Material Efficiency and the 3 Rs

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Introduction

Significant pressure is being brought to bear on material manufacturers to green the materials and products produced by industry in general – and the construction sector is no exception, for good reason. The construction industry and its products are responsible for the following environmental impacts, namely:

45% of global energy generated is used to heat, light and ventilate buildings and 5% to construct them;

40% of water globally is used for sanitation and other uses in buildings; and

70% of global timber products end up in building construction (Edwards 2002:10).

Apart from these impacts, there are other environmental impacts arising out of material use including the consequences of mining (including pollution and contamination of water, soil and air); the need for mining rehabilitation at end-of-life; the toxins, including volatile organic compounds and ozone depleting substances, produced for, used in, and emitted by the manufacturing process; and the disposal of waste products during the construction period and at end-of-life.

While green (or greener) materials should demonstrate a significant reduction in all of the above, chemicals, water and energy will still remain embodied in the material. Thus, any saving in material represents a reduction in environmental impact. Truly, the time has come to employ the phrase "less is more", a term coined by Robert Browning is the 1855 poem 'Andrea del Sarto', and later adopted by Mies van der Rohe as a precept for minimalist design.

The purpose of this chapter is to make building designers aware of how to reduce environmental impacts by improving material efficiency particularly through recycling, reuse, material substitution, maintaining existing products for longer, re-using components from unwanted products, and designing products with less material through light-weight design or dematerialisation.

Material efficiency

Material efficiency can be described as "the pursuit of technical strategies, business models, consumer preferences and policy instruments that will lead to a substantial reduction in the production of high-volume, energy-intensive materials required to deliver human well-being" (Allwood, Ashby, Gutowski and Worrell 2013). Allwood et al correctly argue that the motivations for material efficiency include reducing energy demand, reducing the emissions and other environmental impacts of industry, and increasing national resource security.

The industrial sector accounts for almost one-third of global energy demand with most of that energy required for the production of bulk materials (Allwood et al 2013). The headline figures for material resources incorporated in the built environment, and wastes and emissions generated, by the UK construction industry in 1998 (Smith, Kersey and Griffiths 2002) are as follows:

Table 1: Total resource use in UK construction industry

Resource	Consumption
Material resources incorporated in the built environment	363.4 Mt
Energy used	7.8 Mt of oil equivalent
Wastes generated	151.0 Mt
Emissions generated	28.0 Mt

To identify material efficiency opportunities the total resource use must be further broke down as shown in Table 2.

Table 2: Total material resource use in UK construction industry

Resource	Consumption
Primary materials and products	295.5 Mt
Secondary materials and products	21.6 Mt
Recycled materials and products	43.0 Mt
Reclaimed materials and products	3.3 Mt
Total	363.4 Mt

As the opportunity to achieve higher material efficiency is located in primary materials and products (it constitutes over 80% of total material resource use), a further breakdown is provided in Table 3 below.

Table 3: Total primary material resource use

Material/product	Total Used (Kt)
Quarry products	125,871
Cement, plaster, etc.	97,992
Stone and other non-metallic mineral products	43,631
Bricks and other clay-based products	5,979
Ceramic products	4,313
Fabricated metal products	3,938
Finishes, coatings, adhesives, etc.	1,447
Glass-based products	1,415
Plastic products	1,402
Cabling, wiring and lighting	190
Total primary material resource use	295,450

As can be seen from the table above, a staggering 94% of primary material resource use is ascribed to products used essentially in wet works of construction (stone, sand, cement, clay). It is unfortunately also the area most difficult to control. Although gains can be made through modular design, significant gains will only come about through changing construction methods.

While many bulk material manufacturers have taken significant steps to reduce the energy consumption of their production facilities, the reality is that further energy reductions are not really possible without a) significant technological breakthroughs with regard to these current production processes and/or, b) the development of a next-generation of bulk materials with a significantly lower energy footprint.

While both of these hold promise, reducing the throughput of virgin raw materials is a critical immediate goal in reducing energy use and emission, and a key strategy in material efficiency. Allwood et al note that there are a number of steps that can be taken to achieve this including increasing recycling, material substitution, maintaining existing products for longer, re-using components from unwanted products, designing products with less material through light-weight design or dematerialisation, and switching to renewable energy.

Recycling

Recycling is the process whereby waste materials are changed into new products or components thereby preventing the waste of potentially useful materials, reducing the consumption of fresh raw materials, reducing energy usage, reducing pollution and reducing landfill. Recycling has become a key component of modern waste reduction although it is by no means unique to contemporary society: archaeological excavations provide ample evidence of materials or products being recycled, especially during periods of scarcity.

Recycling is a fundamental part of the shift toward a green economy with its focus on zero waste. It is also the third component of the “Reduce, Reuse and Recycle” hierarchy. As noted by the Northern California Compactors “these products are recycled by converting them into items worth using for the second time. This is typically done by breaking down the product into its raw materials and reusing them to manufacture something new or similar to the old product. When customers purchase products made from recycled material, the overall environmental benefits are multiplied as less energy and resources are consumed in manufacturing these products as compared to the goods that are manufactured for the first time” (Environmental Expert 2013). Though reusing products or reducing their consumption in the first place can possibly have greater long-term benefits, recycling and composting are the perfect means of managing the discarded items and other kinds of waste. In a majority of cases, the prime difference between these two techniques pertains to the materials involved – manufactured or organic (Environmental Expert 2013).

Much of what is used in the building process can be recycled: in the Menlyn-on-Maine development in Pretoria where over 200 houses were brought down to make way for a new inner-city development, the bottom structures of the houses were all recycled through careful deconstruction rather than demolition. Foundation walls and slabs were recycled as base course for the roads and for underslab filling in the new buildings.

Regrettably, despite its potential, levels of metals recycling are generally low (UNEP 2010). In reality, the metals available in society constitute an ‘above ground mine’ which, if recycled strategically, could shift metal stock use from below ground to above ground.

The quality of the recyclates are key to the success of recycling: for example, clear glass is preferred over coloured glass for recycling, and polished steel over coated steel as the coating has to be removed first. Designers can assist the recycling process by keeping their material palette simple, for example, using polished steel or aluminium hand railing or framing rather than finishing the rail with a coating.

A higher quality recyclate is more likely to be recycled, thereby offering significant benefits including reducing environmental impact, supporting economic growth by maximising value, return higher value to the recycling industry, and boost consumer and producer confidence in the waste and resource management sector which will also encourage investment in that sector (DEFRA 2013). Protecting recyclate quality and avoiding cross-contamination is one of the reasons why green building assessment systems require that waste be separated.

As noted by the Northern California Composters, “recycling, in its own, is a very large industry that employs more than a million workers who are paid about $37 billion per year, employed by companies who are making a profit of over $236 billion every year” (Environmental Expert 2013).

Re-using components from unwanted products

Reuse is to use a component or product again, either for the same function or for a different function, after it has been used. Reuse is one of the easiest strategies aimed at decoupling natural resource use and environmental impacts from economic growth to implement. A desktop review undertaken by the CSIR (2005) indicated that substantial efforts were and are increasingly underway in South Africa in pursuit of recycling and the reuse of materials generally, and construction products specifically.

Much of what is used in the building process can be reused: in the Menlyn-on-Maine development case study cited earlier, the top structures of the houses were all reused through careful deconstruction rather than demolition. Roof tiles and sheets, all roof timbers, insulation, rain water goods, fascia boards, bricks, fenestration and doors, steel, plastic, sanitaryware, floor finishes and wall finishes were all made available for reuse[1].

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[1] In private conversation with the developer.

Table 4: The case study below is indicative of the circumstances under which reuse is optimal.

In this case study a condition of the refurbishment contract was to recover the face bricks used in the interior partitioning of the building. However, the contractor – who is a specialist in this field – recovered, in addition to what was called for in the tender, a quantity of aluminium scrap, face bricks, carpets, ducting, insulation, and pine as well as meranti timber was recovered. The measured quantity of recovered material is listed in the table below.

Materials	**Quantity**
Bricks, ROK	30,000
Ceilings, acoustic panels	250 sq.m.
Ceilings, tees	250 sq.m.
Doors	30
Partitions, boards	200
Partitions, studs	240
Power skirting	110 lengths
Sanitary ware	9 sets
Tiles, wall	120 sq.m.
TOTAL	

Based on the expertise of the contractor and the incentive of the offered by the client the recovery rate achieved for ROK's was 80%, and 15% for face bricks. On this basis, this particular contractor would have a 50% advantage over another contractor based on the value of recyclable material alone. In reality, the advantage will most probably be higher than that as the transport costs for some of the new materials will be higher than those of the equivalent recycled material.

It must be remembered that in developing countries, unlike developed countries, very little construction waste from a construction site is actually wasted: most of the bulk materials used in the construction sector such as aggregates, steel, aluminium, timber, pvc, cement fibre, and clay-based products, is salvaged and reused in low cost and informal settlements. For this and other reasons, the use of recycled materials presents similar difficulties to those of industrial waste. Given the dispersion pattern of construction waste, and the difficulty of collection, it is unlikely that the use of salvaged building materials could be undertaken on a national scale and in sufficient quantity to make a significant contribution to the objectives of this study. Therefore while the reuse of construction materials is to be encouraged, this activity will be most effective at the local level.

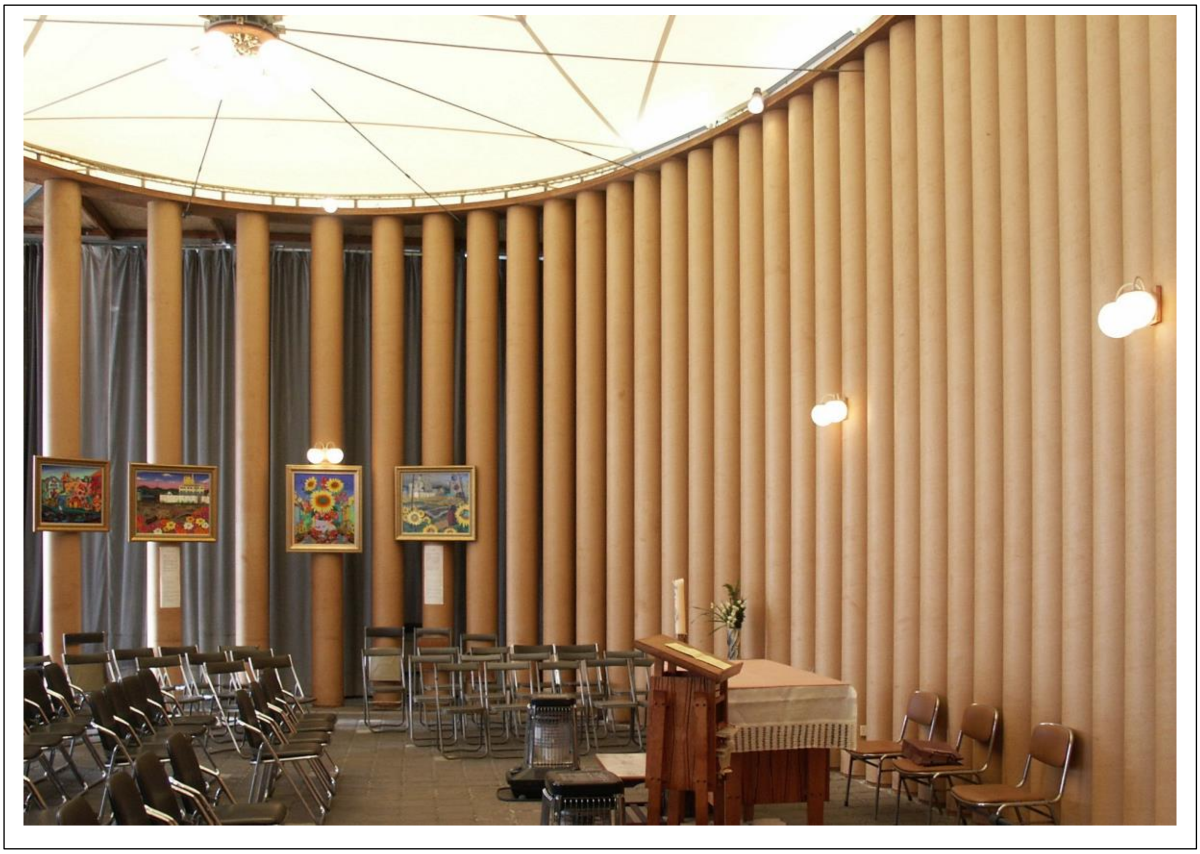
Reducing the throughput of virgin raw materials

Material substitution

The desktop review undertaken by the CSIR in 2005 revealed substantial activity in the use of industrial waste that lead to the conclusion that the application of material substitution through the use, for example, of industrial waste are driven in large part by the financial cost and environmental implications to the enterprise of producing and discarding waste. Improved input to output ratios, stringent environmental regulation, dwindling landfill capacity and high transport costs are growing pressures that are increasingly impacting on all industries with the objective of eliminating waste.

Various attempts have been made in the building sector with regard to material substitution, most notably the work of the acclaimed Japanese architect Shigeru Ban. Ban works with cardboard tubes (see Figure 1) to quickly and efficiently provide emergency shelter: the use of paper and cardboard is related to its availability in a post-disaster scenario compared to conventional materials.

Figure 1: Takatori Catholic Church, Kobe, 1995



Source: Wikimedia

Given the 2005 CSIR review of the use of industrial waste for construction purposes, one can draw two conclusions. Firstly, it is to be expected that the generation of waste will progressively continue to reduce, and the limited residual waste will increasingly be used to generate added value through the manufacture of new products. Secondly, due to the nature and location of the waste, it is difficult to centralise sufficient material to enable a new product to be manufactured. Future product development in this field will therefore occur in specific response to the opportunities offered by the type and location of the waste material. For these reasons, it is unlikely that the use of industrial waste as a resource for the manufacture of new mainstream construction products holds any significant promise in terms of energy and emission reduction.

Maintaining existing products for longer

An obvious way of reducing material use is to use materials that will last for as long as possible. Fortunately, the construction sector is one of the sectors where this is generally the case – infrastructure is designed to last because of the high cost of construction.

Notwithstanding this, the lifespan of these materials can be extended by the way they are installed, and finished. Epoxy-coated steel or aluminium is more difficult to reuse than polished steel or aluminium since in the former instance the finish must first be removed which may, in itself, be material intensive.

Choosing a low maintenance finish will reduce material intensity in terms of ongoing maintenance, and extend the lifespan of the material. A wall built from facebrick will over its life cycle require far less resource use than a wall built of run-of-the-kiln bricks that are plastered and painted.

Although timber may often last for many decades, using it in harsh conditions will result in premature degradation and thus replacement, at worst, or frequent maintenance, at best.

Since buildings are generally designed for long life, it is possible to reuse buildings rather than to demolish them. In many cities reusing warehouses has become fashionable: this is particularly so in cities with a waterfront where warehouse and other industrial-type buildings were located either along a river or the sea. Heritage buildings are similarly highly reusable in part because they are located in historic quarters of the city and because they are often also protected by law.

However, most buildings can be reused, and where this is not possible or desirable, components of a building can be reused including, at a minimum, floors, columns, beams and load bearing walls. Very often facades and fenestration can also be reused, and, again, where not possible or desirable, those components can be removed and reused elsewhere, or recycled.

Heritage Square in Cape Town is a fine example of extending the life of existing products: this collection of 18th century town houses, associated outbuildings and a warehouse on Bree Street (once earmarked for demolition to make way for a new parking garage) was redeveloped through a combination of restoration and careful insertion of new uses. Not only were significant gains made in terms of resource use, but an irreplaceable artefact of Cape Town's heritage was retained for the benefit of future generations.

Figure 2: Heritage Square, Cape Town

Source: Llewellyn van Wyk

Dematerialization

Dematerialization of a product literally means using less – preferably no – material. Although the latter sounds unfeasible in the construction sector, ultimately the shift from a reliance on products to services is the process of dematerialization. A good example of this is hot-desking, i.e. where a working space is shared between two or more people. Another example would be car-pooling.

The basic idea is simple: relieve ecosystems of the demands made by man by using less virgin raw material (Aachener Stiftung Kathy Beys 2015). Japan is one of the countries that have adopted dematerialization and resource efficiency as an economic and societal strategy through its *Junkangata Shakai* (sound material-cycle society) programme in 2000. Their Fundamental Law for Establishing a Sound Material-Cycle Society of 2000 emphasises a utilization hierarchy beginning "with resource reduction, on to reuse, material recycling, thermal recycling and final disposal" (Wuppertal Institute 2008:7).

In architecture dematerialization involves designing with a view to achieving the same outcome while using less material (less is more). As Brown and Lutz-Carrillo (2009:2) note "dematerializing the built environment as a goal for the way we approach the world leads to a re-examination [of] the necessity of building in the shifting environment, designing for things like flexibility, durability, and deconstructability as well as the particular materials and resources used for the manufacture and operation of a particular building." Brown and Lutz-Carrillo argue that there are three steps to dematerialization of the built environment: the first is to evaluate which buildings and building typologies are still relevant and abandon those which have become obsolete; the second is to re-evaluate the nature of the necessary buildings with the objective of meeting multiple needs with one structure or space; and the third is to find innovative ways of reducing the quantity of materials needed in the built environment and engineer buildings to operate more efficiently (2009:2).

In an experimental house designed by the CSIR and built on the Built Environment's Innovation Site in Pretoria (see Figure 3 below), redesigning the slab from the conventional 100mm thickness to a 50mm thick Continuously Reinforced Ultra-thin Concrete Pavement (CRUCP) reduced the amount of concrete used by 2 cubic meters. A further reduction of 3.5 cubic meters of concrete was made by replacing conventional strip foundations with a raft slab providing an overall saving of 5.5 cubic meters of concrete or 13.42 metric tonnes.

Figure 3: Ultra-thin concrete raft slab

Source: Llewellyn van Wyk

Brown and Lutz-Carrillo also posit an argument for rematerialization which involves the use of materials that are designed and manufactured for reuse (2009:3).

Designing out Waste

Designing out waste can be done through designing with regard to the dimensions and properties of the material being used, designing on a modular basis, and designing for disassembly.

Designing with the dimensions and properties of the material to be used requires that the material dictates the component being designed, not the other way around. Floor and wall tiling is a case in point: too often designers do not set the floor or wall dimensions to match those of the floor or wall finish, especially where use is made of individual components such as tiles. Secondly, the design of the floor pattern ignores the dimensions and shape of the tile resulting in extensive cuttings, most of which is of a dimension which restricts its future use and results in the cutting being dumped.

It is possible to design in a manner that minimises cutting: the dimensions of the rooms of the low income house designed by the CSIR was based on the dimensions of the walling element, in this case, hollow concrete masonry blocks (see figure below).

Figure 4: CSIR designed house, Kleinmond

Source: Llewellyn van Wyk

As can be seen in the illustration, use is made of full blocks and half blocks: as a result, cutting is eliminated (there is no visible sign of cut blocks around the construction site), and because of this the time to erect this house was 50 per cent less than a comparable house built by the same construction crew a few months earlier[2]. Not only was there a significant reduction in material, but also in time, the two main cost centres in construction.

Designing for resilience

Resilience is an ecological term used to describe a circumstance where an organism is able to withstand impacts which would ordinarily force it into another state. Climate change is likely to give rise to impacts which could push a number of organisms into an altered state, perhaps even to collapse. Building resilience is an inherent objective of an adaptation and mitigation strategy: in the building sector resilience has to do with withstanding impacts arising from climate change like higher wind speeds. If the actual loads exceed the design loads buildings will fail, with a concomitant material damage and loss.

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[2] In private conversation with the contractor.

Incorporating resilience into building design and construction includes ensuring that the building is not located in areas that are, or will become, vulnerable to climate change impacts, i.e. coastal areas and/or areas of likely land slippage. Secondly, designing in anticipation of climate change will involve anticipating higher structural loads arising from higher wind speeds. Thirdly, building resilience will include designing buildings that are easily adaptable to changing functional requirements (loose-fit) to minimise potential material loss arising from future alterations.

Conclusion

From a resource perspective, the greenest building is probably the building not built: the second greenest building is arguably an existing building where the resource use is already accounted for. Where a new building is required, or where alterations and additions are made to an existing building, a design approach aimed at minimizing resource use is an imperative if the ecological footprint of *homo sapiens* is to be kept within planetary boundaries. Fortunately, as this chapter demonstrates, there are a number of strategies that can be employed that have demonstrated that it is possible to substantially reduce resource consumption while achieving the same outcome.

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