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The Greening of the Concrete Industry

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ABSTRACT

Concrete is the most widely used construction material worldwide, with billions of tons produced every year. This volume alone is the basis for an enormous environmental footprint of the concrete industry. In addition, the production of Portland cement which binds the various aggregate components together is very energy intensive and releases large amounts of CO_2, a known greenhouse gas, into the atmosphere. The cement industry is estimated to be responsible for approximately 6 to 7 percent of all CO_2 produced worldwide.

The concrete industry has been working for several decades by now to reduce its environmental impact, by making concrete more environmentally friendly, or “green”. This paper summarizes the most important steps that have been taken in this direction or are expected to be taken. These steps can be divided into three major categories. First, there is the partial replacement of Portland cement by other cementitious materials, such as fly ash, ground granulated blast furnace slag, silica fume, etc. Most of these materials are pozzolans and, equally important, byproducts of industrial processes. This means their use has the dual advantages in that these materials serve as partial cement replacement and at the same time avoid the need of being land filled.

The second category consists of various materials from the solid waste streams, such as recycled concrete, post-consumer glass, scrap tires, plastics, carpet fibers, etc. These materials can be used as aggregates, fillers, or fiber reinforcement. By identifying and exploiting certain inherent properties it is possible to add value to such materials, which otherwise will have to be disposed of at considerable cost. Also included in this category are renewable materials such as wood products, bamboo, and various natural fibers such as sisal and hemp.

The third category may be labeled as “Other”, as it includes reduction of water consumption (important in arid countries), improved durability {which reduces the maintenance and replacement costs), concrete mix designs for specialty concretes such as for applications with low thermal conductivity, improved fracture toughness and energy

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dissipation capacity, pervious concrete (to reduce storm water run-off), carbon sequestration through the carbonation process, etc.

1. Introduction

The attribute “green”, when used in the context of concrete technology, used to have a very specific meaning, indicating that the concrete has not sufficiently cured for a specific application. In recent years, that word has acquired a second meaning, implying that a material, a process, or just an attitude is environmentally friendly and is basically a synonym for “sustainable”. The concept of sustainable development is a fairly old one. The first person who has formulated it in specific terms appears to have been Hans Carl von Carlowitz (1645 – 1714), a forester of Saxony. Being in charge of the King’s forests he realized that trees should be cut at a rate no higher than at which they could regenerate and sustain themselves [1]. Probably the most widely quoted definition of “Sustainable Development” was coined in the well-known Brundtland Report as “… the development that meets the needs of the present without compromising the ability of future generations to meet their own needs” [2].

Americans used to have difficulties incorporating such a principle into their lifestyles. There were a number of reasons for this. North America is blessed with an abundance of natural resources. Recycling or conserving such natural resources was not perceived as being important. The pioneers who settled the sparsely populated continent had more pressing problems to worry about. The situation was quite different in Japan and Europe, where the devastations of World War II led to a scarcity of many resources. But the basic tenet of sustainability was self-evident enough to prompt President Theodore Roosevelt to state in 1910: “I recognize the right and duty of this generation to develop and use the natural resources of our Land, but I do not recognize the right to waste them, or to rob, by wasteful use, the generations that come after us”.

If there was any doubt about the finite size of our planet and its natural resources, it was the photos taken by our astronauts of “Spaceship Earth”, which is finite in size indeed, together with its natural resources, and we better learn to live within our means. An important landmark was the first Earth Day of 1970, which was instrumental in raising public awareness of the issues on hand and eventually led to the Green Building movement.

The general requirements of sustainable development can be phrased in terms of the following specific actions to be taken by the engineering community:

1. First, we need to remedy the mistakes of the past by cleaning up our contaminated water and soil.
2. Next, we should stop polluting our air, water and soil, and avoid the release of greenhouse gases into the atmosphere that are known to contribute to climate changes.
3. Then, we should utilize our natural resources, whether material or energy, at a rate no greater than at which they can be regenerated.

4. And finally, we need to find a proper balance between economic development and preservation of our environment, that is, to improve the living standard and quality of life, without adversely affecting our environment.
There are several software systems to quantify the sustainability of buildings. The best known and probably most widely used one is the “Leadership in Energy & Environmental Design” (LEED) rating system of the US Green Building Council, which assigns points in a number of categories, such as sustainable sites, water efficiency, energy & atmosphere, materials & resources, indoor environmental quality, and innovation & design process [3]. The major metrics underlying such rating systems are the carbon footprint, the embedded energy, and various life cycle cost analyses.

2. Concrete and the Environment

It is a well-known fact that concrete is by far the most widely used building material. Worldwide, more than 10 billion tons are produced each year. The 500 million tons produced in the United States represent about two tons each year for every man, woman and child. The only other commodity which is used more widely is water.
There are a number of reasons why concrete is so popular. If properly designed and produced, it has superb mechanical properties and durability. The Romans made concrete that lasted 2000 years and is still doing just fine. Concrete is moldable into basically any shape or form and is adaptable to many different climates and applications. It has excellent fire resistance, is generally available in just about every country on earth and it is affordable. Because of its heavy mass, concrete has good sound and thermal insulating properties. But probably the most intriguing general advantage is the fact that concrete is an engineered material. It can be engineered to meet almost any set of reasonable performance specifications, more so than any other building material currently available.
There are also a number of disadvantages or rather challenges. Because of its relatively low tensile strength it is typically reinforced with steel bars. And to overcome its brittleness or low fracture toughness and energy dissipation capacity, it can be reinforced with a variety of randomly oriented and uniformly distributed short fibers. Also the weight-to-strength ratio, often considered to be a liability because it increases foundation costs, can be improved. We can now produce concrete that is almost as strong as steel. Yet, at about one third the specific weight, it is possible to match the weight-to-strength ratio of steel, without resorting to lightweight aggregate.
Looking at the sustainability aspects of concrete, there seem to be daunting challenges. But concrete’s bad reputation is worse than it deserves. The concrete industry has simply become a victim of its own success. To produce 10 billion tons of concrete, you need 10 billion tons of material. It is because of these vast amounts of natural resources needed that the industry leaves a large environmental footprint, which is a tough challenge to overcome.

In addition, it is well known that the production of each ton of Portland cement releases almost one ton of CO_2 into the atmosphere. Worldwide the cement industry alone is estimated to be responsible for about 6 to 7% of all generated CO_2. The production of Portland cement is also very energy-intensive. Although the North American plants have improved their energy-efficiency considerably in recent decades, it is technically next to impossible to increase that energy-efficiency much further below the current requirement of about 4 GJ per ton.

Then there is the demolition and disposal of obsolete or damaged concrete structures, pavements, etc., which constitutes another environmental burden. Construction debris contributes a large fraction of our solid waste, and concrete constitutes the largest single component. Finally, there is the water requirement which is enormous and particularly burdensome in those regions of the earth that are not blessed with an abundance of fresh water. The concrete industry uses over 1 trillion liters of water each year worldwide, and this does not include the wash water and curing water.

But not everything about concrete is environmentally bad. For example, concrete is generally produced locally with local materials, thereby reducing the energy and cost of transportation. And through the process known as carbonation, it also consumes CO_2, thereby offsetting some of the negative aspects of cement production. The reinforcing steel is almost 100% recycled, and because of its hardness and stiffness, a concrete pavement offers less rolling resistance than asphalt, thereby increasing the fuel efficiency of motor vehicles. Concrete can be made so porous that it becomes pervious, thereby drastically reducing storm water runoff. Then there are the excellent thermal properties, due mostly to its thermal mass that is an advantage both in summer and winter. And by its reflectivity it cuts down on the so-called heat island effect.

3. Potential Tools and Strategies

To face the challenges listed above, we have at our disposal a number of potential tools and strategies.

1. Since the main challenges are associated with the production of Portland cement, whereas concrete itself is basically environmentally friendly, a primary goal is to use as much concrete with as little Portland cement as possible.
2. Replace as much Portland cement as possible by supplementary cementitious materials, especially those that are by-products of industrial processes. This reduces the amount of CO_2 generated and the amount of embedded energy.
3. Use recycled materials in place of natural resources to reduce the amount of virgin material.
4. Identify and exploit inherent properties of recycled materials, which add value to a resource that otherwise would need to be disposed of as waste.

5. Improve the durability and service life of structures. For example, by doubling the durability of a concrete pavement, the amount of materials needed for its replacement is cut in half.
6. Improve the mechanical properties of the concrete. For example, by doubling the strength of strength-controlled structural members, the amount of materials needed can be cut in half.
7. Reduce the amount of water, for example, by reusing wash water.

4. Use of Supplementary Cementitious Materials

The replacement of Portland cement by other cementitious materials can reduce considerably the environmental impact of concrete production. There are now a number of such materials available.

Fly Ash. The cementitious properties of fly ash have been known for some time. However, its use became widespread only after clean air regulations forced coal-burning plants to install scrubbers or electrostatic precipitators, which prevent fine particulate matter from being released into the atmosphere. Thus, the main advantage of fly ash is the fact that it can replace large amounts of Portland cement. By utilizing its cementitious properties, fly ash is the classic example of adding value to a material that otherwise would have to be land filled or disposed of at great cost. Although Malhotra [4] has shown that it is possible to design high-volume fly ash mixes with 60% and more of Portland cement replaced by fly ash, typical replacement values are on average around 30%.
Replacing part of the Portland cement has also other advantages compared with regular Portland cement concrete mixes. The end product has generally higher strength and improved durability. Because fly ash mixes generate less heat of hydration, they are widely used for massive concrete structures such as dams and heavy foundations. Fly ash is widely available, wherever coal is burned. To top off the list of advantages, fly ash is less costly than the Portland cement it replaces.
The main challenge of fly ash usage is the wide variety of chemical composition, caused by the different sources of coal being burned. But coal ash producers have improved the quality control in recent years, which reduced particularly the amount of loss of ignition due to the amount of unburned carbon. Being a pozzolan, fly ash slows down strength development. However, in many applications, high early strength is not required, and if this is indeed the case, accelerators are available to speed up the strength gains.

Ground Granulated Blast Furnace Slag (GGBFS). As the name implies, GGBFS is a by-product of the steel industry. It is the glassy granular material formed when molten blast-furnace slag is rapidly chilled. Its cementitious properties are well known, therefore it has become a common component of mix designs. Theoretically it can replace all of the Portland cement, but in practice, it is rare that mixes contain more than 70% of the total

cementitious material. Like fly ash, it improves the mechanical and durability properties of concrete and generates less heat of hydration. In some cases so-called terniary systems have been used, that is, blends of Portland cement, fly ash and GGBFS. The cost of GGBFS is quite close to that of Portland cement, but ever since the demise of the US steel industry the availability may be a problem. The slag used in New York City comes mostly from Italy.
Another problem is posed by toxic metals in the slag that may leach out if dumped in regular landfills. Recent studies have shown that such contaminated slag can be used safely and beneficially in concrete applications, since such harmful metals can be immobilized and safely incorporated into the hydration products. Again, the primary advantage of slag is the fact that it is a byproduct of an industrial process, which adds value to the material which otherwise would have to be disposed of at great cost as solid waste.

Condensed Silica Fume. Condensed silica fume or microsilica is the third of the most widely used supplementary cementitious materials. Like fly ash and slag it has the great advantage of being a byproduct of another industrial process, namely the semiconductor production. This siliceous material is so effective in improving the strength and durability of concrete by filling the micropores that modern high-performance concrete mix designs as a rule call for the addition of silica fume. Although it is difficult to handle because of its sub-micron particle sizes, it is also produced specifically for the concrete industry, and the high demand has an impact on the cost.

Solid Waste Incinerator Ash. The serious problem of solid waste disposal in many metropolitan areas calls for drastic action. For example, New York City, which probably generates more solid waste per capita than any other major city, especially after closing of the Freshkill Landfill, the world's largest, is barging its solid waste to the lowest bidder among neighboring states. It has also constructed so-called waste-to-energy facilities to burn the solid waste. The resulting fly ash and bottom ash have been proposed for use in concrete, primarily because of their cementitious properties. But aside from the political aspects of finding suitable sites for such facilities, known as "NIMBY" ("not in my back yard"), there are unresolved technical problems, primarily because of the unacceptably high content of heavy metals that need to be immobilized. More research is required before such ash can be used as partial substitute for Portland cement on a large industrial scale.

Other Potential Supplementary Cementitious Materials. Rice husk ash has been proposed for use in rice-growing countries. The rice husk is generally burned without attempts to harness the released energy or capture the ash which has been studied by Mehta long ago [5]. Also sugar cane bagasse ash has been studied primarily in sugar-growing countries [6]. Phosphogypsum is a byproduct of the gypsum industry and has been studied for its cementitious properties. Currently it is simply deposited on mountains, posing environmental health problems, exacerbated by low levels of radiation emitted by the radon present in the base material. Also the cement kiln dust generated during the cement production process has been studied for its suitability as supplementary cementitious material.

5. Use of Waste Materials as Aggregate

Since by volume aggregate constitutes the main ingredient of concrete, the substitution of various components of the solid waste stream for virgin materials such as crushed stone and sand is a task of high priority in making concrete more environmentally friendly. A number of possibilities have been explored with more or less success.

Recycled Concrete Aggregate. Construction and demolition waste constitutes a major portion of all solid waste, with 200 to 300 million tons generated annually in the United States alone. The traditional disposal of these large amounts of waste in landfills is no longer an acceptable option, especially in countries like Japan, where the remaining landfill capacity has been estimated to last for only a few more years [7]. Together with the increasing scarcity of suitable virgin material for aggregate, the pressure is particularly severe on the Japanese construction industry to find ways of substituting recycled concrete as aggregate (RCA) for virgin aggregate. In many countries recycled concrete debris is used mostly for road-base or sub-base material [8]. Since such material is generally less expensive or “valuable” than high-quality aggregate, such uses constitute a less desirable form of “downcycling”.

The technical problems of producing new concrete with RCA are well known and have been studied thoroughly [9,10]. A major concern is the variety of contaminants found in recycled concrete originating from the demolition of buildings and other structures that have served for many years, such as plaster, soil, wood, gypsum and asphalt. If the amounts of such contaminants exceed the maximum limits set by codes and specifications, they need to be sorted out before use. This problem does not exist with concrete returned to the plant for various reasons.

Other technical problems are associated with the low density of crushed recycled concrete, especially of the fines that have high water absorption capacities and therefore have a negative impact on the workability of concrete with RCA. However, a recent study has shown that it is quite possible to produce high-quality concrete using low-quality RCA by incorporating the idea of internal curing [11,12]. The key is sufficient pre-mix saturation of the aggregate which provides the cement with a reservoir of moisture for hydration. Even though conventional wisdom holds that the quality of concrete produced with low-quality RCA is generally lower than that of concrete produced with high-quality (virgin) aggregate, many applications do not call for high-performance concrete. Also, the substitution of small amounts of RCA (say 10 to 20 percent), has typically a minor effect on the concrete performance and still can make a dent on the mountains of construction and demolition debris.

When evaluating the economics of substituting recycled concrete aggregate for virgin aggregate, the role of transportation cost can quickly become a deciding factor, especially for the replacement of existing pavements. The total cost of virgin aggregate includes the processing and transportation of both the virgin aggregate to the site and the removal of the old pavement to the nearest dump plus the applicable tipping fees. The cost of the recycled aggregate does not include the tipping fee but what can be referred to as a performance deficit that needs to be quantified. If the cost of transportation becomes large enough, the RCA option will be the more economical one.
The use of RCA in the United States is not as widespread as in Europe and Japan. However, the demolition of the old Stapleton Airport in Denver was touted as the world's largest concrete recycling job, with 6.5 million tons enough to build Hoover Dam.

Crushed Post-Consumer Glass

Post-consumer glass is another example of a suitable aggregate for concrete, as research at Columbia University has shown [13]. It costs taxpayers of New York City 60 million dollars each year to dispose of its waste glass. The major argument against its use as an aggregate of Portland cement concrete is the alkali-silica reaction (ASR), but research has shown that there are several ways of preventing ASR from occurring or to suppress its detrimental consequences. Moreover, there are several advantages of using glass as an ingredient of concrete. Rather than disposing it as a waste material, we can add value to it by using it beneficially. It is of relatively low cost and widely available. Its basically zero water absorption is an advantage in mix design as it improves the flowability of the mix. Its very high hardness and abrasion resistance are well known. So is its excellent durability and chemical resistance. By grinding the glass very finely, it has been shown to have pozzolanic properties, i.e. it may be used as a partial replacement of the Portland cement. The most intriguing benefit, however, is the esthetic potential of glass particles sorted by color and matched with the colored matrix as background, as well as light reflection and refraction. These tools offer almost limitless artistic and visual effects.
Regarding the economics of post-consumer glass as aggregate, one needs to distinguish between commodity products such as paving stones and value-added products. Commodity products are associated with high volumes and low profit margins. In contrast, value-added products such as terrazzo tiles are produced in much smaller volumes with higher profit margins. Moreover, recyclers collect from the source (municipalities) and the end user, who can afford higher material costs because consumers are willing to pay more for the end products. Glass particles sorted by color can compete with costly specialty aggregates such as marble chips and granite. Although glass concrete products are already being produced commercially, the costs do not yet reflect the commercial potential, because of inadequate competition.

Plastics

Of the millions of tons of all kinds of plastics discarded each year, only relatively small amounts are being recycled. Plastics come in many different forms and chemical compositions, which complicates the recycling process as well as their use as concrete ingredients. Because the different types of plastics are typically commingled, it is generally not economical to separate them in volume. De-polymerization or chemically breaking plastics down to their virgin components is not possible with currently available technologies. Many plastics can be recycled back into blank feedstock to be used as input for thermosetting or plastic manufacturing. However, the quality is lower and less uniform than that of virgin material, therefore manufacturers generally prefer to down-cycle post-consumer plastics into alternate uses such as plastic lumber.
An intriguing possibility is the use of foamed plastics such as Styrofoam as ultra-light weight aggregate for thermal insulating concrete [14]. Styrofoam is a popular packaging material which is difficult to recycle otherwise. Although density strongly correlates with strength of concrete materials, ultra-lightweight concrete can be produced with sufficient strength for some applications such as building facade elements.

Dredged Material

The Port Authority of New York and New Jersey needs to dredge about three million cubic meter of sediment each year to keep the shipping lanes open and also to deepen them to accommodate the larger modern shipping vessels. Before the passage of clean ocean legislation the dredged material was simply dumped in the open ocean. Since this is no longer an option, the material needs to be deposited in engineered landfills because of the high levels of toxic heavy metals, PCB’s, oils, etc. The expense of such deposition threatens to seriously affect the financial viability of the Port Authority – a problem that is shared by most major ports. Treatment methods are available that involve the chemical encapsulation such that these contaminants cannot leach out [15]. In order to avoid the siting problem, it has been proposed to process the material on a barge directly after being dredged. First studies have demonstrated the practical feasibility, however, further research is necessary to make it also economically feasible.

Rock Spoils

The construction of tunnels such as for the Second Avenue Subway in Manhattan requires the excavation of large amounts of material, referred to as spoils, which is proportional to the tunnel’s cross-sectional area. Not counting the subway stations, the construction of the tunnel liner requires amounts of concrete that are proportional to the tunnel perimeter. This means that contractors can be very choosey in selecting from the spoils the material most suitable to serve as aggregate, as only relatively small amounts of material would go back into the tunnel. This recycling of the spoils saves transportation and disposal costs, but causes a logistics problem, as there is potentially a large time difference between when the material is excavated and when it is used to produce concrete.

Tires

The hundreds of millions of scrap tires discarded each year in developed countries pose serious environmental problems. Tire dumps are unsightly and pose significant health hazards as they serve as breeding grounds for mosquitoes and can cause fires that can burn for months or even years.
Probably the most meaningful method of recycling used tires is to reuse them after retreading. The barriers to such reuse due to public perception are well known, but latest research and industry efforts promise an increase in such reuse [16]. Yet, the most common disposal method at present seems to be to burn them for the generation of steam and electricity or heat. The use of tires as alternate fuel in cement kilns is widespread throughout the US and Europe. But their value as fuel is considerably less than that of the original, so that such a use constitutes another example of down-cycling.
The most common ways of recycling rubber in cement composites and concrete is to use it as shredded, chipped, ground, or crumb rubber, with sizes ranging from shredded pieces as large as 450 mm to powder particles as small as 75 m. Because of the large differences between Young's moduli of rubber and cement matrix, major differences in mechanical behavior are to be expected between concrete with conventional natural aggregate and with rubber containing concrete. Most significant is the loss of compressive and tensile strength as well as stiffness with increasing rubber content. The rubber particles constitute not only weak inclusions; they also are responsible for large tensile stresses in the cement matrix, which lead to early cracking and failure. On the other hand, the rubber particles have a restraining effect on crack propagation, which leads to a significant increase in ultimate strain, ductility, and energy absorption capacity [17], which may be exploited by using them in shock absorbers. However, the large deformations introduce damage, which may limit such devices to one-time use.

Other Materials Suitable for Recycling

Waste wood, mostly in the form of wood chips and saw dust, has been investigated in regions with major lumber industries, e.g. to produce floor materials with improved thermal insulating properties [18].
In the United States, 100 million tons of sand are used in foundries for the production of steel and other metals. Such foundry sands have been shown to be suitable for the production of concrete [19]. The same is true for pulp and paper mill residuals [20]. Even agricultural waste materials have been found to be suitable as filler material [21].

6. Reinforcing Materials

Bamboo

Bamboo is a functionally graded material with amazing properties. In tension it approaches the strength of steel. Rapidly growing, it is the quintessential renewable material and at the same time sequesters carbon from the atmosphere. Its strength is being utilized in China and other countries for scaffolding, but it also has been investigated as a reinforcing material that could serve as a substitute for reinforcing steel bars [22]. The nodes resemble the deformations of steel reinforcing bars and have the potential of improving the bond strength between matrix and reinforcing bars. Being an organic material, the main challenge of its use is the chemical interaction with the alkali in the cement matrix which lowers the durability of the composite. More research is needed before bamboo rods can serve as substitute for standard steel reinforcing bars.

Natural Fibers

In fiber-reinforced cement composites, uniformly dispersed and randomly oriented short fibers are currently in wide use primarily to improve their fracture toughness, ductility and energy absorption capacity. Scores of different materials are currently used to produce such fibers, e.g. steel, polypropylene, polyethylene, nylon, AR-glass and numerous others. But natural fibers such as hemp and sisal fiber have also been studied as potential substitutes for manufactured fibers. Their tensile strengths are excellent, but like bamboo and other organic materials, they are vulnerable to chemical interaction with the alkaline pore solution of the Portland cement matrices, which affects the durability – a problem currently being investigated.

Carpet Fibers

Carpet manufacturers are required by law to take back old carpets that are being replaced by new carpets. The high cost of disposal is an incentive for the industry to recycle old carpeting by recycling the fibers, made typically of nylon or polypropylene. The use of such fibers in fiber-reinforced cement composites has been studied and shown to have potential [23].

Tire-Derived Steel

When tires are shredded to retrieve the rubber for other uses, the remaining steel reinforcement promises to be a suitable reinforcing material in slurry-infiltrated concrete (SIFCON), where the reinforcing material is first placed in the formwork, and a cement slurry is added to fill all the voids, resulting in an extremely tough material.

7. Conclusions

As this paper hopes to show, there are ample opportunities for the concrete industry to become more environmentally friendly or "greener". The economics of each individual suggestion depend largely on the specific application. All indications are pointing into the same direction, namely that of increased economic feasibility of recycling:

1. Market forces are responding to supply and demand. As natural resources are becoming increasingly scarce, the price advantage of recycled material will increase.
2. Government can and does intervene with incentives and disincentives, such as tax advantages on the one hand and outright prohibition on the other hand.
3. The general public is becoming increasingly aware of the need to conserve our natural resources and appears to be willing to pay more for recycled and environmentally friendly materials.
4. The costs associated with recycling, i.e. collection, processing and transportation and the associated necessary capital investments are real and need to be taken into account.
5. But these are partially offset by the cost of disposal as waste if the materials are not recycled.
6. An important factor is the price of competing materials or those materials to be replaced by recycled material, if any.
7. Any beneficiation or added value can easily tip the balance, as was demonstrated by utilizing the esthetic potential of colored glass aggregate.
8. Very important is the generation of competition. As recyclers are discovering the possibilities to make money, more of them will be competing, thereby lowering the cost.

In general one can say that virgin materials have a quality control advantage over recycled materials, but the economic feasibility is certain to improve over time for a number of reasons:

1. It is a fact that suitable virgin materials will become increasingly scarce.
2. Material that does not get recycled will have to be disposed of as "waste" at increasing monetary and environmental cost.
3. The exploitation of qualities inherent in certain waste streams offers additional advantages.
4. The general public is becoming increasingly aware of the need to use our natural resources sparingly in order to conserve them for future generations.

As long as owners and developers did not recognize the economic benefits of recycling and other sustainability measures, it was often up to governmental agencies to take the lead. But it is fair to say that the situation has changed drastically: developers have discovered that their bottom line is helped by pursuing sustainability over the entire spectrum of construction. There are numerous examples to be found in New York City alone. The developers of the Solaire, the first “green” residential high-rise building, realized that they could charge higher rents than for comparable units in buildings that were built without adhering to sustainability principles or “LEED-rating”. Also the developers of the Conde Nast Building on Times Square first subscribed to sustainability principles because they thought the value of positive publicity was sufficient to offset the added initial cost and they were pleasantly surprised when they discovered that the bottom line was positive to begin with. This prompted them to develop the neighboring property for the Bank of America by “pulling out all the stops” and go for the highest LEED rating possible. Thus it is safe to say that it is not a question of “whether” but “when” the use of recycled materials in construction becomes a routine matter, giving the construction industry all the incentives to become “greener”.

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