example, a composite material cannot undergo continuous loop recycling as it represents a practically inseparable mix of materials (Bjørn and Hauschild, 2012). Applying C2C would be particularly problematic in the building and construction industry due to the great number of materials that are known to be difficult if not impossible to recycle (Kibert, 2006).

Disposal of biological “nutrients” by composting may harm the environment

The C2C presumption that nature can safely process biological “nutrients” is problematic because biomaterials are made by combining natural and synthetic materials resulting in a new material that has no precedence in nature (Kibert, 2006). Hence, whether biodegradation has a positive influence (nutrients) or negative impact (waste) on eco-systems is not firmly established. In addition, species reaction is unpredictable and for some, growth may be inhibited, for others, it could be stimulated (Bjørn and Hauschild, 2012). The available evidence suggests that this presumption will lead to violation of C2C Principle 3. For example, the replacement of a forest with an FSC certified plantation results in the loss of many species for which the forest system once provided habitats.

Complete reliance on solar income may not be achievable

Reliance of the global economy on renewable energy as the only source of energy for powering our industrialised society is not practicable. Because ecosystems rely on solar radiation for their functioning, wholesale global diversion of solar energy for human use can have immediate and adverse effects on the very same ecosystems which provide services essential to human well-being. If biomass were the primary source of energy worldwide, production would need to increase seven-fold to meet the needs of the present generation and forty-fold by 2100 if economic growth follows the pattern predicted by IPCC (Huesemann, 2004). The land allocation implications are prohibitive and unachievable because all agricultural land may need to be co-opted to grow energy crops. Similarly, other sources of renewable energy such as wind, hydroelectric, photo voltaic and solar thermal would all have major environmental impacts if deployed at a large enough scale.

Discussion and future directions

This chapter attempted to make clear the difference between the terms “green” and “sustainable” and the implications for measuring the environmental burden that each building material contributes to a building’s overall footprint. The two terms have been used interchangeably but the literature indicates that they are fundamentally different.

Green benchmarks environmental improvements against existing products. As such, it is never known whether an improvement effort lowers or increases absolute environmental burdens. Green “picks the low hanging fruit”, that is, incremental improvements are achieved in part of a system while leaving relatively intact the larger system within which the product is embedded. This approach has been shown to encourage hidden trade-offs. By contrast, sustainability measures environmental improvements against reductions in the flows from and to nature. It follows that measuring the environmental burden associated with a product would entail (i) whole system analysis to discover the causative factors for unsustainability (ii) quantification of the reductions in resource use and pollution described in terms of actual environmental issues, for example, reduction in GHG emissions or reduction in toxicity.

Two approaches to measuring industry contributions to sustainability have been reviewed – eco-efficiency and eco-effectiveness. It is clear that the two differ fundamentally from each other.

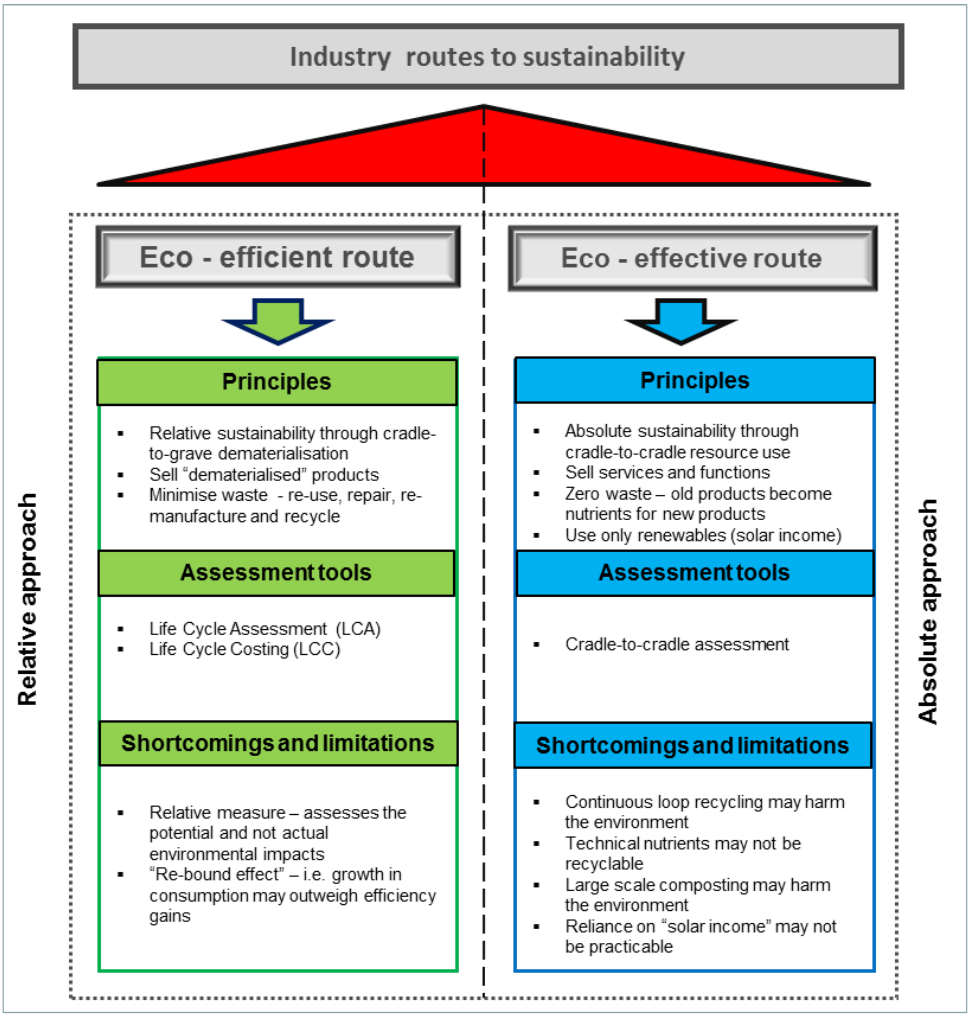

Figure 2: Two approaches to measuring industry contributions to sustainability

Eco-efficiency uses dematerialisation strategies to reduce the negative environmental impacts and cost of doing business. When dematerialisation strategies include extended producer responsibility (EPR), materials are diverted from the traditional, linear trajectory into a closed loop that maximises their service intensity. Eco-efficiency is however a relative measure which is somewhat focussed on short term environmental improvements that have been shown to cause long-term adverse effects, especially when it is used without EPR. Furthermore, eco-efficiency cannot assess toxicity hence complementary tools such as Risk Assessment (RA) would be needed in building material applications.

By contrast, the advocates of eco-effectiveness believe that industry solutions can repair and even regenerate eco-systems. Eco-effectiveness starts with the assumption that materials can only be used sustainably within closed loops which mimic the functioning of natural systems. Hence, a number of strategies which include C2C design, positive lists and Product service systems (PSS) are applied to encourage the use of "solar income", eliminate waste and foster continuous loop recycling. However, the positive message of eco-effectiveness comes with a number of caveats. The enormous energy requirements of large scale continuous loop recycling are not likely to be met even if the energy source were "100% solar income". Because of the Second Law of Thermodynamics continuous loop recycling is likely to cause widespread dissipation of materials and environmental impact is as yet unknown. Similarly, the biological "nutrients" which are supposedly "good" for nature do not in fact have a precedent in nature and could potentially disrupt ecosystem functioning.

Despite the differences in their approaches to sustainability and the shortcomings and limitations, eco-efficiency and eco-effectiveness do agree on one issue – materials loops need to be closed to accelerate the local, regional and global shifts towards sustainability, and progress made towards sustainability needs to be quantifiable. Methods for measuring the environmental performance of materials would therefore need to extend beyond EOSL to focus on a range of options which instead of discarding used materials as waste will preserve them as resources.

The key issues needing to be addressed to facilitate closed loop materials cycles for buildings are:

- Implementation of extended producer responsibility (EPR), PSS or a similar policy framework. This is likely to create an enabling environment for building material and component manufacturers to internalise costs.
- Design for deconstruction at the building level. This will enhance recovery of components at EOSL and also make maintenance and refurbishment work easier as building components can be readily removed and replaced
- Design for extended service life and disassembly at the component level. This will enable direct re-use, re-manufacture and repair, which recover as much of the economic as well as and ecological value of a components as possible, to be prioritised over other actions such as recycling that entails greater resource use.
- Design for recycling on the material level with the proviso that (i) materials manufacturing and use are benign (ii) materials dissipated from recycling are harmless. Recycled materials would thus replace virgin raw materials as the predominant resource for the manufacture of new building materials and components.

The mines of the future will be the cities, not virgin mountainsides; the timber lots will be old houses, not virgin forests; and steel mills will be located near the junk yards and other sites where raw material is available. While virgin materials will continue to be needed, they will only supplement recycled inputs, rather than vice versa (Young and Sachs, 1994).

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