ESCSI

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# A Holistic Approach to Sustainability For the Concrete Community

## Lightweight Concrete-Two Millennia of Proven Performance

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## INTRODUCTION

The future viability of the concrete community will be determined by its response to the global issue of sustainability. New research and technology, and the rapid development of the green building movement clearly point out that change in current life styles are essential if we are to maintain and improve our way of life. In 2002 the U.S. Green Building Council accelerated the activity and interest in sustainable design and construction. Their already popular "LEED" (Leadership in Energy and Environmental Design) rating system was advanced and may soon provide the basis on which all designs are built. The monumental importance of energy efficient building designs was pointed out in the Metropolis October 2003 article "Turning Down the Global Thermostat". In this article Edward Mazria's (well known architect and author) startling conclusions are reported:

> "Architects – together with the building industry are responsible for just about half of America's energy consumption and half its greenhouse gas emissions, which are produced by burning coal, gasoline and other fossil fuels".

Attitudes of the concrete community as with all other groups need to be revised to meet the demands and challenges of green buildings and future generations. One of these changes includes the use of materials that will extend the service life of concrete and additionally make concrete a contributor to the more efficient use of energy and raw materials. This paper covers the use of structural lightweight aggregate in concrete and demonstrates how this addition can benefit the entire concrete community.

Lightweight aggregate has been successfully used for well over two millennia with widespread use in the past eighty years. It is this track record of proven performance that interests the design community, owners and researchers. This paper also shows how lightweight aggregate contributes to sustainable development by maximizing structural efficiency, conserving energy, lowering transportation requirements, and improving concrete durability.

We use the generally adopted definition of "sustainable development" presented by the 1987 UN World Commission on Environment and Development: "Sustainable development meets the needs of the present without compromising the ability of future generations to meet their own needs".

**PRODUCT EVALUATION – Structural Lightweight Aggregate**

The first step toward designing sustainable structures is product evaluation. How is the product made? Is the product an efficient use of the raw materials? How will the product perform? What happens to the product when its useful life is over?

Structural lightweight aggregates are produced in manufacturing plants from raw materials, including suitable shales, clays, slates, fly ashes, or blast-furnace slags. Naturally occurring lightweight aggregates are mined from volcanic deposits that include pumice and scoria. Pyroprocessing methods include the rotary kiln process where raw material is fed into a long, slowly rotating, slightly inclined cylinder where it's fired in excess of 1000°C. This manufacturing process is similar to portland cement. The manufacturing processes are producing a uniform, high quality ceramic product that is structurally strong, stable, durable and inert, yet also lightweight and insulative. No single description of raw material processing is all-inclusive, and the reader is urged to consult local lightweight aggregate manufacturers for physical and mechanical properties of lightweight aggregates and the concrete made with them.

The increase usage of processed lightweight aggregates is evidence of environmentally sound planning, as these products have lower transportation requirements and use raw materials that have limited structural applications in their natural state. This minimizes demands on finite resources of quality natural sands, stones and gravels.

Lightweight aggregates have a low-particle relative density because of the cellular pore system. The cellular structure within the particles is normally developed by heating certain raw materials to incipient fusion; at this temperature, gases are evolved within the pyroplastic mass, causing expansion, which is retained upon cooling. Strong, durable, lightweight aggregates contain a uniformly distributed system of pores that have a size range of approximately 5 to 300μm, developed in a continuous, relatively crack-free, high-strength vitreous phase. Pores close to the surface are readily permeable and fill with water within the first few hours of exposure to moisture. Interior pores, however, fill extremely slowly, with many months of submersion required to approach saturation. A small fraction of interior pores are essentially non-interconnected and remain unfilled after years of immersion (ACI 213R-03).

The ceramic nature of the aggregate insures the product is inert and highly resistant to degradation, thereby providing concrete with a key component that has stood the test of time. These same properties also render the product environmentally benign in that it can be reused as fill or base material. In many applications, the aggregate is blended into soils that benefit from the water absorbing characteristics of its pores nature which provide a nutritional and moisture buffer that modify climate and environmental changes.

**PRODUCT INTERFACE – Structural Lightweight Aggregate in Concrete**
An essential step toward sustainability is evaluating how the product interfaces with adjacent products and what effect this has on the performance of the combined material, in this case structural lightweight concrete.

Concrete failing prematurely should not be tolerated. Whether by microcracks or macrocracks, a major source of failure is initiated at cracks. Therefore, mitigating cracking becomes an essential element in sustainability. Adding lightweight aggregate to concrete mitigates crack formation, as demonstrated in the following narrative.

Core samples taken from hulls of 80-year-old lightweight concrete ships as well as 40 to 50-year-old lightweight concrete bridges reveal that the concrete has a dense contact zone at the lightweight aggregate/cement matrix interface. This zone has very low levels of microcracking throughout the mortar matrix (Sturm et al. 1999). Explanation for this high resistance to weathering and corrosion involves several physical and chemical mechanisms including superior resistance to microcracking. This excellent performance is developed by the significantly higher aggregate/matrix adhesion and the reduction of internal stresses due to elastic matching of coarse aggregate and matrix phases (Holm, Bremner, and Newman 1984). High ultimate strain capacity is also provided by lightweight concrete as it has a high strength/modulus ratio. The strain at which the disruptive dilation of concrete starts is higher for lightweight concrete than for equal-strength normalweight concrete. A well-dispersed pore system provided by the surface of the lightweight fine aggregates may also assist the air-entrainment system and serve an absorption function by reducing concentration levels of deleterious materials in the matrix phase.

Permeability investigations conducted on lightweight and normalweight concrete exposed to the same testing criteria have been reported by numerous researchers Khokrin (1973), Nishi et al. (1980), Keeton (1970), Bamforth (1987), Bremner et al. (1992). It is of interest that, in every case, despite wide variations in concrete strengths, testing media (water, gas, and oil), and testing techniques (specimen size, media pressure, and equipment), lightweight concrete had equal or significantly lower permeability than its normalweight counterpart. Khokrin (1973) further reported that the lower permeability of lightweight concrete was attributed to the elastic compatibility of the constituents and the enhanced bond between the coarse lightweight aggregate and the matrix.

One principal difference between lightweight concrete and normalweight concrete is the development and positive influence of the contact zone. The contact zone in lightweight concrete is the interface between two porous media: the lightweight aggregate particle and the hydrating cementitious binder and has been demonstrated to be significantly superior to that of normalweight concrete. This improvement in the quality, integrity, and microstructure stems from a number of characteristics unique to lightweight concrete, including but not limited to the following:

- The alumina and silicate rich pozzolanic surface of the fired ceramic aggregate combines with the $Ca(OH_2)$ liberated by hydration of the portland cement;
- Reduced microcracking at the matrix lightweight aggregate interface because of the elastic similarity of the aggregate and the surrounding cementitious matrix The modulus of elasticity of concrete depends on the relative amounts of paste and aggregate and the modulus of each constituent. Elastic incompatibility of the constituents of normalweight concrete result from the higher moduli of sand, stone, and gravel that are all significantly greater than the moduli of lightweight aggregate particles.

  Essentially, a lower $E_c$ value for lightweight concrete results in a reduced stiffness, as defined by the product of modulus of elasticity and moment of inertia, *EI.* Reduced stiffness can be beneficial at times in cases requiring improved flexural response, such as bridges, structures where differential settlement may occur.
  Hygrol equilibrium between the two porous phases: lightweight aggregate and a porous cementitious matrix is fundamentally different than the usual condition with dense aggregates, where bleed-water lenses form around the non-absorbent coarse natural aggregates that have a *w/cm* ratio significantly higher than the matrix. The accumulated water at the interface is subsequently lost during drying leaving voids and a weak low-quality aggregate/matrix interface (ACI 213R-03).

  When pozzolans are added, the high-quality microstructure of the contact zone of concrete containing lightweight aggregate is moderately enhanced. In contrast, when high-quality pozzolans are used in concretes containing normalweight aggregates, this zone of weakness is significantly improved.
- With lightweight concrete the cementitious hydration is enhanced due to the process of internal curing. Time-dependent improvement in the quality of concrete containing lightweight aggregate is greater than that with normalweight aggregate. This is due to better hydration of the cementitious fraction provided by moisture available from the slowly released reservoir of water absorbed within the pores of the lightweight aggregate. This process of internal curing is made possible when the moisture content of the aggregate, at the time of mixing, is in excess of that achieved in 1-day submersion. This fact was first documented in

1967 by Campbell and Tobin. Their tests confirmed that availability of absorbed moisture within the lightweight aggregate produced a more forgiving concrete that was less sensitive to poor field-curing conditions.

High cementitious concrete is vulnerable to self-desiccation and benefits significantly from the added internal moisture. This application is especially helpful for concrete containing high volumes of pozzolans that are sensitive to curing procedures. While improvements in long-term strength gain have been observed, the principal contribution of internal curing rests in the reduction of permeability that develops from a significant extension in the time of curing. In 1959 Powers et al., showed that extending the time of curing increased the volume of cementitious products formed, which caused the capillaries to become segmented and discontinuous.

**STRUCTURAL EFFICIENCY – Lightweight Concrete in Structures**
All products should optimize structural efficiency by improving the strength to weight ratio.

*Buildings* – A major reason lightweight concrete is used is for weight reduction which often enhances the functionality, architectural expression or constructability of a structure. In building this is achieved by thinner fire resistant slabs, longer spans, expressive roof design, taller buildings, additional floors added to existing structures and when building on locations with poor soil conditions. Weight reduction optimizes land use by affording a smaller footprint, which allows surrounding space to be more people friendly.

Less building materials are also used:

- The reduction in foundation loads may result in smaller footings, fewer piles, smaller pile caps, and less reinforcing;
- Reduced dead loads may result in smaller supporting members (decks, beams, girder, and piers)
- Reduced dead load will result in reduced inertial seismic forces;

*Bridges* - With bridges, this may allow a wider bridge deck (additional lanes) being placed on existing structural supports with minor or no modifications. Improved constructability may result in balanced cantilever bridge construction where lightweight concrete is used on one side of a pier and normalweight concrete used on the other to provide equal weight while accommodating a longer span on the lightweight side of the pier. This has permitted locating piers closer to land with significant reductions in cost.

On bridge deck replacements or overlays the deck may be thicker to allow more cover over reinforcing or to provide better drainage without adding additional dead load to the structure. Lightweight concrete has been used to create longer bridge spans, thereby reducing the need for costly and aesthetically unacceptable piers.

*Precast* - Longer or larger precast members can be manufactured without increasing overall weight. This results in fewer columns or pier elements in a system that is easier to lift or erect with fewer joints or more elements per load when transporting. There are several documented cases where the savings in shipping cost far exceeded the increased cost of using lightweight concrete. At some precast plants each elements shipping cost is evaluated by computer to determine the optimum concrete density;

*Marine* - In marine application, increased allowable topside loads and the reduced draft resulting from the use of lightweight concrete may permit easier movement out of dry docks and through shallow shipping channels.

*Specified density concrete* - Specified density concrete is becoming increasingly used to enhance design flexibility and project economics. Specified density is defined as concrete containing limited amounts of lightweight aggregate that result in equilibrium concrete densities greater than 120 $lb/ft^3$ (1920 $kg/m^3$) but less than concrete composed entirely of normalweight aggregates. The increasing usage of specified density concrete is driven by engineers' decisions to optimize the concrete density to improve structural efficiency (strength to density ratio), to reduce concrete product transportation and construction costs, and to enhance the hydration of high cementitious concrete with very low *w/cm* (ACI 213R-03).

*Insulation* - The low thermal conductivity of lightweight concrete provides significantly better insulating qualities for thermally sensitive applications such as cryogenic applications or high temperature petroleum storage structures.

**CONSTRUCTION EFFICIENCY - Environmental and ergonomic impact**

*Transportation* — Construction requires transportation! Therefore, there is a direct correlation between cost as well as the environmental impact. Transportation costs are directly related to the weight of concrete products, demonstrating a significant economic advantage when using lightweight concrete. The range of products includes large structural members (girders, beams, walls, hollow-core panels, double tees) to smaller consumer products (precast stair steps, fireplace logs, wall board, and imitation stone). Two trucking studies conducted at a U.S. precast plant are shown in Table 1.1. These studies demonstrated that the transportation cost savings were seven times more than the additional cost of lightweight aggregate. Savings vary with the size and mass of the product and are most significant for the smaller consumer-type products. For example, one manufacturer of lightweight concrete wallboard has shipped products to all 48 mainland states from one manufacturing facility.

Fewer trucks in congested cities are not only an environmental necessity but will also generate fewer public complaints. The potential for lower costs is possible when shipping by rail or barge but is most often realized in trucking where highway loadings are posted.

**Table 1.1**
**Analysis of Shipping Costs of Concrete Products ***

| | Project Example Number 1 | Project Example Number 2 |
|---|---|---|
| Shipping Cost per Truck Load | $ 1,100 | $ 1,339 |
| Number of Loads Required | | |
| Normalweight | 431 | 87 |
| Lightweight | 287 | 66 |
| Reduction in Truck Loads: | 144 | |
| Transportation Savings | | |
| Shipping Cost per Load | $ 1,100 | $ 1,339 |
| Reduction in Truck Loads | x 144 | x 21 |
| Transportation Savings: | $ 158,400 | $ 28,119 |
| Profit Impact | | |
| Transportation Savings | $ 158,400 | $ 28,119 |
| Less: Premium Cost of lightweight concrete | - 17,245 | - 3,799 |
| Transportation Cost Savings by using lightweight concrete | $ 141,155 | $ 24,320 |

- Courtesy of Big River Industries, Inc.

With ready-mix concrete up to 25% more, lightweight concrete can be delivered to the job site per truck load than with conventional concrete. This also translates into fewer trucks on the roads and around congested construction sites.

*Sustainability of the Workforce - Ergonomics* – Less weight makes concrete labor friendly. The best example of lightweight concrete and ergonomics is with concrete masonry. The Center for Infrastructure Research, University of Nebraska at Lincoln reported that long-term problems stem from heavyweight concrete masonry units. "Concrete masonry is a dominant material in wall construction. Over $10 billion worth of masonry walls are constructed in the United States every year. However, the industry is facing a shortage of qualified masons, and the average age of active masons has been gradually increasing due, in part, to the hard work they have to do in lifting heavy concrete masonry units. The load of lifting these blocks, day after day, can make drudgery out of a day's work for a mason, especially after many years. **Some masons must retire early due to the heavy lifting, and many masons experience crippling back and shoulder injuries before retirement".** This continual loss of skilled labor is expensive to replace and may ultimately make masonry non-competitive.

By reducing the weight of concrete masonry and other concrete products that must be physically handled by labor we enhance sustainability to our workforce. It is common knowledge that lighter components have a positive effect on constructability, for example (ESCSI info sheet 3650.3, 1996):

- At the same strength, lightweight concrete masonry units are up to 40% lighter than traditional concrete masonry units. Less weight minimizes the physical demands on masons and equipment, resulting in fewer injuries and workers' compensation claims. Repeatedly lifting less weight also extends a mason's career, and allows women and men to work efficiently.
- Concrete masonry units that weigh less will increase mason productivity up to 21% on 8x8x16" units, and 55% on 12x8x16" units. Increase productivity means earlier completion and lower overhead costs. Even though a mason will lay approximately 20% more wall area in a year, the mason still lifts 15% less weight (about 94 less tons per year).
- Less weight extends equipment life because lighter loads mean less wear and tear and helps insure safer scaffolding and worker platforms. Less weight means it is easier to meet OSHA weight requirements.

**STRUCTURAL PERFORMANCE – How does the product affect the overall performance of the structure?**

*Fire resistance* - Lightweight concrete is more fire resistant than ordinary normalweight concrete because of its lower thermal conductivity, lower coefficient of thermal expansion, and the inherent fire stability of an aggregate already heated to over 2000 °F (1100 °C); As reported in ACI 216 "Standard Method for Determining Fire Resistance of Concrete and Masonry Construction Assemblies", when slab thickness is determined by fire resistance and not by structural criteria (joists, waffle slabs e.g.), the superior performance of lightweight concrete, will reduce the thickness of slabs resulting in significantly lower concrete volumes.

*Service life of the structure* - The first known use of lightweight concrete dates back over 2000 years. There are several lightweight concrete structures in the Mediterranean region, but the three most notable structures were built during the early Roman Empire and include the Port of Cosa, the Pantheon Dome, and the Coliseum.
The Port of Cosa, built about 273 B.C., used lightweight concrete made from natural volcanic materials. These early builders learned that expanded aggregates were better suited for marine facilities than the locally available beach sand and gravel. They went 25 miles (40 km) to the northeast to quarry volcanic aggregates at the Volcine complex for use in the harbor at Cosa. Broken shards of calcined clay vases were also used in the piers....the first usage of manufactured aggregate. This harbor is on the west coast of Italy and consists of a series of four piers (~ 13 ft [4 m] cubes) extending out into the sea. For two millennia they have withstood the forces of nature with only surface abrasion. They only became obsolete because of siltation of the harbor.

The Pantheon, finished in 27 B.C., incorporates concrete varying in density from bottom to top of the dome. Roman engineers had sufficient confidence in lightweight concrete to build a dome whose diameter of 142 ft (43.3 m) was not exceeded for more than nineteen hundred years. The structure is in excellent condition and is still being used to this day for spiritual purposes.

The Coliseum, built in 75 to 80 A.D., is a gigantic amphitheater with a seating capacity of 50,000 spectators. The foundations were cast as lightweight concrete using crushed volcanic lava. The walls were made using porous, crushed-brick aggregate. The vaults and spaces between the walls were constructed using porous-tufa cut stone. After the fall of the Roman Empire, lightweight concrete use was limited until the twentieth century when expanded shale, clay and slate lightweight aggregate became available for commercial use (ESCSI 1971)

While it is clearly understood that the terms high strength and high performance are not synonymous, we may consider the first modern use of high-performance concrete to be when the American Emergency Fleet Corporation built lightweight concrete ships (1917-1920) with specified compressive strengths of 5000 psi (35 MPa) was obtained with a unit weight of 110 lb/ft$^3$ (1760 kg/m$^3$) or less, using rotary kiln produced expanded shale and clay aggregate. Commercial normalweight concrete strengths of that time were approximately 2500 psi (17 MPa).

In energy-related floating offshore concrete structures, great efficiencies are achieved when a lower density material is used. A 25% reduction of mass in air will result in a 50 % reduction when submerged. Because of this, the oil and gas industry recognized that lightweight concrete could be used to good advantage in its floating structures as well as structures built in a graving dock and then floated to the production site and bottom founded.

Several hundred bridges have incorporated lightweight concrete into decks, beams, girders, or piers. Transportation engineers generally specify higher concrete strengths primarily to ensure high-quality mortar fractions (high compressive strength combined with high air content) that will minimize maintenance. Thousands of bridges in the United States are functionally obsolete with unacceptably low load capacity or an insufficient number of traffic lanes. Structural lightweight concrete has played a major roll in bringing these structures up to modern compliance in an environmentally responsible way.

**ECONOMICS OF SUSTAINABILITY**

The use of any building material is predicated on cost, functionality, aesthetics, or a combination of these. The "politically correct" minimum first cost methodology of owners, designers and public officials around the world has contributed to a non-sustainable system. Decisions based on first cost ignore life long maintenance, rehabitation and operating cost. A stronger-faster-is-better attitude has unfortunately lead to an unintended consequence, a high level of widespread early age cracking. Life cycle costing is the only way to evaluate the sustainability of a project.

The cost of lightweight concrete per cubic yard (cubic meter) is usually higher than a comparable unit of ordinary concrete. The following example is a typical comparison of unit cost between lightweight and normalweight concrete on a bridge project.

> Assume the in-place cost of a typical short span bridge may vary from 50 to 200 $\$/ft^2$ (540 to 2150$\$/m^2$).
> If the average thickness of the deck was 8 in. (200 mm) then one cubic yard ($m^3$) of concrete would yield approximately 40 $ft^2/yd^3$ ($5m^2/m^3$) of deck area.
> Using lightweight concrete with a premium in the range of 20 $\$/yd^3$ (26 $\$/m^3$) over normalweight concrete would result in: 20 $\$/yd^3$/40 $ft^2/yd^3$ = 0.50 $\$/ft^2$ (5 $\$/m^2$) or generally less than a 1% increase (reference ACI 213).

This increase is more than offset by the cost savings in reduced concrete and reinforcing in girders, piers, footings, as well as other benefits covered earlier.

**OVERALL ENVIRONMENTAL IMPORTANCE**

Very early in the conceptual design an evaluation of how the structure interfaces with its environment needs to be made. Structures using these products must blend with and enhance the sustainability and the overall quality of life.

*Energy consumption* - Edward Mazria, author of the 1979 book "The Passive Solar Energy Book" claims the conventional wisdom of his profession, architecture, is dangerously out of touch with reality. Mazria reorganized the existing data of the U.S. Energy Consumption by sector and exposed architecture as both the problem and potential solution for global warming (Metropolis, Oct. 2003). The Metropolis article points out by "combining the energy required to run residential, commercial, and industrial buildings along with the embodied energy of industry – provided materials like carpet, title and hardware, architecture accounts for 48% of energy consumption. Total energy consumption as reported is shown in the following table:

| Sector | U.S. Energy Consumption published data | U.S. Energy consumption re-arranged by Edward Mazria |
|---|---|---|
| Industry | 35% | 25% * |
| Residential | 21% | * |
| Commercial | 17% | * |
| Architectural | — | 48% |
| Transportation | 27% | 27% |
| Total | 100% | 100% |

* All or a portion included in Architecture.
(Source Metropolis, October 2003)

When viewed from Mazria's architecture prospective, architecture is shown to be the primary $CO_2$ emitter. This points out the pressing need for widespread change in the way buildings are designed. Buildings and structures need to be more energy efficient and engage environmental issues.

**U.S. $CO_2$ Emissions by Sector**

| Sector | 1950 mmt | 2000 mmt | % Increase |
|---|---|---|---|

| | (million metric tons) | | |
|---|---|---|---|
| Industry * | 215 | 330 | 53 |
| Architecture | 275 | 720 | 162 |
| Transportation | 180 | 520 | 189 |

* U.S. $CO_2$ Emission have been essentially constant at about 330 mmt since 1970 (Source Metropolis, October 2003)

*Thermal performance* - Lowering the concrete density increases thermal resistance. For example concrete at 90 $lb/ft^3$ has an R value of 0.26/inch where the R value for 135 $lb/ft^3$ concrete is approximately .10/inch. In other words the 90 $lb/ft^3$ concrete have a 260% better insulation factor then the 135 $lb/ft^3$ material (ESCSI info sheet 3201, 1999).

Henderson Engineering, Inc., Kansas City, MO, performed an energy cost study on a "big box retail" building for the Expanded Shale, Clay & Slate Institute to determine how lightweight concrete masonry at 90 $lb/ft^3$ affected the LEED category EA1 when compared to normalweight concrete masonry at 135 $lb/ft^3$. Several locations were evaluated with results for Omaha, NE (a central location) listed as follows:

- Heating peak loads for exterior walls was 44% less.
- Cooling peak loads for exterior walls was 51% less.
- Total building heating peak load was 12% less.
- Total building cooling peak load was 2% less.
- Total building annual energy consumption was 2.2% less.

These savings translate into 5.5 cents per block per year. That savings is significant and extends over the life of the structure. This life cycle savings per block is many, many times greater than the potential higher first cost of the block. The peak load savings allow for smaller, more economical HVAC equipment to be used in many cases. This in turn lowers initial equipment cost and weight, and reduces peak demand on utility infrastructure. The annual energy consumption savings was calculated using flat rate energy cost. Additional benefits will result when using off-peak utility rates that are a consequence of longer time lags made possible with lightweight concrete.

*Embodied energy* - It is well documented that the total embodied energy to build a building is only 1 to 3% of the total occupant energy used by that building over its useful life (Construction Technology Laboratories report project no. 180028 conducted for ESCSI 2001). In light of the facts that approximately 97 to 99% of the energy used throughout the building life cycle is primarily a function of climate and occupant behavior, it becomes obvious that our biggest energy resource is efficiency.

*Performance* - From a performance perspective, concrete has room for improvement. There are many examples of concrete deteriorating after 10, 20 or 30 years in service. This is unacceptable when compared to numerous examples of concrete structures lasting well over 100 years and in some cases 2000 years. Poor performing concrete has frequently resulted from inadequate specification and/or improper designs for the intended use. The entire concrete community (owner, designer, material supplier, concrete manufacturer, and contractor) has fallen short by not implementing and transferring the currently available knowledge needed to insure that quality concrete is specified and constructed. Raising the minimum requirements in building codes and ACI and ASTM standards may be required to meet sustainable development demands and lower life cycle cost.

Society must now define and require a profoundly extended service life from its structures. Are 100, 300 or 1000 year design lives appropriate? Its becoming very evident that economic and environmental burdens will not allow future generations to replace structures (utility lines, bridges, roads, buildings, etc) every 20, 30 or 50 years. Many of our structures are designed as essentially throw away structures. To meet the challenges of sustainable development the concrete industry needs to recognize our global responsibility and offer longer lasting products that are properly specified, designed and constructed.

**CONCLUSION**

Examples have shown where the use of lightweight aggregate in concrete has saved materials, labor and transportation cost, as well as improving the performance and service life of concrete. In addition, it has shown how using lightweight aggregate can lower the overall energy consumption of structures throughout their useful lives. These benefits all fit into the green building movement and help projects become LEED certified. The use of lightweight aggregate often lowers initial construction cost and most importantly, significantly lowers the life-cycle cost of the structure.

When viewed from a larger perspective the authors acknowledge that this paper is but a small step forward, and recognize that for the successful achievement of true sustainable development, a fundamental shift in attitudes, belief systems and conscious behavior must take place. All construction materials must be evaluated from a total life cycle assessment. This is the only way to determine the real cost and life impact of a product, structure or social behavior. To develop a sustainable world we must shift from our current short-term way of doing and evaluating things, to a long term, holistic mind set that recognizes performance and the interdependence of all life. Considering the fact that architecture (building performance) accounts for a major part of total U.S. energy consumption, initial cost can no longer be the determining criteria when evaluating the usefulness of a product or structure.

The biggest hurdle in creating a sustainable social, economical and political society is overcoming the belief that "it can't be done". Many people believe that any significant move toward sustainable development will result in a disruption of our current system. We do not share this position. We believe a sustainable way of life can be immediately implemented in a positive, responsible and practical way. If everyone involved in the building industry especially Architects and engineers, started to create energy efficient building designs, major positive environmental changes would take place.

The perception that fast track construction saves time and money needs to be re-evaluated. There are numerous examples of the old adage, "Haste makes waste," being true with Fast-Track. From a long-term sustainable development perspective, in some cases fast-track attitude may be counter productive and result in non-sustainable construction practices and poor performing buildings and structures.
As stated earlier the primary objective of truly achieving sustainability is to change beliefs and attitudes. This requires concern for long-term performance with minimal maintenance and energy requirement in our designs, as well as efficiency and responsibility in our manufacturing. There are many changes that can be accomplished in the present that will yield major positive results for humanity now and in the future. We have listed just a few improvements that affect the concrete community.

AFTER ALL, SUSTAINABILITY IS JUST GOOD DESIGN AND COMMON SENSE!

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