Ecology of Building Materials

(full dress rehearsal)

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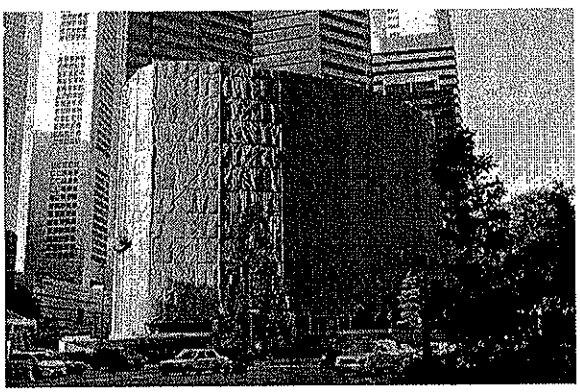


Globally
Building consumes:
- *40% or world's raw resources (3 b tons)*
- *16% of world's fresh water*
- *Up to 40% of world's energy*
- *35% of timber harvest*
- Buildings produces
- *40% of solid wastes going to landfill*
- *40% of harmful air emission*

35% of world's CO2 emissions

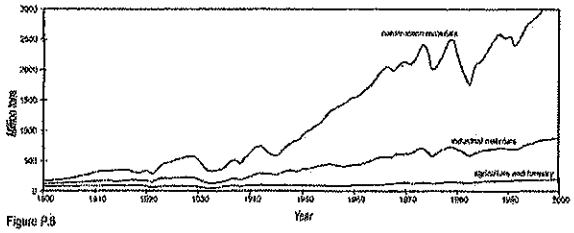


Figure 2.8

Materials use for construction, industrial, agriculture and forestry in the United States between 1900 and 2000.

Source: Matos and Wagner, USGS

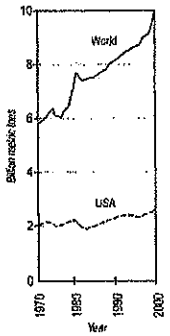


Figure 2.8

Amount of materials consumed in the US and the World.

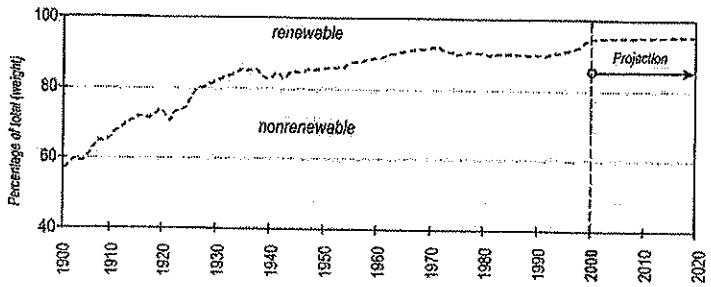


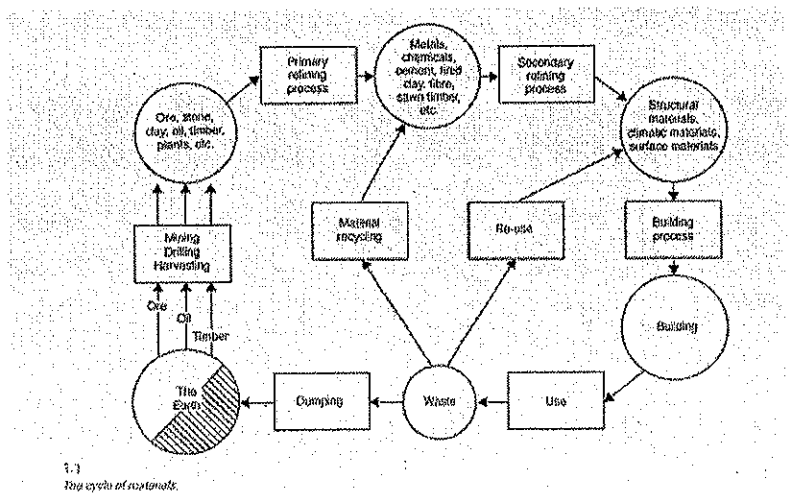
Figure 2.9

Percentage of renewable versus nonrenewable materials consumption in the US. Since the beginning of the 20th century the use of renewable resources in the economy as a whole has decreased from 42 percent to less than 5 percent today (not including fossil fuels - a nonrenewable resource).

Sources: Matos and Wagner (1998).

Profligacy

600 tonnes of material
used to produce
60 tonnes of product
of which
6 tonnes are in use

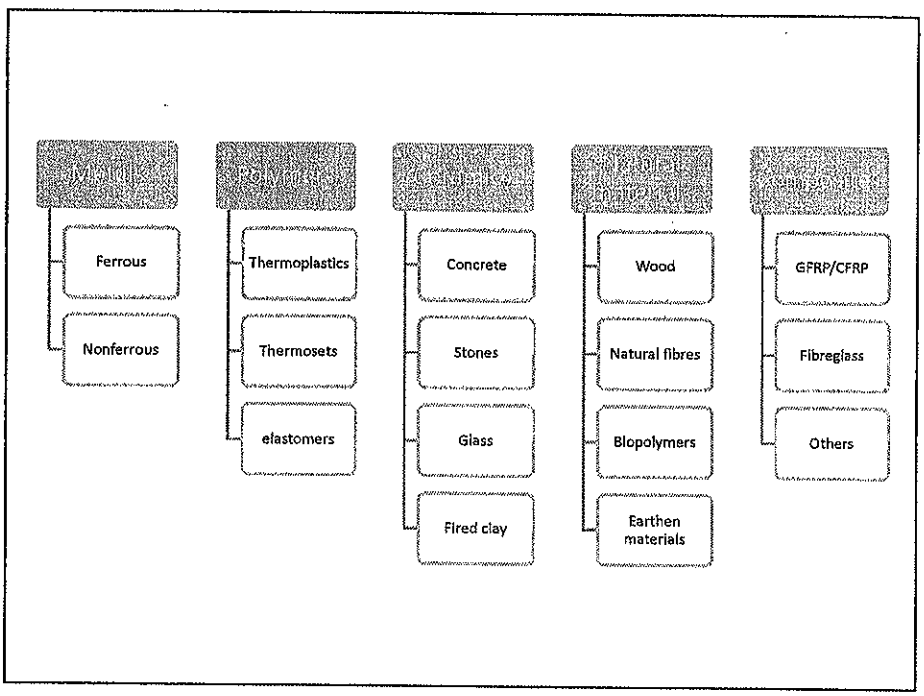


1.1
The cycle of materials.

Ref: The Ecology of Building Materials, Bjorn Berge

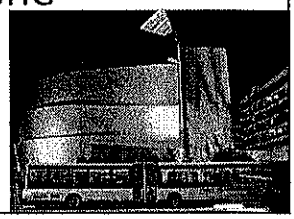
Non-renewable resources used in the manufacturing of building materials

Raw Material	Reserve (years)	Reserve Base (years)
Aggregates (sand, gravel	Very large	Very large
Clay, for fired products	Very large	Very large
Copper	31	61
Iron	95	219
Quartz	Large	Large
Tin	22	40
Titanium	122	240
Zinc	22	46
Nickel	41	90
Coal	150	
Natural gas	63	
Crude oil	41	



Metals: Steel and Aluminium

- High embodied energy and environmental impact
- High potential for recycling
- Each tone of recycled steel
  - Saves 1000kg of ore, 500 kg of coal
  - 80% of energy as compared to from ore
- Recycling of Al eliminate 95% of GHG as from bauxite

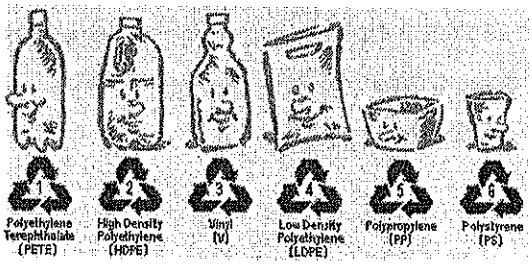


Concrete and concrete products

- Most widely used construction materials in the world, ~10 billion tons/year
- After water, most consumed substance on Earth
- Cement production – 7-10% of world's total CO_2 emission
- Cement – energy intensive manufacturing ~4GJ/ton
- Demolition/disposal of concrete – waste disposal problem
- Huge water consumption – 1 trillion gallons of water/year (excluding wash water & curing water)

Plastics

- High potential for recycling
- Toxicity – esp PVC
- Biobased polymers – corn, agribased, biodegradable

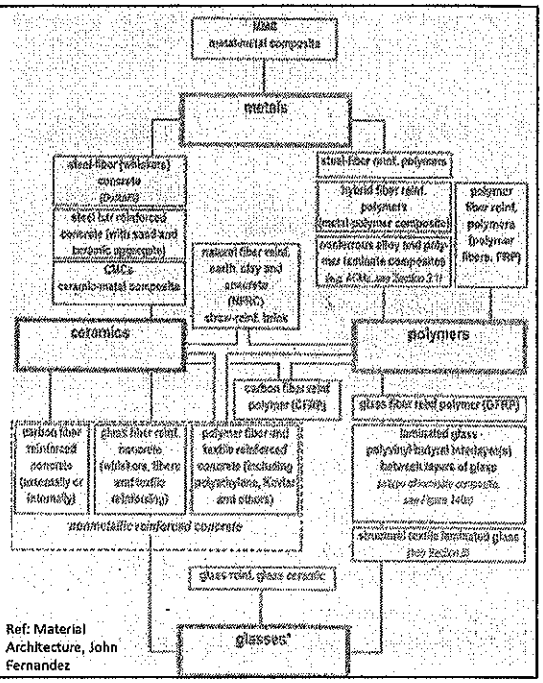


Polymer	Embodied energy (MJ/kg)
Low density polyethylene (LDPE)	80.5
High density polyethylene (HDPE)	79.9
Expandable polystyrene (PS)	83.7
Polyvinyl chloride (PVC)	65.2
Acrylonitrile butadiene styrene (ABS)	95
Polycarbonate (PC)	116.8
Epoxy resins	140.7

Wood and wood products

- Dimensional lumber, engineered wood, plywood, composite materials and wood fibre
- Sustainable sources?
- Recycled wood/content
- Treatment – coating, preservatives

Composites



Ref: Material Architecture, John Fernandez

Material	Weight (kg/m3)	Durability	Primary energy consumption (MJ/kg – Central Europe)	Use of water (Litres/kg)
Aluminium (50% recycled)	2700	high	184	29000
Steel (100% recycled)	8000	high	10	
Structural concrete with Portland cement	2400	high	1	3400
Glass	2400	high	8	680
Ceramic tiles	2000	Very high	8	400
Bitumen	1000	Low/medium	5	
Expanded polyurethane	35	Low/medium	110	18900
Polyvinyl chloride	1380	Medium/high	84	
Timber (untreated)	550	Medium/high	3	330
Wood fibre board (hard without bitumen)	900	Medium/high	15	2500

Material	Global warming potential (g of CO2 eq) (g/kg)	Acid potential (g of SO2 eq) (g/kg)	Waste from the production process (g/kg product)
Aluminium (50% recycled)	11102	60	715
Steel (100% recycled)	557	3	
Structural concrete with Portland cement	65	1	32
Glass	569	44	
Ceramic tiles	571	4	9
Bitumen	489	4	3
Expanded polyurethane	3900	30	486
Polyvinyl chloride	1400	13	
Timber (untreated)	116	1	25
Wood fibre board (hard without bitumen)	766	3	80

Primary energy use for the production

Metals/alloys	From the ore (MJ/kg)	50% recycling	100% recycling
Aluminium	165-260	95	30
Copper	80-127	55	
Steel	21-25	18	6-10
Zinc	47-87		

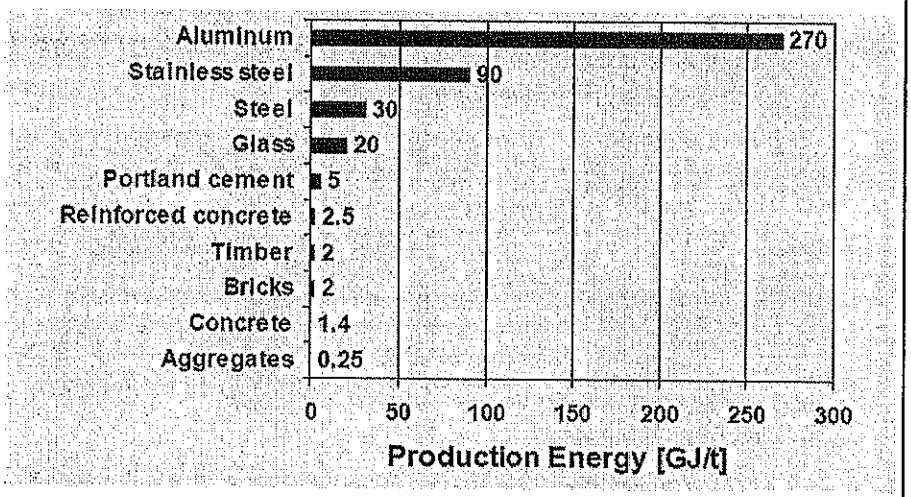
Material	MJ/kg	Temperature (deg C)
Calcined lime	4.5	900-1100
Calcined natural gypsum	1.4	200
Portland cement	4.0	1400-1500
Glass from raw materials	10.0	1400
Glass, 50% recycled (varies according to the type of glass and its purity)	7.0	1200
Stone (granite, marble, limestone)	0.2-0.3	-

Table 1 CO_2 Emission Inventory Data of Cement Production[1]

Company	Gross CO_2 Emission kg-CO_2/ton	Country of Headquarter	Year Reported
Holcim	660	Switzerland	2007
Cemex	717	Mexico	2006
Cimpor	668	Portugal	2007
CSR	751	Ireland	2006
Heidelberg	698	Germany	2006
Italcementi	733	Italy	2007
Lafarge	667	France	2007
Molins	722	Spain	2005
Taiheiyo	718	Japan	2006
Titan	689	Greece	2007
SCG	688	Thailand	2007

Table 2 Emission Inventory Data of Aggregate Production[2]

Aggregate Type	CO_2 Emission kg-CO_2/ton
Coarse-Granite	45.9
Coarse-Basalt	35.7
Fine-River Sand	13.9



Green Building materials are

- Resource Efficient
  - Durable
  - Salvaged for reuse, refurbished, remanufactured, recycled
  - Easily recyclable/reusable
  - From waste or water reducing process
  - Sustainably harvested from renewable resources
  - Minimally packaged with recyclable packaging

Green Building materials are

- Resource Efficient
  - Reduce/eliminate need for another material
  - Locally extracted/manufactured
  - Energy efficient in use
  - Low embodied energy (extraction, processing, transportation)
  - Generate renewable energy
  - Water-efficient

Green Building Materials are

- Healthy
- Zero or low emissions of toxic chemicals
- Moisture and mold resistant
- Low maintenance (no toxic cleansers)
- Filter indoor pollutants
- Emit no VOCs
- Monitor indoor pollutants or poor ventilation

Green Building Materials are

- Healthy
- Manufactured with low pollution process and from non toxic components
- Free of toxic materials – chlorine, lead, Hg, As
- Not ozone depleting

Definition of Green Products

Summary of Product Standards for *GreenSpec*

1. Products Made with Salvaged, Recycled, or Agricultural Waste Content
   - 1a. Salvaged products
   - 1b. Products with post-consumer recycled content
   - 1c. Products with pre-consumer recycled content
   - 1d. Products made with agricultural waste material
2. Products That Conserve Natural Resources
   - 2a. Products that reduce material use
   - 2b. Products with exceptional durability or low maintenance requirements
   - 2c. Certified wood products
   - 2d. Rapidly renewable products
3. Products That Avoid Toxic or Other Emissions
   - 3a. Natural or minimally processed products
   - 3b. Alternatives to ozone-depleting substances
   - 3c. Alternatives to hazardous products
   - 3d. Products that reduce or eliminate pesticide treatments
   - 3e. Products that reduce stormwater pollution
   - 3f. Products that reduce impacts from construction or demolition activities
   - 3g. Products that reduce pollution or waste from operations

Definition of Green Products

4. **Products That Save Energy or Water**
   - 4a. Building components that reduce heating and cooling loads
   - 4b. Equipment that conserves energy and manages loads
   - 4c. Renewable energy and fuel cell equipment
   - 4d. Fixtures and equipment that conserve water
5. **Products That Contribute to a Safe, Healthy Built Environment**
   - 5a. Products that do not release significant pollutants into the building
   - 5b. Products that block the introduction, development, or spread of indoor contaminants
   - 5c. Products that remove indoor pollutants
   - 5d. Products that warn occupants of health hazards in the building
   - 5e. Products that improve light quality
   - 5f. Products that help noise control
   - 5g. Products that enhance community well-being

Certification

- 1st party
  - marketing claims, product specification, MSDS
  - Not independently tested/verified
- 2nd party
  - Trade association/consulting firm
  - Conflict of interests?
- 3rd party
  - Most robust

From Certification to Labeling (ISO definition)

- Type I: Multiple attribute set of predetermined requirements
- Type II: Single attribute environmental claims (energy consumption, emissions, recycled content)
- Type III: Comprehensive and detailed product information

Eco-Labelling



Category	Key environmental criteria
Adhesives/sealant (GLS-040)	IAQ (VOC, formaldehyde, aldehydes) Toxicity
Bricks (GLS-023)	Contain waste/recycled materials (>10%) Leaching test
Cement and precast concrete products (GLS-022)	Blended cement with post industrial wastes (slag, fly ash) Concrete and concrete products with wastes (MSW, slag) Carbon footprint
Paint/coating (SGL-032)	IAQ (VOC) Toxicity (Hg, Cd, Cr, aromatic solvents, formaldehyde) Solar reflectance (reflective paint)
Panel boards/wallboard for interiors (GLS -041)	IAQ (VOC, formaldehyde) Toxicity Recycled content
Products made from recycled/renewable fibres (GLS-035)	Recycled wood and/or organic fibres From sustainable pulp cultivated from sustainable managed source IQA and toxicity

Singapore Green Building Council Product Listing

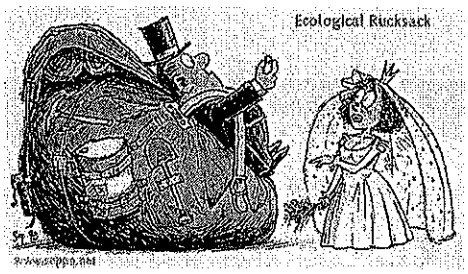
http://listing.sgbc.sg

Considerations

- Environmental Criteria
- Economical criteria
- Technical performance
- Materials vs components
  - Low-e glass vs normal glass
  - Concrete vs pre-cast components
  - Bamboo strips vs strand-woven bamboo

Different Shades of Green

- Carbon footprint
- Life cycle assessment
- Water efficiency labelling scheme
- Energy efficiency labelling scheme



A. Definition Total quantity (in kg) of materials moved from nature to create a product or service, minus the actual weight of the product. That is, hidden material flows. Ecological rucksacks take a life cycle approach and signify the environmental strain or resource efficiency of the product or service.

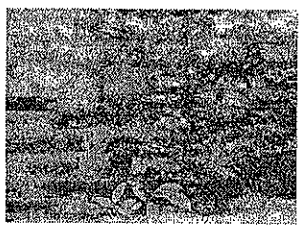
B. Main Features

Measure the amount of materials not directly used in the product, but displaced because of the product. That is, represent the materials necessary for production, use, recycling and disposal of a product, but not the materials used in the product.

Source: www.grdc.org

Lifespan of Building Components

- Different definition of lifespan
  - Technical lifespan
    - How long will a component last, usually end of curve
  - Economical lifespan
    - Replacement of components based on costs
    - Cost of failure and repair versus cost of replacement
    - Theoretically 3/4 of technical lifespan
  - Aesthetical lifespan
    - Depends of user demand
    - Sometimes very short



Service Life Planning

Construction elements	Material or type	Category of Design Life (2)			Maintenance, repair and assumed replacement (1)	Category of Failure (3)	Remarks
		Replaceable	Maintainable	Lifelong			
Glazing	Glass	√	√		Possible replacement 35 years	B,D,F	Expected lifespan of 35+ years
	Sealant	√			Re-apply after 15 years	D	For external works, provision of access must be made
	Aluminium frame			√		D,F	
Façade railing	Paint/coating	√			Re-paint after 5 – 7 years	D	For external works, provision of access must be made

(1) – The need for replacement should be confirmed by inspection

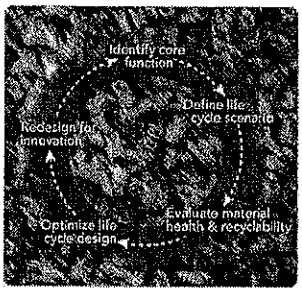
(2): Categories of design life for components or assemblies

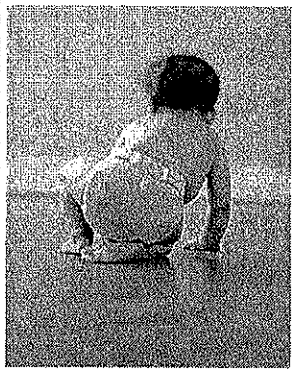
Category	Description	Life
1	Replaceable	Shorter than the building life and replacement can be envisaged at design stage
2	Maintainable	Will last, with periodic treatment, for the life of the building
3	Lifelong	Will last for the life of the building

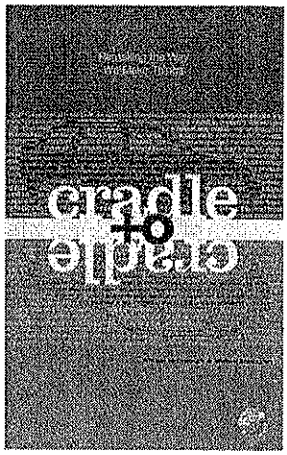
(3) Effects of failure

Category	Effect	Example
A	Danger to life (or of injury)	Sudden collapse of structure
B	Risk of injury	Falling glass panel
C	Danger to health	Serious damp penetration
D	Costly repair	Extensive scaffolding required
E	Costly because repeated	Window fastening
F	Interruption of building use	Disruption of lift
G	Security compromised	Broken door latch
H	No exceptional problem	Replacement of light fittings

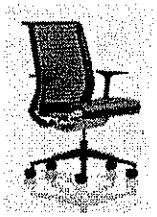
Recyling or Downcycling?



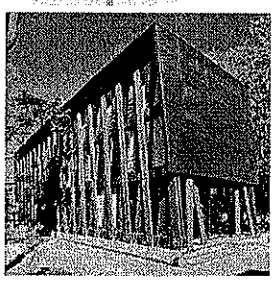


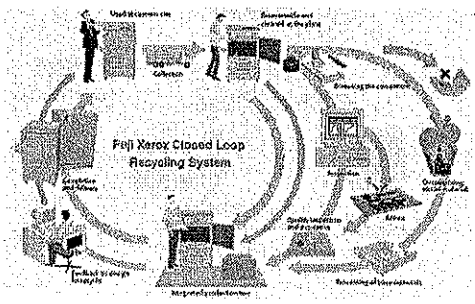


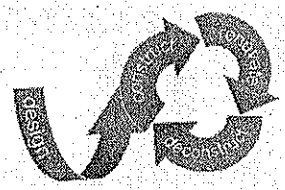
Design for Deconstruction (DfD)





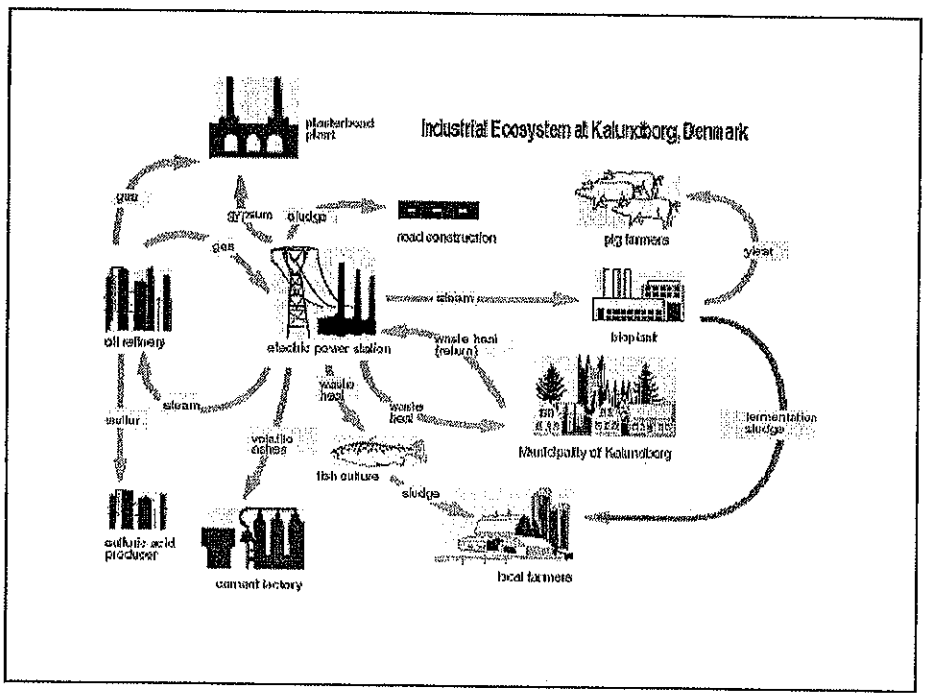




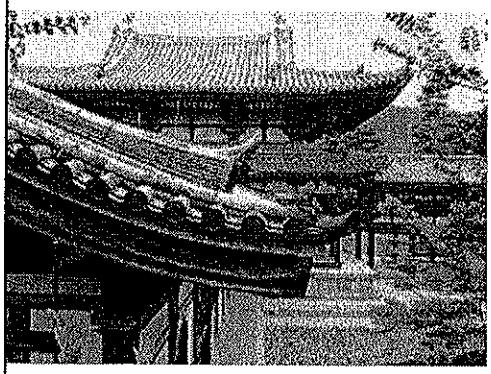


Closing the Loop

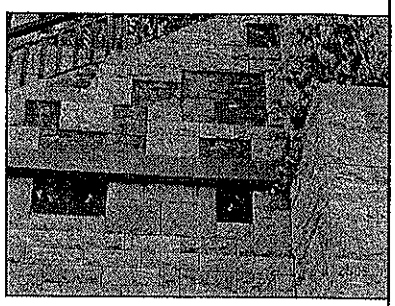
- Dis-assemblable
- De-constructable
- Recyclable/re-usable
- Safe disposal
- Cradle to cradle
- Waste to wealth
- Symbiosis



Maintainability, Durability and Pathology

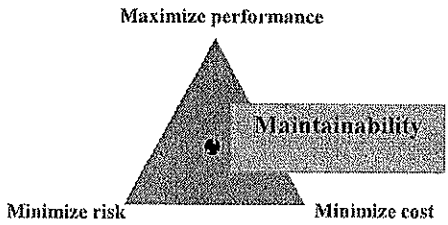


Durable and carefully detailed roofing materials and very large overhangs contribute to the longevity of traditional Japanese temples, such as this 950-year-old Phoenix Hall at Byodoin, near Kyoto.



Learning from Failures

Achieving the optimum performance throughout the building life span within minimum life cycle cost.



Sustainable Maintainability

- Flexibility and adaptability
- Accesability
- Cleaning
- Replacement
- Refurbishment
- Inspection/performance based monitoring
- Work methods – dry, wet, time, dust

Failure and Durability – problem statement

Construction	40
Design	45
Products	15

- Fragmentation of the construction industry
- Overemphasis on new-build in education and training
  - Lack of interests in maintenance/repair and refurbishment

Building Pathology (BP)

- a systematic treatment of building defects, their causes, their consequences and their remedies.
- more than just a science that studies the influencing factors and the mechanisms of degradation processes in building materials and structures.

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Classification of Defects/Failures

- Design – conceptual, detail, detailing/drawings, SPECIFICATION
- Workmanship
- Materials –
  - wrong materials,
  - wrong use of materials,
  - incompatible materials,

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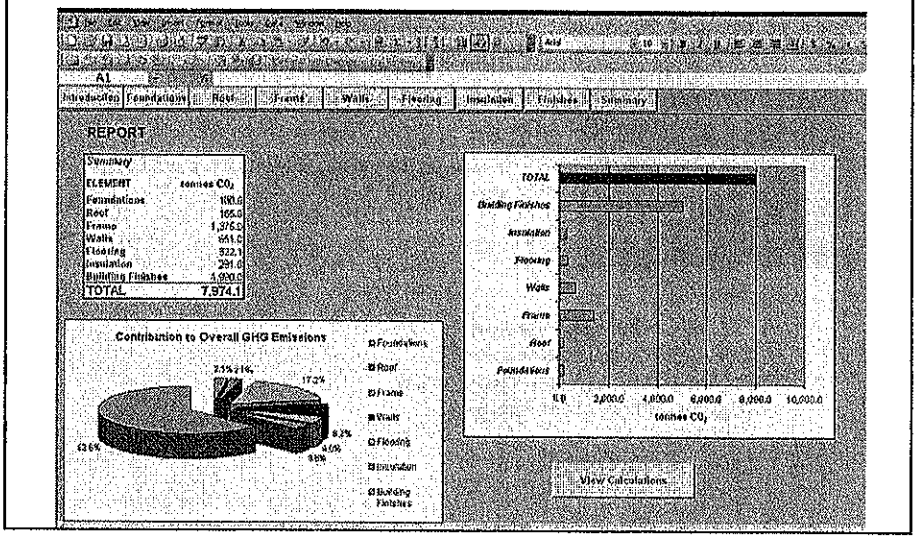
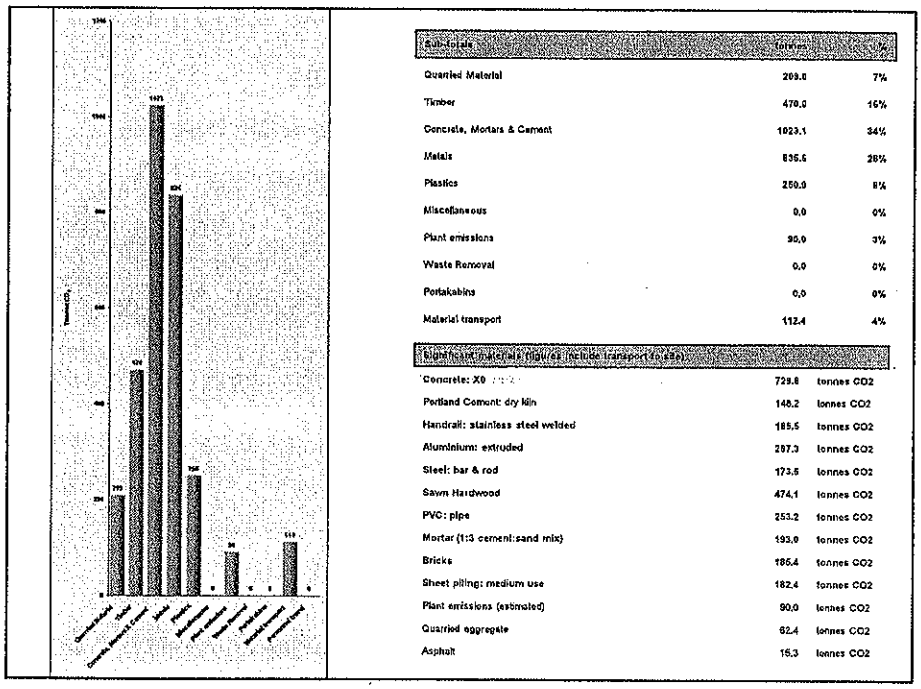
Diagnosis and Prognosis

- Failure Mode and Effect Analysis (FMEA) – Feedforward
  - Recognize and evaluate failures and find its effects
  - Design FMEA
  - As Built FMEA

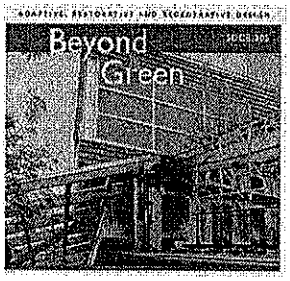
Failure Mode	Locations and extent	Effect and risk	Intervention strategies
Corrosion of rebars with spalling of concrete due to low cover and carbonation	Sporadic and widespread in Level s B, G and 2	Can lead to further deterioration of structure and corrosion of bars	Treat corroded bars with primers, patch repairs spalled concrete with PMM and apply anti carbonation coating.
Water seepage through slabs –due to failure of waterproofing membrane in wet areas and pond or cracking of slab	Random and localised to few levels mainly G (next to pond) and roof level	Can lead to corrosion of bars and poor indoor air quality	Re-apply waterproofing membrane to all wet areas, including the pond. Consider to remove failed membrane. Check of corroded bars and repair accordingly. Inject cracked slabs and consider chemical treatment to cracked carpark floor.

Carbon Calculator





Beyond Green – Regenerative Design



One Fundamental Process of Creation & Repair

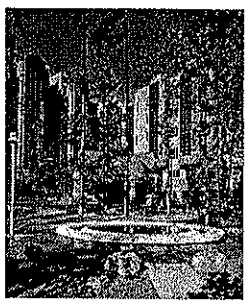
In Nature, the same process grows and heals organisms.

".....when you build a thing you cannot build that thing in isolation, but must also repair the world around it, and within it....." Christopher Alexander

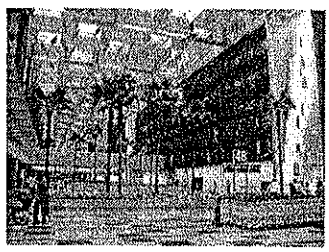
Biophilia in Practice: Buildings that Connect People with Nature

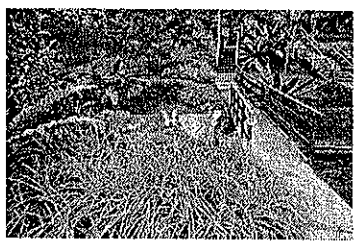


This living wall, installed by Air Quality Solutions, Ltd., of Guelph, Ontario, at the University of Guelph–Humber, is designed to remove pollutants from the indoor air, but also offers biophilia benefits.



At the Christus St. Michael Health Care Center in Texarkana, Texas, designed by WHR Architects, Inc. of Houston, nearly every hospital room looks out on trees or other natural landscaping elements.





Eco-retrofitting

- Modifying buildings/urban areas to improve overall human and environmental health and to reduce resource depletion, degradation and pollution
- Integrated and ecological design approach instead of mere addition of energy saving equipment
- Planning strategy not just buildings but whole suburbs, cities and urban infrastructure

Eco-retrofitting

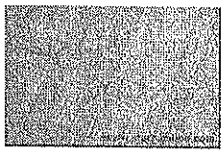
- Planned obsolescence
- Facadetomies
- In developed nations
  - 1/3 of building construction activities – renovation
  - Renovation and demolition accounts for 91% of annual construction and demolition debris

How Green?

- Bamboo

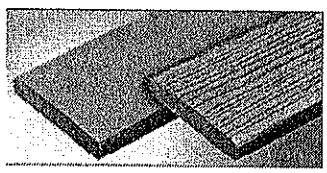
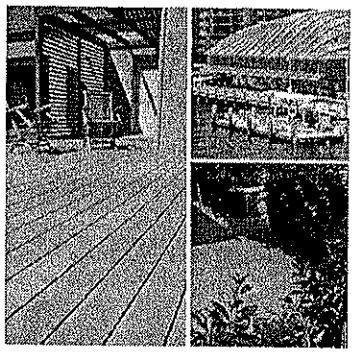




How Green?

- Composite wood

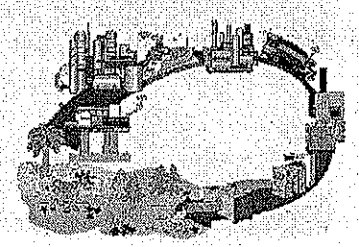
How to Use Certification/Labelling?

- Consider impact of building operations
- Identify preferable and less preferable products
- Look at other aspects – durability, performance (not only environmental)
- One of the tool for evaluating green products
- Not all certifications are equal
- Beware of greenwashing
- No certifications are truly comprehensive
- Ongoing education

Life Cycle Assessment (LCA)

What is LCA? assesses the environmental performance of products and services from the "cradle" to the "grave"

- Raw Material Extraction
- Manufacturing & Transportation



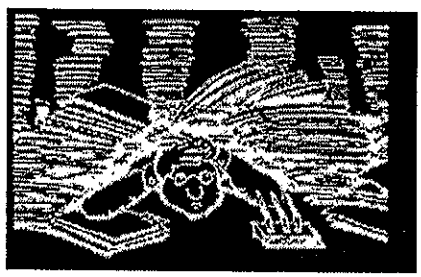
- Packaging
- Useful Life, durability & maintenance
- Disposal and/ or recycling

Life Cycle Assessment (LCA)

- Tools
  - Customized Product Matrix – based on goals and project requirements
  - Software- e.g. Building for Environmental and Economic Sustainability (BEES), LCAid, ATHENA, SimaPro7, ENVEST
  - Green Guide Specifications
  - Carbon Calculator

How do we analyze a material or product?

- By using a 3-step process that includes:
  1. Research
  2. Evaluation
  3. Selection



Sustainable Material Environmental Assessment

- Research.....Data Collection
  - Raw Materials – Recycled, Renewable, Re-used
  - Durability and Maintenance – Product warranties
  - Manufacturing Process & Location
  - Transportation
  - Disposal
  - First and Second Costs
  - Material Safety Data Sheets (MSDS)
  - IAQ test Data
  - Environmental Statements

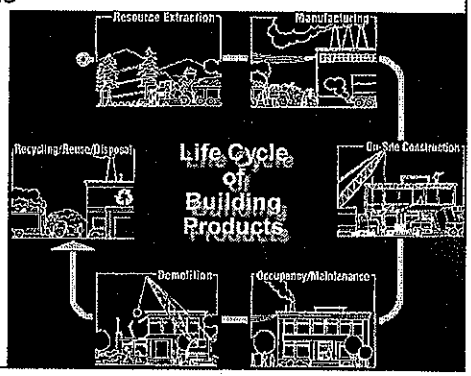
- Evaluation.....Life Cycle Assessment
- LCA evalutes:
  - Environmental burdens

  Associated with:

  Product

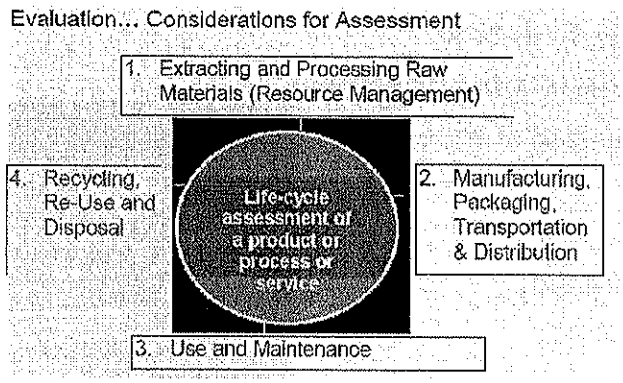
  Process

  Activity



- Evaluation....LCA

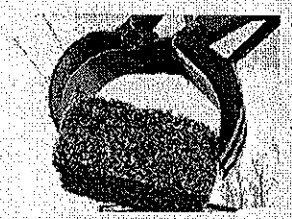
1. Identifying and Quantifying
   - Energy used
   - Materials used
   - Wastes released
2. Assessing their impact
3. Identifying and evaluating
   - Opportunities to affect environmental improvements



Evaluation… Raw Material Extraction

Resource Management takes two things into consideration:

1. Recycled Content:

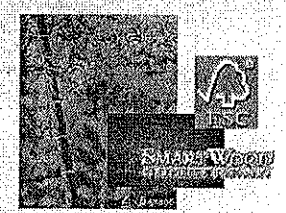


- Post-consumer A reclaimed waste product that has already been in use by a consumer
- Post-industrial Waste from a industrial process that is put back into a product during manufacturing

Evaluation… Raw Material Extraction

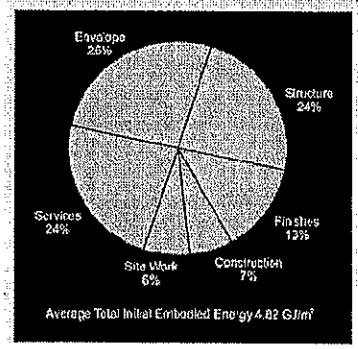
Resource Management takes two things into consideration:

2. **Sustainably Managed:**
   - Natural, plentiful or renewable materials harvested from sustainably managed sources, preferably with an independent certification



Renewable resources are replenished at a rate equal to or greater than their rate of depletion

Evaluation… Manufacturing, Transportation, and Distribution

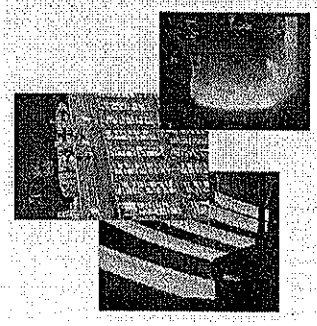


Initial Embodied Energy

Represents the non-renewable energy consumed in the manufacture, transport, and distribution of a product

Left: Breakdown of Initial Embodied Energy by Typical Office Building Components Averaged Over Wood, Steel and Concrete Structures (Cole and Kernan, 1996).

Evaluation… Manufacturing, Transportation, and Distribution

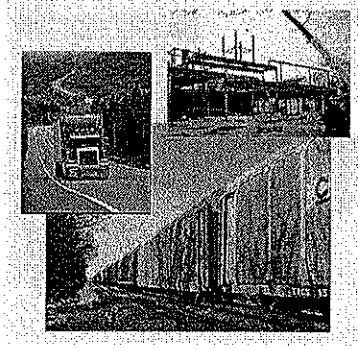


Initial Embodied Energy has two components:

1. Indirect Energy

- Acquisition of raw materials
- Materials processing
- Manufacturing
- Transportation related to above activities

Evaluation... Manufacturing, Transportation, and Distribution



Initial Embodied Energy has two components:

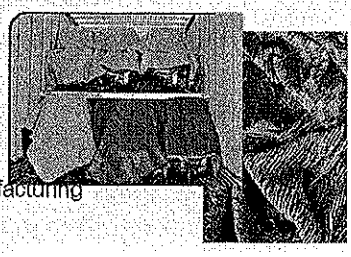
2. Direct Energy

- Transportation to site
- Construction

Evaluation... Manufacturing, Transportation, and Distribution

Strategies to reduce Initial Embodied Energy

- Locally Available
- Recycled or recyclable Product Packaging
- Resource Efficient Manufacturing Process



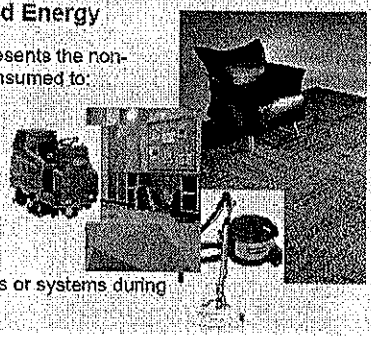
Evaluation... Use and Maintenance

Recurring Embodied Energy

In buildings, this represents the non-renewable energy consumed to:

- maintain
- repair
- restore
- refurbish
- replace

materials, components or systems during the life of the building.

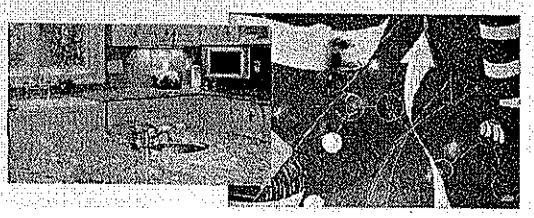


Evaluation... Use and Maintenance

Durable Materials

The longer a material is used, the less it's replaced

- utilizing fewer resources
- diverting material from the waste stream



Evaluation... Use and Maintenance

Healthy Maintenance

Consider what it takes to keep a material clean:

- Cleanser types (toxicity, VOC's)
- How often it needs to be cleaned
- Process- Is there more than one step? If so, what are they?



Evaluation... Recycling, Re-Use and Disposal

What happens to a material when it's useful life is over?

- Recycled?
- Down-cycled?
- Reused?
- Land Filled?



Evaluation… Indoor Air Quality

- Low or Non- Toxic
- Minimal Chemical Emissions
- Low-VOC Assembly
- Moisture Resistant
- Healthfully Maintained



BEES 4.0 Building for Environmental and Economical Sustainability

- Developed by The Building & Fire Research Laboratory of the National Institute of Standards and Technology (NIST)
- BEES compares materials *independent* of their application
- Balances environmental and economic performance based on the decision maker's values
- Evaluates products as they relate to one another
- Based on consensus standards
- Designed to be practical, flexible, and transparent

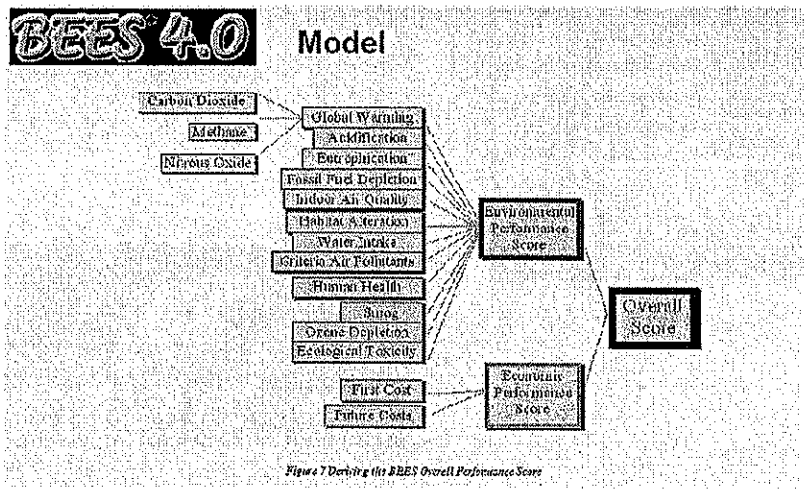


Figure 7 Deriving the BEES Overall Performance Score

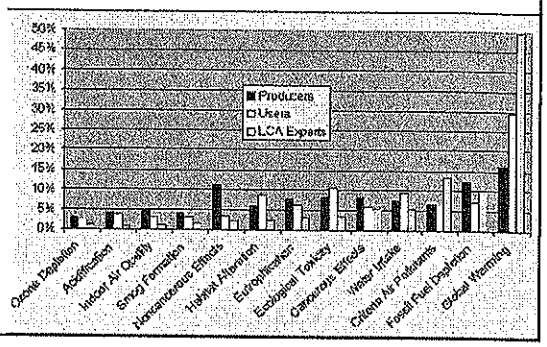
BRE Green Guide to Specification

- Life cycle assessment
  - Environmental issues
    - Climate change – Greenhouse gases and global warming potential
    - Fossil Fuel depletion
    - Ozone depletion
    - Human toxicity to air and water
    - Ecotoxicity
    - Waste disposal
    - Water extraction
    - Acid deposition
    - Eutrophication
    - Smog
    - Minerals Extraction

  Note: Embodied Energy – addressed in the above issues

Issues	%
Climate change	38
Fossil Fuel Depletion	12
Ozone Depletion	8.2
Human toxicity to air	7.0
Waste disposal	6.1
Water extraction	5.4
Acid deposition	5.1
Eutrophication	4.3
Ecotoxicity	4.3
Smog	3.8
Minerals Extraction	3.5
Human toxicity to water	2.6

Weightings



Selection... Identify Goals

The key to Material Selection is identifying the Goals of your client. What is important to them?

- Locally Available (Upstream environmental impacts)
- Warranty/ Durability (second costs)
- First Costs
- Design Aesthetics/ color availability
- Recycled Content
- Recyclability/ Disposal (downstream environmental impacts)
- Maintenance

Sustainable Material Environmental Assessment

Selection… Prioritizing Goals

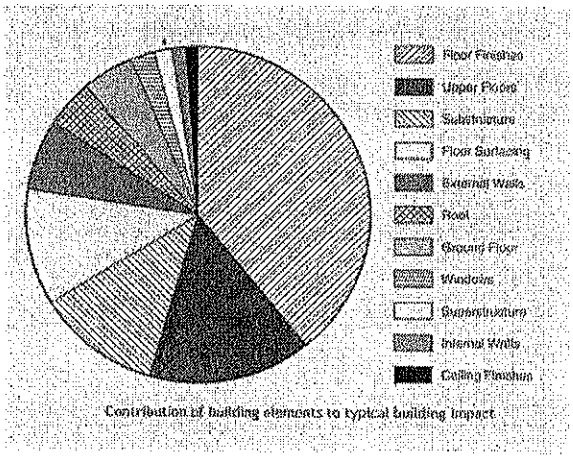
The next step is prioritizing those goals. What is most and least important to the client?

1. Warranty/ Durability (second costs)
2. Design Aesthetics/ color availability
3. First Costs
4. Recycled Content
5. Recyclability/ Disposal (downstream environmental impacts
7. Maintenance
8. Locally available (upstream environmental impacts)

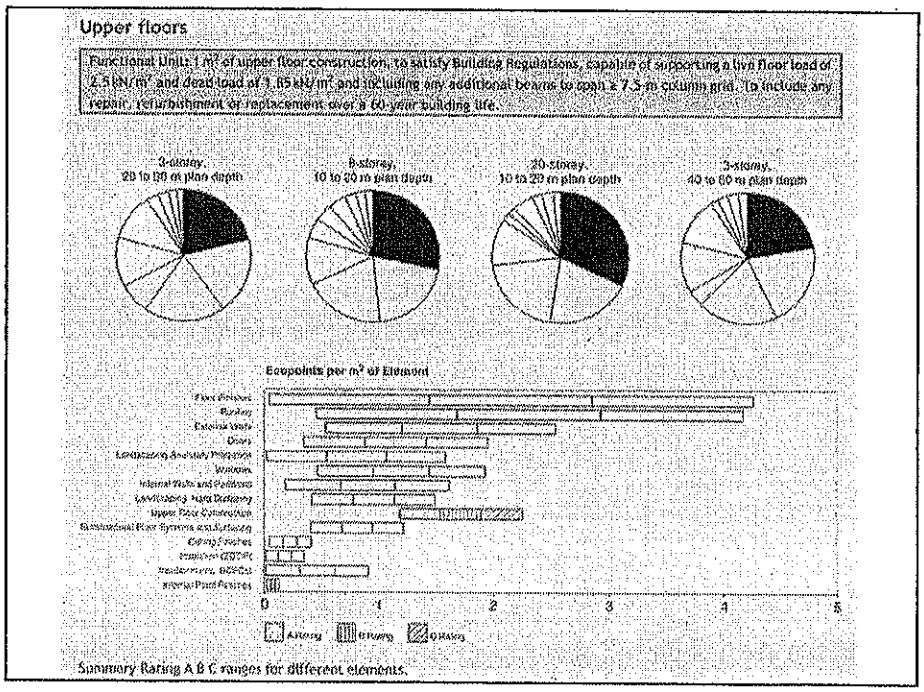
Environmental Assessment Matrix

Composite Decking	weighted value	Trex Origins	Score	pro/con	Everlast	Score	pro/con
Description		wood-plastic composite made from recycled/recycled polyethylene and reclaimed hardwood sawdust in Amphibolatory same proportions			Everlast is made from 100% recycled HDPE		
Warranted Durability	25	25 year warranty, probably longer resistant to moisture, bacteria growth and most corrosive substances	15	pro	50 year warranty, maybe longer resistant to moisture, bacteria growth and most corrosive substances	20	pro
Design Aesthetics/ varieties	15	different colors: Winchester Grey, Madeira, Woodland Brown	5	con	different colors: brown, medium beige, black, silver grey, grassgreen, mahogany	15	pro
first cost (5/4x6 board)	15	$26.97	6	con	$13	12	pro
recycled content	15	100% Trex uses both post-consumer and/or post-industrial materials. The reclaimed plastic comes primarily from grocery sacks and stretch film, and the waste wood is from woodworking manufacturers	10	pro	100% Everlast Plastic Lumber is made of 100% recycled HDPE plastics (household milk jugs, water bottles, and clean food tea containers)	15	pro
Recyclability	8	cannot be reused or recycled	0	con	100%	8	pro
Maintenance	5	easy cleaning using hot water and brush	5	pro	easy cleaning using hot water and brush	5	pro
Local Content/origin	5	Winchester, VA (dist. ca. 500 miles)	3	pro	Pottsville, PA (dis. ca. 150 miles)	4	pro
Ratings and Cert.		rated by www.healthybuilding.net "less environmentally preferable"			rated by www.healthybuilding.net "most environmentally preferable"		
Total	100		46	con		79	pro

Putting in Perspective



Contribution of building elements to typical building impact



Summary Rating A B C ranges for different elements.

Beyond Products/Materials

- Evaluating supplier/manufacturer/vendor
  - Energy efficiency
  - Water conservation
  - Toxic substance reduction/elimination
  - Recycling – product recyclability, recycling process
  - Waste reduction/elimination
  - Product lifespan
  - Products to service – extended producer's responsibility
  - CSR – corporate sustainability responsibility

Nano coatings/thin films.....photocatalytic TiO2

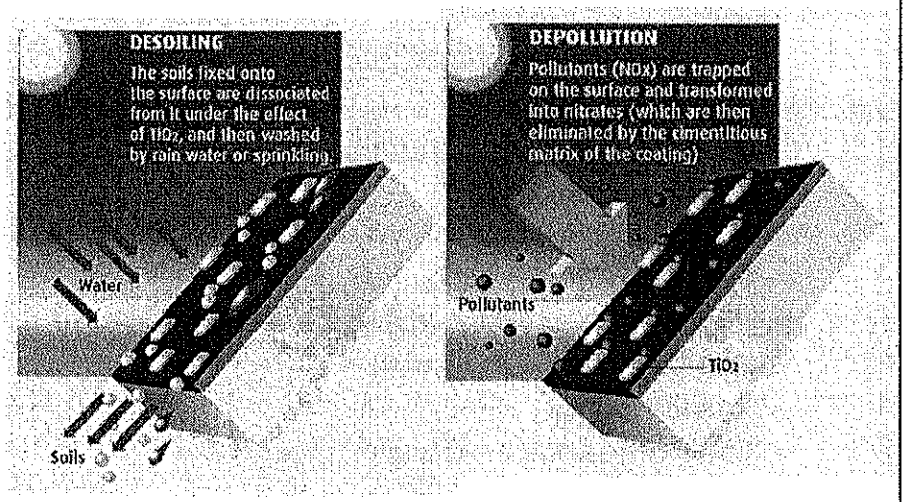
Photo Catalyst

Light

Wave length

< 388nm

A substance that increases the rate of a chemical reaction while undergoing no permanent change in composition itself

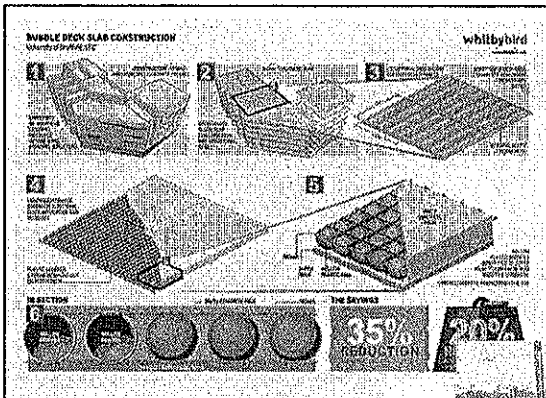


Mystifying Blue Smoke

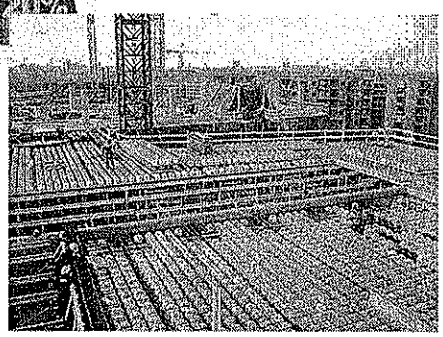
Bulk Nano porous silica Super Insulation… Aerogel

- Invented 65yrs ago
- Made up of up to 99.5% of air
- Lightest solid but can support up to 4000 times of its weight.
- Structural materials

- Possibilities
  - Thermal barrier for roofs/ walls (Currently used as heat insulator on Mars rover)
  - Skylights, wall and roof barrier
  - Adhesives and sealants

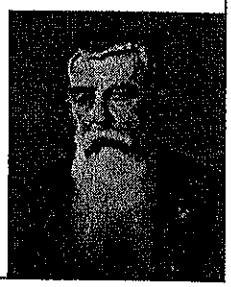


Bubbledeck



Mineral Paint

- Originated ~ 1878 in Bavaria, West Germany
- Initiated by King Ludwig I – passion for fine Italian artistic lime fresco
- Invented by Adolf Wilhelm Keim – water glass (potassium silicate)
  - Silicate Mineral Paint
    - Opaque
    - Translucent



Mineral Paint

- How it works
  - At surface

    Potassium silicate + carbon dioxide
    = silica gel + potash

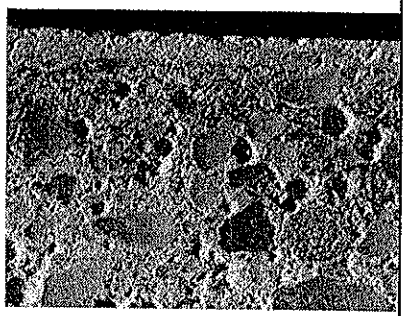
    $Ki_2SiO_3+CO_2 = SiO_2 + K2CO_3$

  - At substrate surface

    Potassium silicate + substrate = calcium silicate + potash

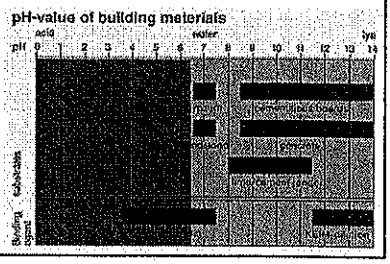
    $Ki_2SiO_3+CaCO_3 = CaSiO_3 + K2CO_3$

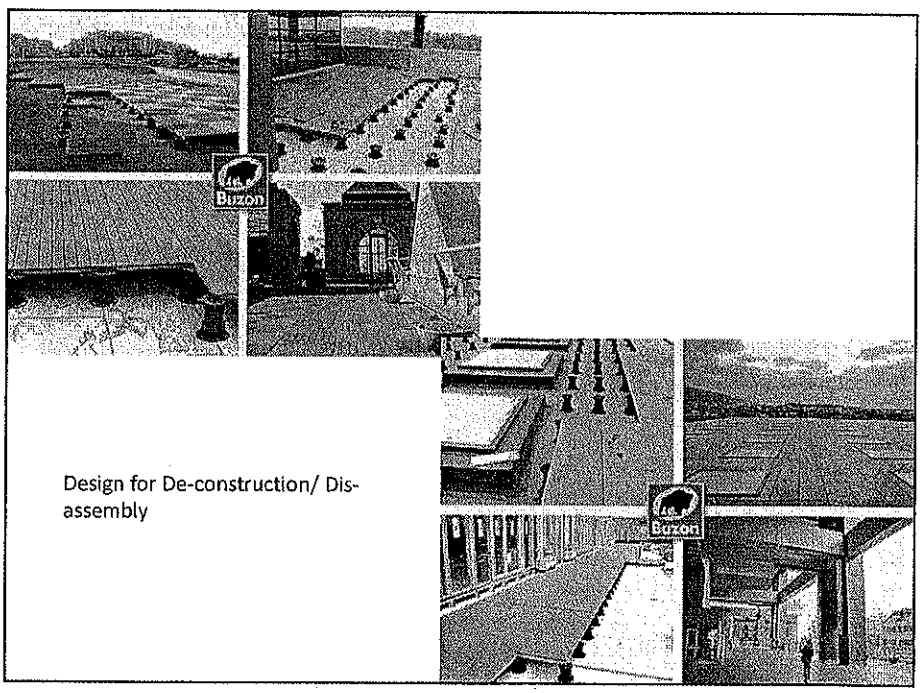
    (Potash is by-product – will be washed out by rain or air humidity)

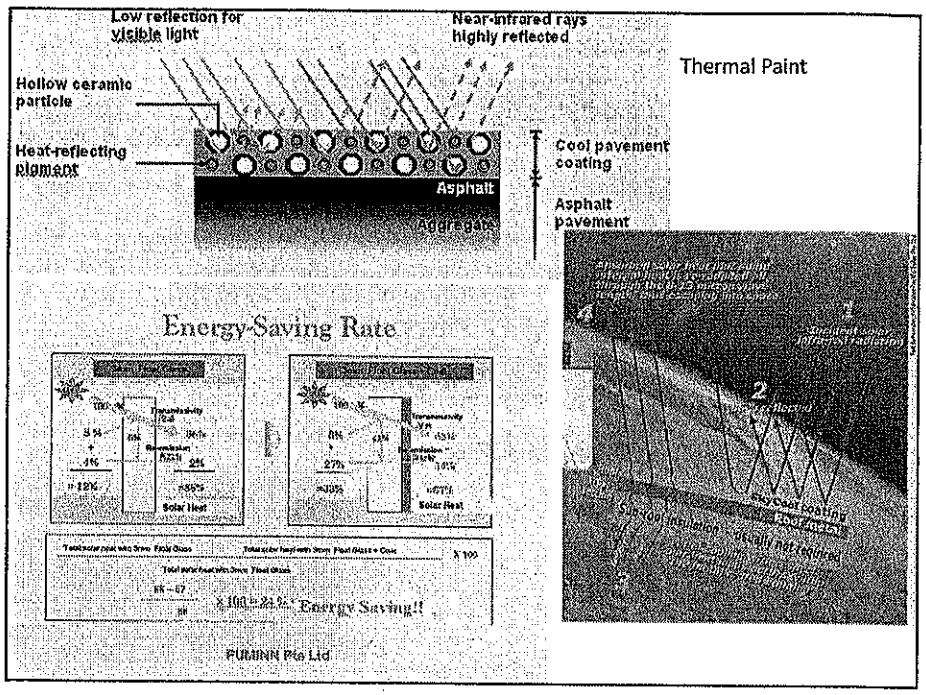


Mineral Paint

- Advantages
  - Non film forming – binds chemically with substrate
  - Similar coeff of thermal expansion with substrate
  - Similar alkaline nature – alkaline resistance
  - Durable in acid environment
  - Breathable
  - Lightfast and UV resistance

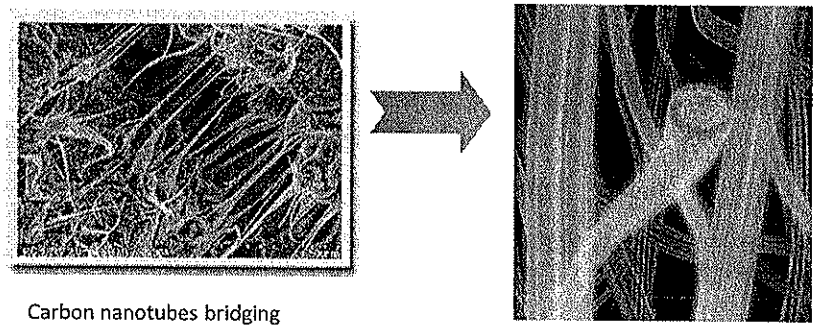




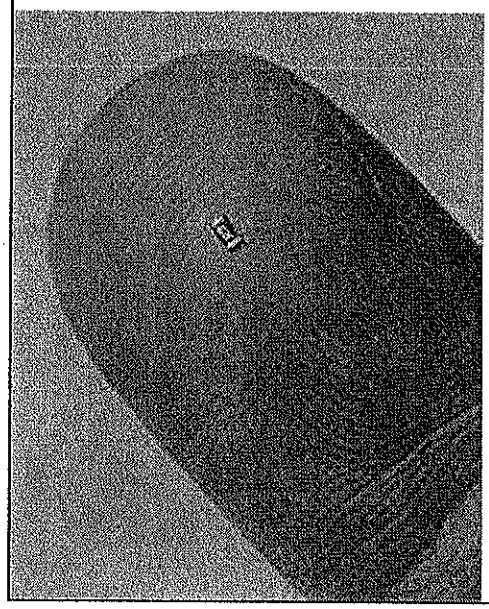


Nano particles, nanotubes

From carbon to miracles



Carbon nanotubes bridging cracks in a cement composite



Buildings That "Live"

Embedded Sensors:

Radio Frequency Identification Device(RFID)

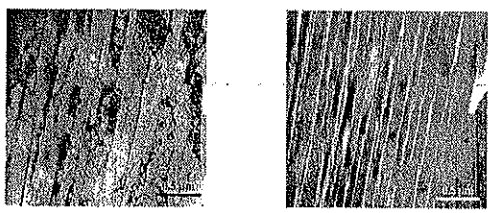
Microelectromechanical systems (MEMS)

Fibre Optics

Corrosion sensors

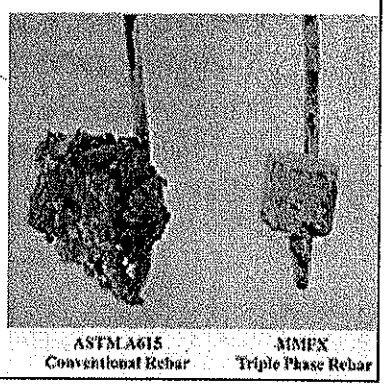
Nanostructure modified bulk materials Tackling Corrosion

- Nanostructure modified steel makes use of nano sheets of austenite so that the steel is carbide free.
- The resulting microstructure makes the steel corrosion resistant and improves its strength.



Bright Field image (BF) Dark Field image (DF)

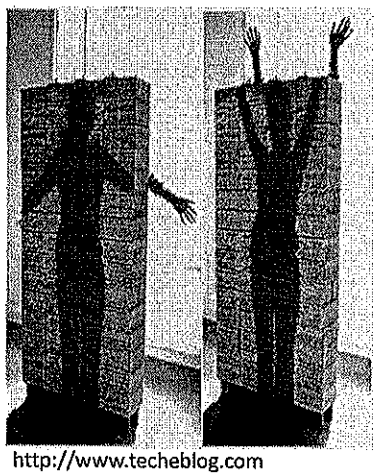
FIGURE B – MMFX – TEM PACKET LATH MARTENSITE MICROGRAPH



ASTMA615 Conventional Rebar MMFX Triple Phase Rebar

Transmit Light Through.... concrete

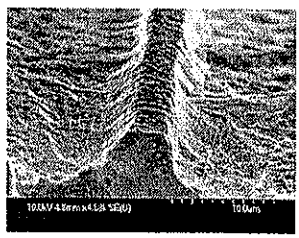
- Invented by a Hungarian architect in 2004. Its called LiTraCon.
- Optical fibers added into concrete mix
- Can transmit light up to 20m
- Will not affect compressive strength
- Thick walls with light transmitting effect

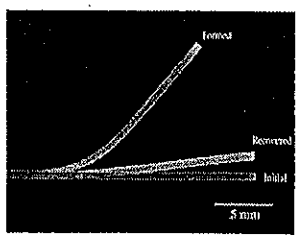


http://www.techeblog.com

Materials that remembers.....

- Shape Memory Alloys - metals that can return to a previously defined shape
- Electrical current may be passed through the metal to apply this heat.
- Smart buildings that can withstand deformations during earthquake





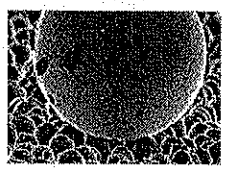
The Lotus Effect – Self Cleaning







Surface of Lotus leaf



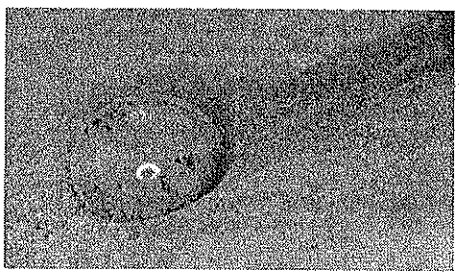
Drop of water on Lotus leaf. Contact angle up to 170°

The Lotus Effect

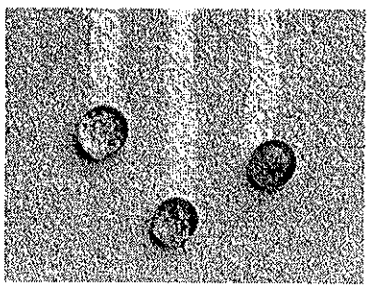
Leaves of Lotus plant are superhydrophobic

Surfaces always dry and clean

Wax on leaf surface has micro & nano scale roughness

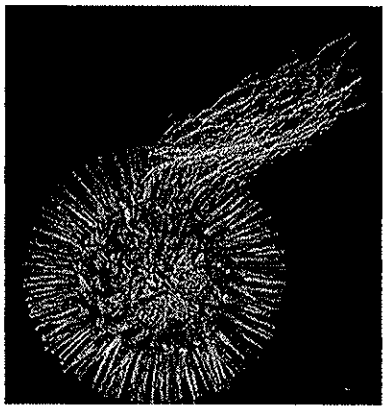


A water droplet is cleaning the plant surface



Lotusan - exterior paint on buildings

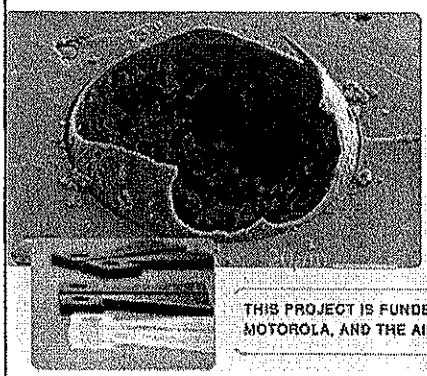
Velcro





Biomimicry

Self Healing



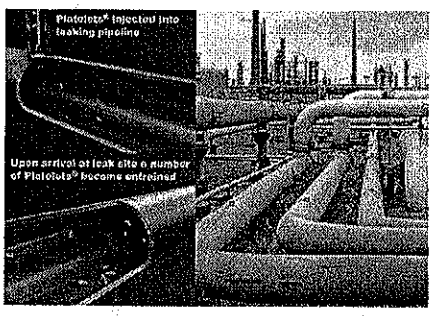
Inspired by biological systems...

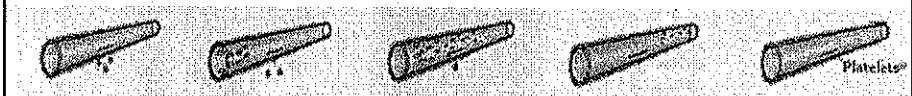
In nature, damage to an organism elicits a healing response. We apply this concept to synthetic material design and have developed a self-healing polymer.

Tiny capsules containing a healing agent are embedded in the polymer. When the material is damaged, the capsules rupture and release the healing agent, which repairs the cracks.

THIS PROJECT IS FUNDED BY THE NATIONAL SCIENCE FOUNDATION, MOTOROLA, AND THE AIR FORCE OFFICE OF SCIENTIFIC RESEARCH.

Pipe sealing - Platelets





Fluid leaks from a defect in the pipeline

Platelets® introduced into line and carried to the leak site with fluid flow

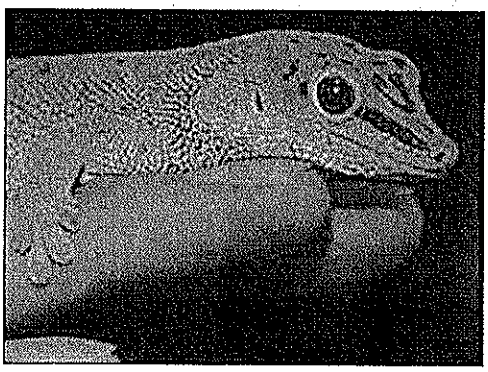
A number of Platelets® become entrained into the leak

Seal achieved – excess Platelets® continue down the line

Detection process can be carried out

Gecko

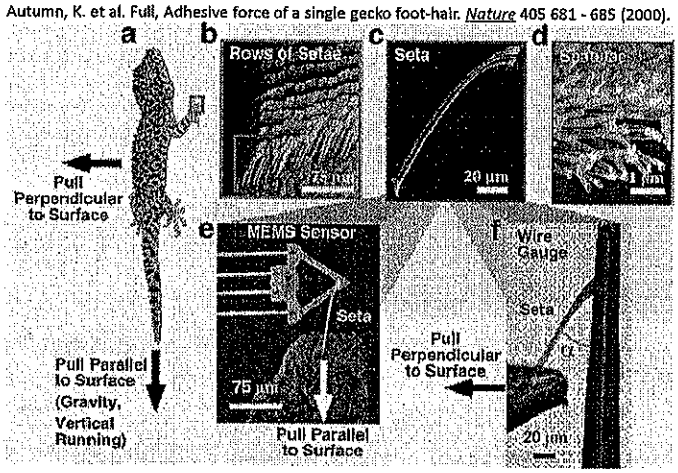






Gecko Tape

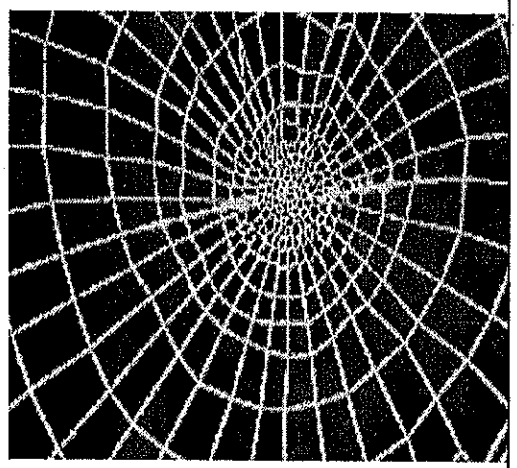
Autumn, K. et al. Full, Adhesive force of a single gecko foot-hair. *Nature* 405 681 - 685 (2000).



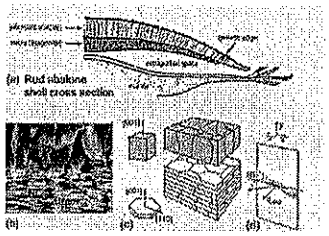
www.biomimetics.org.nz

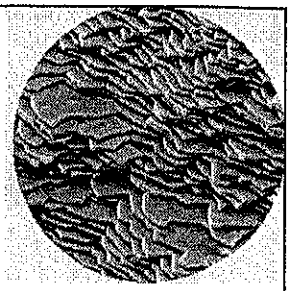
Natural Fibres

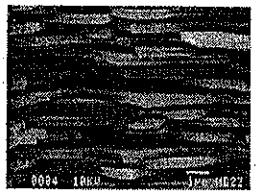
A fibre, stronger than steel, more extensible than Kevlar, completely recyclable and in contrast to current techno-polymers, spun at ambient temperatures, low pressure and with water as solvent…



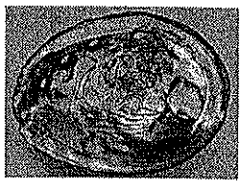








Abalone shell pictures

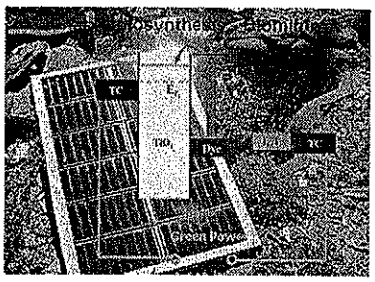


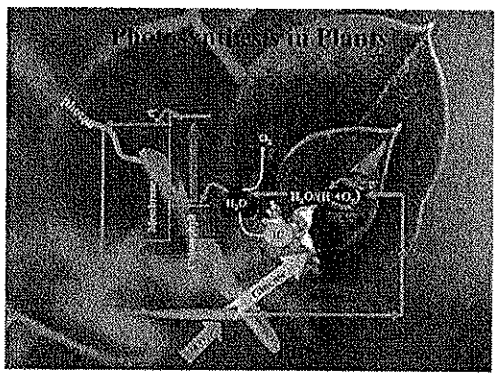
http://www.solids.bnl.gov/~dimasi/bones/abalone/index.html

http://www.treehugger.com/files/2005/03/abalone_shell_s.php

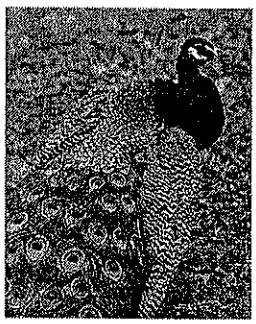
http://www.princeton.edu/~cml/html/research/biocomposites.html

Harnessing the power of the....sun





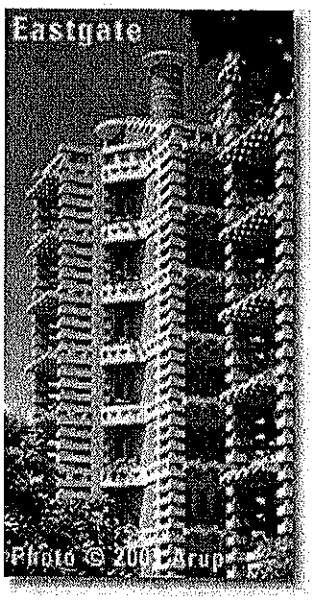
Colours.....
Not From Pigments.... Structural Colour

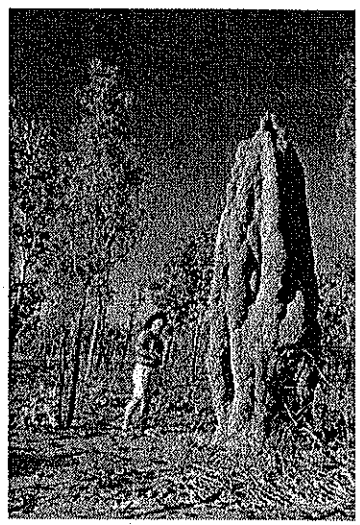


Source:http://www.tonyhill.net/peacockfeathers.ivnu

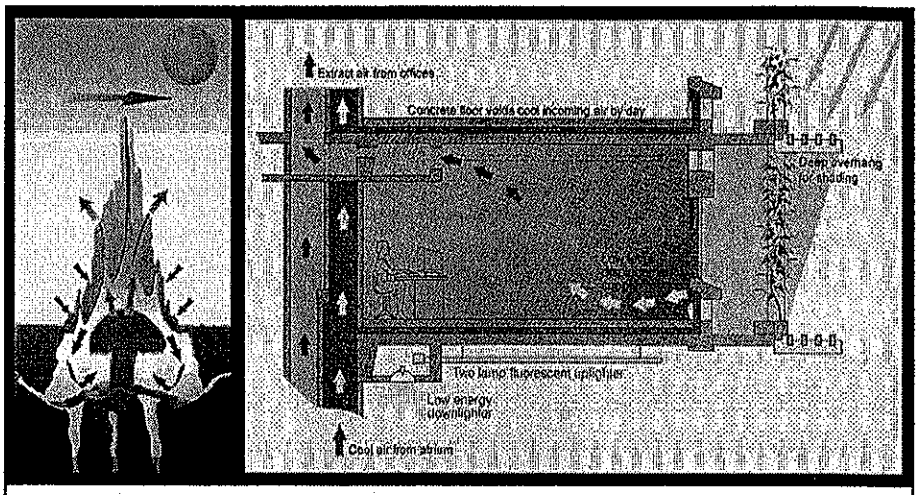


Source:http://www.auroville.org/environment/web_of_life/chameleons.htm4





Zimbabwe's largest commercial shopping complex



East Gate Building (Zimbabwe)
- Idea from termite mound
- Adaptive ventilation
- Building mass Cooling

Eastgate project's achievement:

"The building uses less than 10 percent of the energy of a conventional building its size. These efficiencies translated directly to the bottom line:

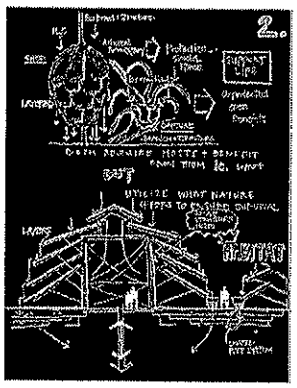
The Eastgate's owners saved $3.5 million on a $36 million building because an air-conditioning plant didn't have to be imported.

These savings were also realized by tenants: rents are 20 percent lower than in a new building next door. ...

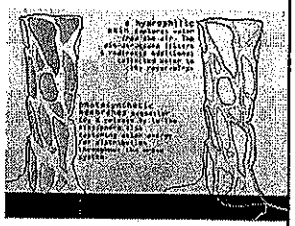
Biomimicry and Architectural Design

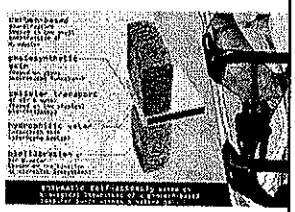
Published on GreenBizSite (http://www.greenerbuildings.com)
HOK, Biomimicry Guild Partner to Bring Nature to Cities and Buildings
September 16, 2008

The goal, according to Dayna Baumeister, the cofounder of the Biomimicry Guild, is "to move beyond just looking like nature to actually performing like nature."



The Lavasa development in India uses biological adaptations from local plants to collect water for the dry season and anchor buildings against erosion.





A proposed 'skin' for buildings was a major biomemetic component of HOK and the Biomimicry Guild's vision of future Atlanta

Envelope

Roofs :
Reflective coatings / films
Solar Roofs
Water salvage
Micro-windmill
Moisture Control : smart vapor retarder
...

Windows – Glazing
Doors - Shutters
Low U /Low e
Selective Glazing
Chromogenic glazing
Self Cleaning
Anti-condensation
Vacuum Glazing
...

Facade – Cladding
Active Facade
Double Skin Facade
Solar Façade
Mobile Facade
Active Acoustic
Sensors / Monitoring
Selective coatings
Prefabricated Panel
Vacuum Insulation
PCM
Self-Repairing ...
...

External Walls :
Vacuum Insulation Panel
Phase Change Materials
"Polar Bear like" insulation
Solar Walls
...

Coverings :
Self cleaning / Anti graffiti
Anti-bacteria
Water/Oil repellent
Dirty-Resistant
"Chameleon like"
" Lotus" effect
Dust resistant
Corrosion resistant
....

Floors - Ceilings - Finishing
Self cleaning
Anti-slippery
Anti-bacteria
Amenity materials
HVAC integration
...

Re-Thinking?
Flow of service

- From physical possession to functional needs
- Focus on the service or utility to be obtained from a product rather than on a product itself
- De-materialization

Greening the Materials for Building and Construction – Part 1

Wong Chung Wan
Director
MAEK Consulting Pte Ltd

Introduction

In his paper presented at the 2001 Conference of the Canadian Society for Ecological Economics (CANSEE) at the McGill University, Montreal, Brian Milani had said that materials are the stuff of economic life in our industrial world. They include the resource inputs and the product outputs of industrial production. How we handle them therefore is a major determinant of real economy efficiency, and also has a major impact on our health and the health of the natural environment.

Buildings world wide, have been well known to consume large amount of our natural resources of up to 3 billion tons of raw materials each year or 40% of total global use, followed by transportation. (Roodmand and Lenssen, 1995) Materials have therefore been well touted as the building block of buildings.

Aside from the needs to cater to increasing housing demands in response to growing population and urbanization programs especially in developing countries, buildings are being put up to feed the economical growth from offices to factories and iconic structures that scrapes the skies to symbolize the arrival of a nation. The sheer size and mass of these structures invariably results in high amount of materials consumed per capita as compared to say electronic products, especially in the wave of miniaturization and nano-technology. Inevitably therefore, materials and the management of their applications should constitute a major component in any sustainable design and green buildings. This is especially so in the light of rapidly changing environment, varying occupancy profile and shift in land use and plot ratio. We have seen before our very eyes, though in disbelief amongst environmentalists, demolition of "not-too-old" buildings, alteration of structurally sound facades and replacement of architecturally "outdated or out of fashion" finishes. Many were carried out not because of technical or safety reasons but rather to replace the perceived obsolete aesthetics. Many were also unfortunately not done with sufficient due considerations given to the future replacement cycles, be it for technical, economical or aesthetical reasons.

Defining Green Building Materials

In order to adequately address the sustainability of the materials to be incorporated into any buildings, a detailed understanding of "Green" building materials is necessary. With the myriad varieties of materials used in buildings today and equally inundating claims of being green, deciding and selecting sustainable materials and products is obviously not a simple task. Specifiers would need to look out for "Greenwashing", misleading environmental claims, vague declarations and multitudes of environmental jargons such as recycled content, recyclable, post industrial

content, post consumer waste and renewable – terms that are not conventionally and traditionally understood by the specifiers.

How then can we best define Green Building Materials? Perhaps Milani had put it very succinctly when he said that a green material is one that simultaneously does the most with the least, fit most harmoniously within ecosystem processes, helps eliminate the use of other materials and energy, and contributes to the attainment of a service-based economy. The definition of Green Building Materials is therefore very broad and encompassing and there are many ways in which they can be classified. A universal and common understanding on the definitions of green material is important as it helps purchasers in selecting appropriate products for their intent and objectives as well as manufacturers wanting to make their products greener. One approach is to classify them plainly as being resource efficient and healthy. Table 1 below gives an outline of criteria under each of these two headings.

Table 1: Green Material Criteria

Resource Efficient	**Healthy**
▪ Durable ▪ Salvaged for reuse, refurbished, remanufactured, or recycled ▪ Easily recyclable or reusable when no longer needed ▪ Manufactured from a waste material (such as straw or fly ash) or a waste-reducing process ▪ Sustainably harvested from a renewable resource ▪ Minimally packaged and/or wrapped with recyclable packaging ▪ Reduce or eliminate the need for another material (e.g., panel construction, or finished concrete flooring) ▪ Extracted and processed locally ▪ Energy efficient or conserving in use ▪ Use less energy in extraction, processing, and transport to the job site (Low in embodied energy) ▪ Renewable energy generating ▪ Water efficient or conserving	▪ Zero or low emissions of toxic or irritating chemicals ▪ Moisture and mold resistant ▪ Low maintenance and require no toxic cleansers ▪ Able to filter indoor pollutants ▪ Emit no volatile organic compounds (VOCs), particularly indoors ▪ Able to monitor for indoor pollutants or poor ventilation (such as carbon dioxide and carbon monoxide detectors) ▪ Manufactured with a low-pollution process ▪ Free of toxic materials such as lead, mercury, and arsenic ▪ Manufactured with a low-pollution process and from non-toxic components ▪ Not ozone depleting (free of HCFCs and halons)

Another excellent example of definition of Green Materials or Product, has been developed under the Greenspec® directory by BuildingGreen, Inc., USA. A summary of Product Standards for

GreenSpec is given in table 2.

Table 2: Summary of Product Standards for GreenSpec

1. Products Made with Salvaged, Recycled or Agricultural Waste Content
   a. Salvaged products
   b. Products with post-consumer recycled content
   c. Products with pre-consumer recycled content
   d. Products made with agricultural waste material

2. Products that Conserve Natural Resources
   a. Products that reduce material use
   b. Products with exceptional durability or low maintenance requirements
   c. Certified wood products
   d. Rapidly renewable products

3. Products that Avoid Toxic or Other Emissions
   a. Naturally or minimally processed products
   b. Alternative to ozone-depleting substances
   c. Alternative to hazardous products
   d. Products that reduce or eliminate pesticide treatments
   e. Products that reduce storm water pollution
   f. Products that reduce impact from construction or demolition activities
   g. Products that reduce pollutions or waste from operations

4. Products that Save Energy or Water
   a. Building components that reduce heating and cooling loads
   b. Equipment that conserve energy and manages loads
   c. Renewable energy and fuel cell equipment
   d. Fixtures and equipment that conserve water

5. Products that Contribute to a Safe, Healthy Built Environment
   a. Products that do not release significant pollutants into the building
   b. Products that block the introduction, development, or spread of indoor contaminants
   c. Products that remove indoor pollutants
   d. Products that warn occupants of health hazards in the building
   e. Products that improve light quality
   f. Products that help noise control
   g. Products that enhance community well-being

Within the local construction fraternity, the use green building materials and products have been increasing especially since the launch of the Building and Construction Authority Green Mark Scheme for buildings. The green materials and products available locally today include water saving plumbing, energy savings electrical appliances, low volatile organic compounds emissions

paint, coating, adhesive and wood products, materials with recycled (waste) content etc. Such products are generally certified under the respective labeling scheme by the National Environmental Agency (NEA,), Public Utilities Board (PUB), the Singapore Environment Council (SEC) and more recently the Singapore Green Building Council (SGBC).

The different definitions of green materials and products as shown demonstrates consistency in the classification of what constitutes sustainable materials and generally in line with the paraphrasing postulated by Milani. In brief, a sustainable material or product is one which the environmental impacts are considered over its life and that positively reduce the overall environmental impact of a building. However, though the definitions are not extraordinarily difficult to comprehend, the complexity involved in the evaluation and selection process are often misguided by the innocently simple definitions. A specific product may not be "green" or certified as green but when used in a way making the building green with reduced negative environmental impact to the performance of the building may be viewed positively. On the other hand a green product employed in dumb ways without due care and understanding on the durability, technical performance and maintenance resulting in wastage and poor service life is certainly not sustainable. Definitions of green materials and products such as those given here usually refers to the products in isolation and generally do not include how a product is used in a building or to make a building green, but rather merely what makes a product green. In order to better understand the appropriate use of a green material, it is essential to understand the relationships involved – in nature, in the economy and between nature and the economy. The equation however, is constantly changing and it is anticipated that the definitions and "standards" for green products will continually change with new information, research data, design concepts and performance requirements. Whilst it is certainly important to look closely at every individual product and material, it is often more efficient to look first at the building system. The eventual objective in trying to create a green building calls for matching of the products to the specific design to minimize the overall environmental impact while at the same time meeting the owners' environmental (and social) and financial agenda.

With the different and wide ranging criteria for defining green material or product, it is extremely difficult to fully quantify the environmental impact of the various materials or even similar materials from different manufacturers. As a result, we find ourselves comparing apples to oranges as we try to weigh the resource extraction impact with indoor air quality impacts and the energy required in use in the building after installation of a product. Meanwhile a product may have high environmental impact during manufacture but lasts much longer than a greener product. However, the expected service life of the building is not known or whether if such durability is required.

As for other material such as cement and the corresponding cement-based products for instance tiles adhesives and pre-packed rendering systems, it may be difficult to accord green certification because of the inherently energy intensive manufacturing (of the cement). Due to the distinct advantages of cement and the associated products, cement is one of the most versatile and durable construction materials known to man – it is economical, easily worked on and durable. At least for the moment, it is not imaginable that cement and its products can be totally replaced in building construction. "Green" certification may thus be given for concrete and cement based products that

had been manufactured with significant efforts to reduce the high energy consumption in manufacture or the high embodied energy of the products such as the use of blended cement that incorporates post-industrial waste (notably ground granulated blastfurnace slag and fly ash), improved efficiency of the kilns, use of renewable energy, recycling of waste (e.g. heat) and use of recycled aggregates (e.g. copper slag).

In addition to the defined criteria for green product or material given herein, there are other strategies which one can adopt in determining the level of "greenness" to suit the specific needs. These generally involve Life Cycle Assessment, which may cover specific environmental impact for instance carbon footprint and global warming potential (GWP). This can be made on individual material, components or even on the entire project basis.

Certification and Labeling

In most construction projects, if not all, the design teams and contractors tend to take, perhaps the easiest approach in identifying and selecting "green" material or product. This is by simply picking products that had received third party and approved certification or labeling. In Singapore's context, the approved labeling for the BCA Building Green Mark certification are the Water Efficiency Labeling Scheme (WELS) for plumbing and water fixtures, Energy Labeling Scheme (ELS) for electrical appliances, and Singapore Green Labeling Scheme (SGLS) and Singapore Green Building Product Certification (SGBP) for various architectural finishes and components. Such an approach is understandable, firstly due to the often lack of time and resources during the design stage to carry out a detailed environmental assessment of the design and material in the fast track projects prevailing in the industry. Secondly, the design teams do not normally have sufficient knowledge to address the environmental assessment of the material and design options in the sea of the complexity as highlighted. Thirdly, the eventual clients such as the developers may not have specified clearly or fully the environmental objectives for and target specific to the projects, for instance the carbon footprint or the desired reduction. Finally, the simply set target of achieving the necessary "score" for the intended Green Mark rating merely requires selection of a labeled product without the need of examining the detailed environmental impact of that product or comparing with other alternatives to make the building as green as possible.

Before a product can be certified, a set of guidelines and criteria against which a product can be judged is established as a standard. A certification is then given if a product meets those criteria. There are three types of certification, namely first-, second- and third party levels, each defining the degree of separation between the certifier and the company whose product is being certified. Third party independent certification is the most robust especially if the third party has attained recognition from a national body.

Moving from certification to labeling, ISO defines different types of labels that can be used for product, depending on what is claimed, as follows:

- Type I: Multiple attribute set of predetermined requirements

- Type II: Single attribute environmental claims (energy consumption, emissions, recycled content)
- Type III: Comprehensive and detailed product information

The Energy Label and Water Efficiency Label are examples of single criteria labeling whilst the Singapore Green Label is based on multi criteria and attempts to evaluate total environmental impact with a comprehensive pre-set requirements. Other types of certification from overseas commonly encountered locally from suppliers include the single attribute certifications like the Forest Stewardship Council (FSC) certification and Greenguard, and multiple attribute eco-label such as the Germany's Blue Angel, Australia's Good Environmental Choice and Japan's Eco Label. These however at the moment are not accorded points under the BCA Green Mark Scheme. It is foreseeable that there will be increasing pressure to mutually recognize other eco-labels but the platforms on which these other certifications are awarded are uncertain. In any case, it is worth to note that not all certifications are equally reliable, none are truly comprehensive and they do not cover all aspects of products including performance.

Presently under the Singapore Environmental Council SGLS and SGBC's product certification, there are long lists of categories for labeling which, for construction related, include cement and precast concrete, brick, tiles/ceramics, panel boards, paints and surface coatings and products made from specified minimum recycled content. There are different types of criteria for each of these categories ranging from the use of municipal solid waste, fly ash, used copper, steel and/or iron slag, use of non toxic materials, low emissions of volatile organic compounds and products from recycled or renewable fibres. SGBC has put in a commendable effort in developing a multi-criteria analysis consistent with the Green Mark assessment and yielding a varied tier of product certification under the SGBP scheme. Depending on the amount of credits earned from each product and applicant, different level of "greenness" is accorded and recognized accordingly. This allows suppliers and buyers to differentiate greener products from amongst those certified. The wide ranging types of building products that had been certified under the SGLS and SGBP are bamboo, architectural paint, waterproofing membranes, composite wood panels, timber decking, door panel, ceiling board, wardrobe, laminate wood flooring, plasterboard and insulation materials. More information can be found from www.sec.org.sg and www.sgbc.sg

There is no denying that many professionals will invariably rely on certification and labeling in selecting green products. However, certification and labeling should be just one tool for evaluating green product - only **one of the** criteria for selection and not **the only** criteria as is the case now.

(This is a 2 part article – part 2 will touch on the relationship between 'green' products or

materials and green building certification such as the Green Mark and LEED certification as well as the process of selection itself)

References and Relevant Resources

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4. J. Atlee and T.K. Altes, Behinnd the Logos: Understanding Green Product Certifications, Environmental Building News, January 2008
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Greening the Materials for Building and Construction – Part 2

Wong Chung Wan
Director
MAEK Consulting Pte Ltd

Eco-Labeling and Green Building

Having discussed the various definitions and labeling of green materials and products for buildings, the next instinctive question commonly raised is how would such labeling contribute to a Green Building? How will it lead to a Greener building? Or what credits can be earned from the use of such materials? These, though are practical questions, are often taken with limited perspective within a very narrow view of simply trying to score points to achieve the desired green ratings for the building.

In Singapore, the Building and Construction Authority's (BCA) Green Mark Scheme for buildings have been put in place since 2005 with the latest revision made in early 2008. In April 2008, it is in fact mandatory for all new buildings, existing buildings undergoing additions or extension or existing buildings undergoing major retrofitting with gloss floor area of more than 2,000 m2 to be at least Certified under the Green Mark Scheme. This scheme is therefore, most commonly used locally for green building design. There is however, increasing interests and requests for certification of green building under the United States Green Building Council's (USGBC) scheme – Leadership in Energy and Environmental Design (LEED), either as an alternative or in addition to the Green Mark. This trend is attributed to growing demand from Multinational Corporations, whose corporate objectives emphasize on environmental sustainability and Corporate Social Responsibility (CSR). How then would the selection and use of eco- or green-labeled products contribute to these certifications?

Under the BCA Green Mark Scheme, points are accorded for the use of labeled products and materials, the quantum which may be given depend on the impact of their uses. More points will be given if the products or materials are used extensively throughout the development as compared to just the common areas. Presently there are two categories for the Green Mark, namely Residential and Non-Residential Building, both for new construction. The scheme for Existing building has yet to be officially launched at the time of writing. The list of possible points for the use of eco-labeled products and materials under the Green Mark is given in tables 1 and 2. For actual computation of scores especially with regards to the weightage and assessment of the impact, reference can be made to the Code of Environmental Sustainability of Buildings Version 1 published by BCA.

LEED on the other hand works on different point allocation formula; some are given based on performance of the building or design whilst others are prescribed simply for the use of labeled or declared materials or products. A summary of the main points that can be attained directly from the use of a labeled or declared product or material under LEED New Construction is given in

table 3. As can be seen, these generally fall under the categories of Materials and Resources and Indoor Environmental Quality. Other labeled products such as energy efficient appliances and air conditioning systems as well as water saving plumbing and fixtures will not result in direct accumulation of credit points. Instead, points can only be secured in the overall savings in the energy demand and reduction in the consumption of potable water. The greater the savings, the higher the points that can be attained subject to the cap as described in the LEED requirements. For further details and explanation of the requirements, scoring and computation of the scores, reference to the LEED Reference Guide published by the USGBC should be made.

Product Assessment and Selection

With available information now on the definition of Green materials and points available for the Green Building scheme, it would seem that assessment and selection of a Green product is rather straight forward, that is, if the objective is simply to secure the credit points. A proper selection of environmental preferred materials unfortunately (or fortunately) is not merely to look at the credit points and make selection accordingly. Quite often, the selection process can be rather complicated. For instance, we may be staring down two different flooring: a composite wood made up polyethylene and waste wood chips and bamboo (rapidly renewable). Both have been eco-labeled and give the same amount of credit points when used. Aside from the cost which can vary depending on the source, how are we then to make the selection?

One frequently cited approach is the use of Life Cycle Assessment (LCA). LCA addresses the environmental performance of the products from cradle to grave, extending from the stage of extraction of raw materials through the manufacturing and transportation, packaging, useful life and the eventual disposal and/or recycling. However, the whole process of LCA can be very extensive involving enormously massive amount of data across the whole extraction, transportation and manufacturing process in evaluating the environmental impact arising from the product. Different analysts use different environmental parameters across different countries but these factors are broadly consistent as they serve to address the environmental issues. The main environmental factors that consistently appear in most LCA are Global Warming, Fossil Fuel Depletion, Ozone Depletion, Human Health (Human toxicity), Water Extraction, Ecotoxicity, Eutrophication and Waste Disposal. Out of this inundating list of issues, the chief parameters in most assessment are global warming and fossil fuel depletion, which account for at least 50% of the weightage in most LCA.

The analysis of a product is a 3 step process. The first is the Research stage where data is collected on the raw materials whether they are virgin, renewable or recycled, durability and maintenance requirements of the finished products, the manufacturing process and location, transportation, disposal strategy, costs (first and second), indoor air quality test data and the material safety data sheets (MSDS). This is then followed by the Evaluation stage – a stage where LCA comes into play. During this stage, the environmental burdens associated with the product, process and activity are identified and quantified. The burdens include energy used, materials used and wastes released and their impact on the environment, whether in a positive or negative way. The former addresses potential opportunities to improve the environment. Though it is ideal in any analysis to

cover the whole life of the component from cradle to grave, which include the use of the component in buildings and its final end life disposal, this is not always possible or easily undertaken at the point of manufacture or design. In fact carrying out the LCA itself is not a task that can be performed by architects and building designers alone

As the amount of information involved in an LCA is massive, there are established tools or program, most of which come with in-built database, that assist in the evaluation and selection of products. Examples of these tools include the Building for Environmental and Economic Sustainability (BEES), ATHENA, LCAid, ENVEST and SimaPro7. Each tool has its own unique approach, design and set of outputs. Whilst the outputs of most of these tools cover the various environmental factors mentioned earlier, some programs meanwhile provide a single output in the form of carbon footprint, based on materials used or by types of building elements. It must be appreciated that the information produced by the LCA tools is no always valuable as stand-alone data. The data would need to be coupled with other information since the LCA data is not an absolute measure of a product value. In addition, the input data is sparse and includes many assumptions that are hidden from the LCA tool user. Though some flexibility is offered in some of the tools to allow the user to vary the weightages to the different environmental parameters to suit the specific objectives, the database incorporated within these programs are derived based on the processes and materials available in the country of origin of the program and thus may not be applicable in Singapore's context. Output of the LCA is also significantly subjected to the veracity of the data available or furnished by the manufacturer or sources. The service life and its impact on the performance of a building on the other hand may not be fully determined at the design stage due to the interplay of a multitude of other influencing factors. To some practitioners, it is at best an academic exercise.

Nevertheless, LCA is a powerful tool in carrying out both an environmental assessment and economic performance of materials and components to allow the user to at least understand the environmental impact of the products and compare between different products. In a recent gathering in 2001 of international experts in Baltimore, USA, issues and the current state of LCA tools were discussed focusing on ways in which these tools affect and concern the building industry. Recommendations were also made to improve and increase the use of CLA tools in future.

In the meantime, an alternative and simpler approach to a fully quantitative LCA, which we have found to be particularly helpful, is the Environmental Assessment Matrix. In this approach, the first 2 stages of the assessment are the similar as described above. In the final stage, the key to material selection is identifying the Goals which the client would view as important according to his corporate environmental objective. These goals include costs, aesthetics, durability, recycled content, maintenance, recyclability etc. Thereafter the goals are prioritized and weightages assigned to them, and scores given to the materials under evaluation. This is a semi quantitative method and best used for comparing at least 2 different types of materials or manufacturing source of similar materials. It can be executed easily in any project and allow the project team a more comprehensible approach towards an environmental assessment.

Beyond Product Evaluation

Fundamentally, in Sustainable Development, the process of selection a product for purchasing does not begin and end with evaluation of the product and costs itself. The environmental performance of the sellers and manufacturers must also be subjected to scrutiny. What are their environmental policies? Are they incessantly reducing the environmental impact of their products, manufacturing process and business dealings? Are they tracking and setting a target for such an improvement, and are they on track in meeting the target?

The purchasers themselves could well institute an Environmentally Preferable Purchasing program, similar to that drawn up by the Environmental Protection Agency (EPA) of the USA. The guide can assist the buyers in the evaluation, addressing for instance environmental performance index and multiple attribute assessment.

Final Remarks

At the end of the day, a green material is not just simply about the label. Neither is it merely concerning the product or material per se. Greening the material is as much a process as it is about the hardware – the process in setting up an environmentally responsible purchasing guide, the process in evaluating the performance- both environmentally and economically, the process of optimizing the use of materials, whether green or otherwise and the process of inculcating the environmental objectives to the entire supply chain such as the product and service providers.

Table 1: Residential Building

Credit	Section	Description	Green Mark Points
RB 1-2	Dwelling Unit Indoor Comfort	Use of energy efficient air conditioners that are certified under the Singapore Energy Labeling Scheme	Extent of coverage: at least 90% of the air conditioners used in all dwelling units: Two ticks – 2 points Three ticks – 6 points Four ticks – 12 points
RB 2-1	Water Efficient Fittings	Use of water efficient fittings that are certified under the Water Efficiency Labeling Scheme (WELS): a) Basin taps and mixers b) Flushing cisterns c) Showerheads, taps and mixers d) Sink/Bip taps and mixers e) All other water fittings	Extent of coverage: at least 90% of the fitting type used (up to 10 points) Good: 0.5 point V. Good: 1 point Excellent: 2 points
RB 3-1	Sustainable Construction	Use of sustainable materials and products in building construction such as: i) Environmentally friendly products that are certified under the Singapore Green Labeling Scheme (SGLS) ii) Products with at least 30% recycled content by weight of volume (applicable only to non-structural elements) *Note: For products that are certified under SGLS and with at least 30% recycled content, points can only be scored either from (i) or (ii) above.*	1 point for high impact item 0.5 point for low impact item (Cap at 3 points) 1 point for high impact item 0.5 point for low impact item (Cap at 3 points) (Up to 6 points)
RB 4-2	Indoor Air Pollutants	Minimize airborne contaminants, mainly from inside sources to promote healthy indoor environment a) Use of low volatile organic compound (VOC) paints certified under the SGLS b) Use of adhesives certified under the SGLS for composite wood products	Extent of coverage: at least 90% of the total internal wall areas. 2 points 1 point

Table 2: Non Residential Building

Credit	Section	Description	Green Mark Points
NRB 2-1	Water Efficient Fittings	Use of water efficient fittings that are certified under the Water Efficiency Labeling Scheme (WELS):	Points scored based on the number and water efficiency rating of the fitting type used (up to 8 points) Weightage: Good: 4 point V. Good: 6 point Excellent: 8 points
NRB 3-1	Sustainable Construction	Use of sustainable materials and products in building construction such as: i) Environmentally friendly products that are certified under the Singapore Green Labeling Scheme (SGLS) ii) Products with at least 30% recycled content by weight of volume (applicable only to non-structural elements) *Note: For products that are certified under SGLS and with at least 30% recycled content, points can only be scored either from (i) or (ii) above.*	1 point for high impact item 0.5 point for low impact item (Cap at 4 points) 1 point for high impact item 0.5 point for low impact item (Cap at 4 points) (Up to 8 points)
NRB 4-2	Indoor Air Pollutants	Minimize airborne contaminants, mainly from inside sources to promote healthy indoor environment i) Use of low volatile organic compound (VOC) paints certified under the SGLS ii) Use of adhesives certified under the SGLS for composite wood products	Extent of coverage: at least 90% of the total internal wall areas. 1 point 1 point

Table 3: LEED New Construction

Credit	Description/Requirements	Points
MR 4.1	Recycled content: 10% (post-consumer + ½ pre-consumer) *Recycled content shall be defined in accordance with the ISO 14021 – Environmental labels and declarations – Self-declared environmental claims (type II environmental labeling)*	1
MR 4.2	Recycled content: 10% (post-consumer + ½ pre-consumer) *Recycled content shall be defined in accordance with the ISO 14021 – Environmental labels and declarations – Self-declared environmental claims (type II environmental labeling)*	1 point in addition to MR Credit 4.1
MR 6	Rapidly renewable materials Use rapidly renewable building materials and products (made from plants that are typically harvested within a10-year cyle or shorter) for 2.5% of the total aluve of all building materials and products used in the project, based on cost	1
MR 7	Certified wood Use of a minimum of 50% of wood-based materials and products, which are certified in accordance with the Forest Stewardship council's (FSC) Principles and Criteria	1
EQ 4.1	Low-emitting materials; Adhesives and sealants	1
EQ 4.2	Low-emitting materials: Paints and coatings	1
EQ 4.3	Low-emitting materials: Carpet Systems	1
EQ 4.4	Low-emitting materials: Composite Wood and Agrifiber Products	1

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Ecology of Building Materials

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What happen to buildings after they are built?

It is a question hardly asked from design to construction and during occupation of the building. It is an issue often beyond the responsibility of the designers and contractor. For many developers, especially those who build and sell the asset, the life of the buildings are hardly taken into consideration as they do not carry the baggage of the works. Even for those who build and own, including ensuring proper maintenance, the fate of the building and the components during the serviceable life are ignored right from the initiation of the project. The phenomenon is exacerbated by the reasonable ease with which the buildings can be demolished and rebuilt with higher commercial yield. This is particularly acute in land scarce and highly urbanized development. There is invariably a school of thought that non-efficient utilisation of land due to low density housing or commercial use should be redeveloped to intensify the use so that virgin landscape can be preserved. Hence, the "justification" for demolition and reconstruction. Whilst such notion is not without merit, the buildings and in particularly the building components should be better optimized.

Recent trends suggest that buildings undergo renovation and "rejuvenation" in increasing frequency, specifically involving architectural finishes and fittings, not always due to failure of the components but because of aesthetic obsolescence. Some are even carried out within the first 2 years of being constructed simply because the new owner does not like the finishes or they do not fit into the corporate theme or design. Such activities, including upgrading and retrofitting of buildings are expected to grow immensely in coming years given the dynamic economic environment today but more significantly to the push to "green" 80% of all buildings in Singapore. Understandably some existing and older buildings may not have been designed and constructed be to energy efficient and environmentally friendly, and there is a need to improve their performances to ensure long term sustainability. However, before one embarks full scale into the tsunamic movement, the inquiry of what happens to the retrofitted building and its components should be raised. Since buildings are well known to consume up to 40% of the world's raw resources, the ecology of the materials used in their construction from manufacture to their service life and finally end of life options need to be seriously considered. The whole ecology of the building materials need to be better understood. This includes specifically in the case of building retrofit, the cycle of the materials after they are removed from the buildings, for instance whether they are recycled, re-used or disposed off. Figure 1 illustrates the possible cycle of materials from manufacture to the end of use.

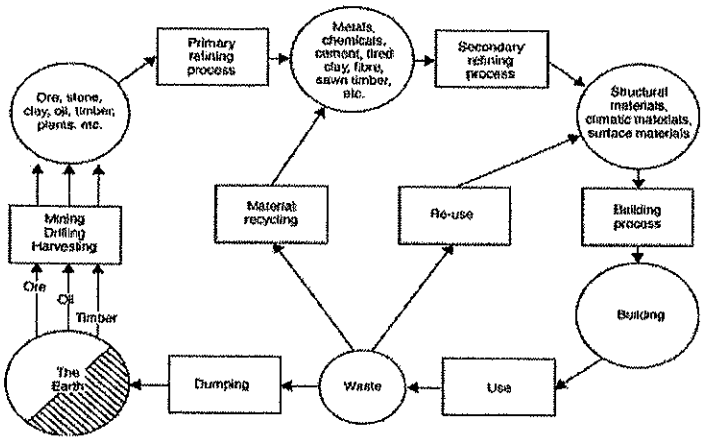


Figure 1: Cycle of Materials (source [1])

The Footprint

In order to understand the environmental footprint of the various materials that goes into buildings, the flows of resources and emissions across them from extraction of the raw resources to manufacture of the materials and product and finally to use and disposal need to be analysed. This can be done through the use of Life Cycle Assessment (LCA) protocol. See Figure 2.

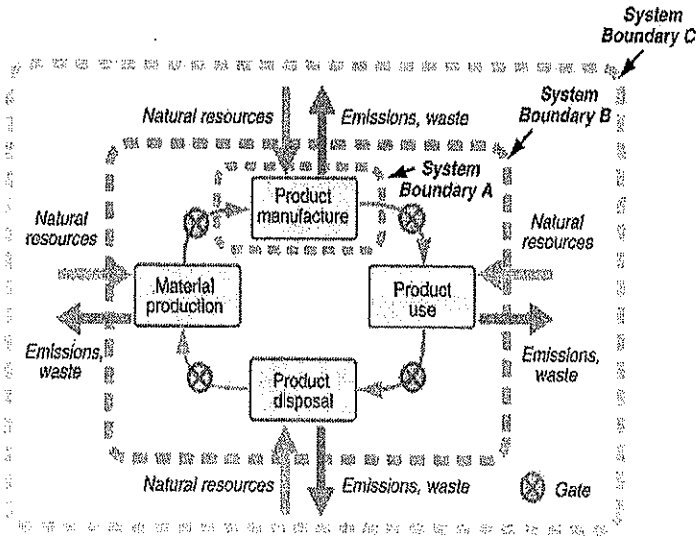


Figure 2: LCA system boundaries with the flows of resources and emissions across them (Source [2])

Some typical characteristics environmental profiles of common building materials should be appreciated. Amongst the various classifications of materials used in buildings, ceramic is the most widely used and it is dominated by concrete in terms of mass of about 84%. The chief environmental concern about the use of concrete is Portland cement due to the high carbon

footprint and energy intensive manufacture. Cement production contributes up t 10% of the world's total CO2 emission. Metals in particularly steel and aluminium which are widely used in buildings are notorious for their high embodied energy and environmental impact. The latter arises from the extraction of the ores. However, metals generally have very high potential for recycling and significantly reduce the embodied energy and green house gas emission as compared to the use of virgin ores. See table 1. Not surprisingly the recycling rate of metal is the highest amongst all the other construction materials.

Table 1: Primary Energy use for the production

Metals/alloys	From the ore (MJ/kg)	50% recycling	100% recycling
Aluminium	165-260	95	30
Copper	80-127	55	
Steel	21-25	18	6-10
Zinc	47-87		

Plastic is the centre of the petrochemical industry and is once touted as the new engineered materials whereby their composition can be concocted properties engineered to suit myriads of applications. However, the popularity of plastics had been marred by concerns with heir eco-toxicity potential. The presence of bisphenol A in epoxy and the isocyanate in polyurea for instance are known carcinogenic. The most infamous amongst them is perhaps polyvinyl chloride (PVC), a product very widely used in buildings from pipes to tiles due to the chlorine compound. Chlorine, originally considered a waste by product from caustic soda production, is a highly reactive chemical that must be combined with other materials. Chlorine compounds are found in nature - the obvious example is sodium chloride, or common salt. But chlorine manufactured by the chloro-alkali process is quite different. This chlorine gas is highly reactive and it must therefore be combined with organic compounds (material containing carbon), and creates organochlorines, which are so rare in natural systems that living organisms cannot cope with them when they enter the ecosystem.

Yet in only a few decades, the modern chemical industry has distributed millions of tonnes of organochlorines per year into our environment. The whole process represents an environmental catastrophe on the largest possible scale. During the 1930's, large amounts of chlorine became available in Nazi Germany as a consequence of a programme meant to make Germany independent of imported cotton in case of war. This programme concentrated on the production of rayon, and to this end large amounts of caustic soda from the chlor-alkali industry were needed. After years of experimenting with stabilisers, lubricants and softeners, it was found that fibres could be made from PVC; these had the added bonus of using up the excess chlorine produced by the expanded chlor-alkali industry. What had previously been a toxic waste by-product of caustic soda manufacturing now became a marketable commodity.

PVC remains the most attractive plastic commercially due largely to the lower embodied energy. See table 2. The toxicity of the chlorine compound however remains and grows with

the popularity of PVC. The toxic waste has been carried from one product to another and not eliminated and while we had solved one problem, we have created perhaps a bigger one.

Table 2

Polymer	Embodied energy (MJ/kg)
Low density polyethylene (LDPE)	80.5
High density polyethylene (HDPE)	79.9
Expandable polystyrene (PS)	83.7
Polyvinyl chloride (PVC)	65.2
Acrylonitrile butadiene styrene (ABS)	95
Polycarbonate (PC)	116.8
Epoxy resins	140.7

Similar to metals, plastics have high potential for recycling but the current rate for recycling is very low due to the lack of facilities and difficulty in sorting them out because of the addition of other compounds such as fibres, talc, glass etc.

Shearing the Layers

Some of the materials may be used until the end of their service life whilst others may not for various reasons. The removal of one component which is intended to be changed can inevitably cause destruction another component which is in good serviceable condition. Often, the environmental burden of the latter outweighs that of the former. An example is the hacking out of marble tiles, the bedding adhesive and substrate just to lay a new waterproofing membrane in wet areas. This underpins the lack of forward thinking on the performance and lifespan of different layers of a building.

This brings us to the concept of Shearing Layers, first coined by architect Frank Duffy and later expanded by Stewart Brand [3]. The Shearing layers concept views buildings as a set of components that evolve in different timescales. See also figure 2. The layers are:

Site

This is the geographical setting, the urban location, and the legally defined lot, whose boundaries and context outlast generations of ephemeral buildings. "Site is eternal."

Structure

The foundation and load-bearing elements are perilous and expensive to change, so people don't. These are the building. Structural life ranges from thirty to three hundred years but in Singapore, few buildings make it past 50 for other reasons

Skin

Exterior surfaces now change every twenty years or so, to keep up with fashion or technology, or for wholesale repair. Recent focus on energy costs and greening of existing buildings has led to re-engineered skins that are air-tight and better-insulated.

Services

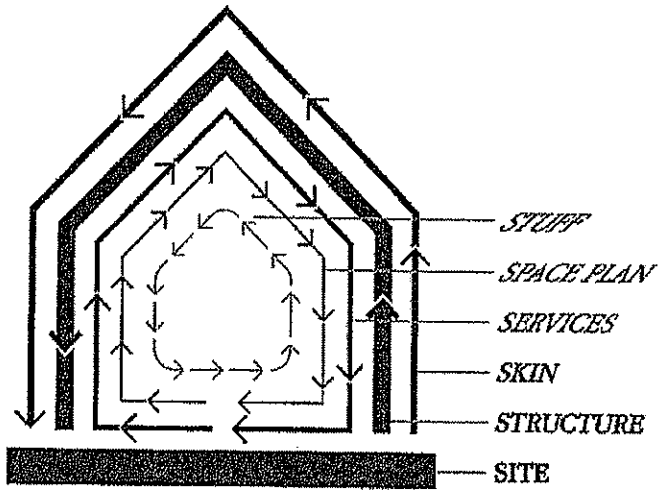
These are the working guts of a building: communications wiring, electrical wiring, plumbing, fire sprinkler systems, ACMV (air conditioning and mechanical ventilation), and moving parts like elevators and escalators. They wear out or obsolesce every seven to fifteen years. Many buildings are demolished early if their outdated systems are too deeply embedded to replace easily.

Space Plan

The Interior layout—where walls, ceilings, floors, and doors go. The dynamic economical forces have often result in short turn-around of tenants of commercial space, which can change every three years or so. These interior finishes thus have very short use-span though some of the materials can inherently have very long life-span.

Stuff

Chairs, desks, phones, pictures; kitchen appliances, lamps, hairbrushes; all the things that twitch around daily to monthly. Furniture is called *mobilia* in Italian for good reason.



SHEARING LAYERS OF CHANGE. Because of the different rates of change of its components, a building is always tearing itself apart.

Figure 2 (Source [3])

The Myth of Recycling

In the design and construction of buildings, to optimize the use of materials sustainably, there is a need to shear the layers of the building and design the replacement strategies accordingly. Otherwise it could lead to unnecessary wastes as seen in the example of the marble tiles in

wet area, typical of hotels for instance. Unfortunately, many owners and contractors alike veiled the guilt by faithfully diverting the waste, which in this case the marble tiles, bedding adhesive and cementitious substrate like screed and plaster, from landfill. These materials often with high environmental footprint are condemned to re-use as hardcore or as fillers for lower end construction products. The marble could have been mined and shipped from Italy whereas the Portland incorporated into the adhesive and substrate is well known for its high carbon footprint and energy intensive manufacturing process. They are technically not recycled but instead down-cycled for they are no longer used as high end products as originally intended. Despite having a service life of at least 60 years, these materials with much greater mass and environmental footprint have been unduly sacrificed because of the limited service life of the thin waterproofing membrane.

Re-thinking and re-designing is in order. The challenge should be to ensure that at the end of the service or use life of a component, it should be able to be re-use as or a raw material for another or similar product of equal value. There is no concept of waste and the cycle should be from cradle to cradle as promulgated by William McDonough [4]. This brings us to the concept of design and construction that are de-constructable, just like the LEGO toys or IKEA furniture. There is also a question as to whether the component is recycled to another building product, reused back in buildings or simply salvaged into say, a decorative display.

De –Construction

There are increasingly designs that allow the components to be removed when not required and reused or easily replaced. The principles of the design for de-construction also synergistically improve the constructability or buildability. Some of the common principles are: [5]

- Design for prefabrication, preassembly and modular construction
- Simplify and standardize connection details
- Simplify and separate building systems
- Consider worker safety during deconstruction and construction
- Minimize building components and materials
- Select fitting, fasteners, adhesive and sealants that allow for quicker disassembly and facilitate the removal of reusable materials
- Design to accommodate deconstruction logistics
- Design to reusable materials
- Design for flexibility and adaptability

With regards to the above principles, consideration should be given to the shearing layers to separate the building systems. The use of dry construction method such as mechanical fixing instead of cement based adhesive as in the case of tiling works for instance could facilitate removal and reuse of the marble tiles in wet areas. Provision of safe access to dismantle and remove the components both within the building and from the building would encourage

disassembly without damaging them. The use of modular and standardize details allows the de-constructed components to be used elsewhere be it in the same building or in another project. Flexibility and adaptability in the design permits the building owners to modify the space layout to suit business expansion plans without destroying and disposal of existing finishes. In order for the materials and components to be reusable, they need to be durable and can be restored should there be superficial damages like scratches, minor blemishes and surface wear. Parts of the components that have distinctively varied lifespan should be decoupled so that parts with shorter lifespan can be changed without the need to dispose the more durable parts. This is often a dilemma in composites. Carpets for example can be produced in two layers with the top layer which is exposed to traffic and wear can be removed and changed frequently whilst leaving the bottom layer intact.

Feed-forward

While every effort may be put in place to ensure that the materials and components used in buildings are optimized with due consideration given to their expected lifespan, premature failure had often occurred. This had resulted not only in costly repair works but also a waste of precious and depleting environmental resources. Building failures have been plaguing the building and construction industry for years with enormous amount of wasteful and unproductive re-works. Lessons from past failures had been poorly documented and there is an acute lack of knowledge management. It is not surprising therefore that many failures that the industry had seen 50 years ago are still rearing their ugly head today despite all the advancement in construction technology. Glaring among them are water seepages, debonding and cracking of tiles, delamination of plaster works and paint failure.

It is high time that the field of building diagnosis and building maintenance be given their due recognition as the knowledge from these fields can be better utilised to prevent or mitigate potential failure. The professionals involved have good understanding of the performance of the constructed asset - where malfunction had occurred, where the building components failed to perform to expectation, how the problems had manifested and the implications of the failures. Their insight should be brought forward to the design table right from the project inception stage. Through the use of failure mode and effect analysis (FMEA) also at times referred to failure mode and criticality effect analysis (FMCEA), the potential failure, its mode and the effect can be forecast. (Ref [6] and [7]) The risks of the failure can then be determined and managed accordingly. This is feed-forwarding, a practice which has been applied for years by many other industries such as automotive and aerospace but only found its permeation into the construction very recently. Similarly Building Pathology (ref [8]) database and Post Occupancy Evaluation are some of the other schemes that can be utilised as part of the feed-forward exercise. With an escalating diversity of materials used in buildings today and the aggressive advent of new and improved materials, the lack of understanding of these emerging products are now leading to new mechanism and mode of failure never encountered previously.

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