A Factor 10 Solution: Integrated Design in Architecture

Factor 10 Engineering for Sustainable Cities

IABSE Henderson Colloquium, Cambridge
July 10th – 12th, 2006

Greg Franta, FAIA
Principal Architect, Built Environment Team
Rocky Mountain Institute
1215 Spruce Street, Suite 301
Boulder, CO 80302 USA

The Issue: Building Energy Consumption and Emissions

Traditional sources of energy production and use are major culprits of atmospheric pollution. Buildings gobble close to 40 percent of the energy used annually in the United States to heat, cool, ventilate, light, and support other operations.[1] This operational energy, plus the energy used to extract, harvest, and manufacture products, transport materials, and construct buildings means the building industry chews through more than half of all the energy used in the United States each year.[2]

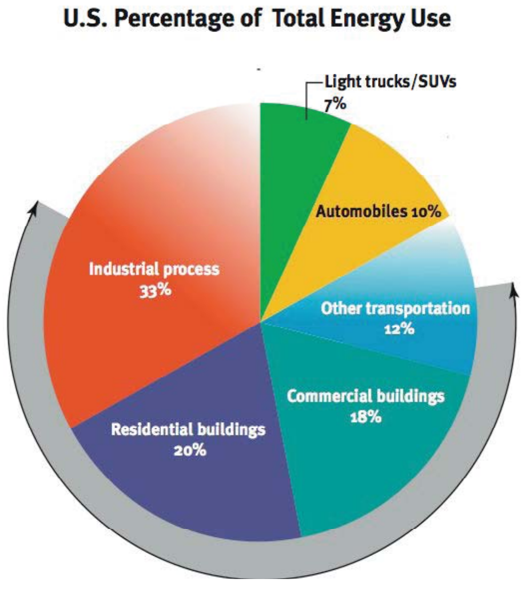

Figure 1. U.S. Energy Use by Sector

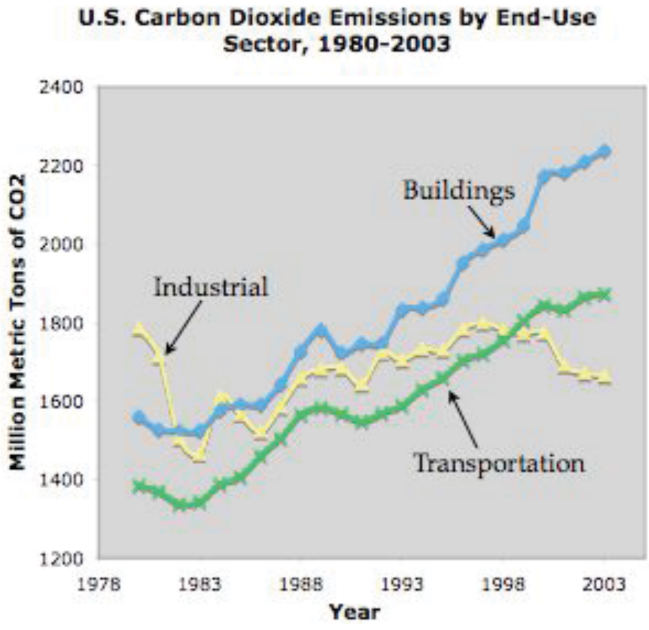

Figure 2. U.S. Carbon Emissions by Sector

[1] Energy Information Administration (www.eia.doe.gov) 2003 data (includes Fig 1.).
Fig. 2 data from table 12.2, EIA Annual Energy Review 2004.

[2] Greg Franta, FAIA, “High-Performance Buildings Through Integrated Design,” RMI Newsletter, 2006.

U.S. building energy consumption is similar to that observed in other industrialized countries. On a global basis, however, buildings appear to have a smaller impact (as shown in Fig. 3 below). Yet given that a good portion of both the transportation and industrial sectors contribute to building related activities, one could make the case that ***worldwide, the building industry (including operations and embodied energy) is the largest single consumer of energy***.

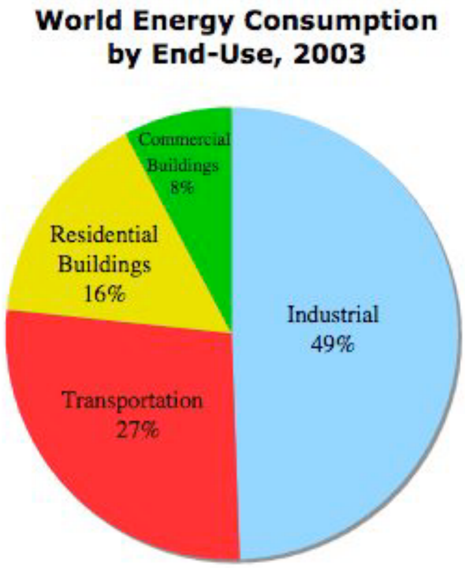

Figure 3. Data from International Energy Outlook, 2006.
World Delivered Energy Consumption by End-Use Sector.

A Solution: Factor Ten Engineering

At Rocky Mountain Institute (RMI), a non-profit applied research center, an ambitious Factor Ten Engineering (10xE) project is already underway. Through development of a casebook on integrative design, and later development of associated instructional methods, we plan to equip the next generation of engineers, and retread the existing ones, with the tools of whole-system design. These whole-system thinkers will then be equipped to develop far more sustainable (and more profitable) solutions to future engineering problems by capturing the interactive effects made available through whole-system design.

The casebook will include a thorough engineering analysis of several dozen of the most interesting cases, organized in facing-columns format with the standard practice case, explaining the difference in design principles between the integrative design and the standard practice. Our aim is to have the design principles build on each other, so that by the end of the book the reader's 'mental furniture is irreversibly rearranged' so they never can go back to designing in isolation. The cases will span the range of engineering disciplines and common applications, and typically achieve order-of-magnitude energy and resource savings -- sometimes considerably more -- with lower-than-normal capital cost. Through astonishing but, once understood, blindingly obvious cases, we aim to bring to firms and classrooms worldwide a sound and compelling pedagogic basis for the nonviolent overthrow of bad engineering. While we believe the target of ten-fold resource productivity through better engineering is achievable, it is clearly not trivial. This optimization will need an extraordinarily high degree of cross-disciplinary thinking in the engineering design process.

Figure 4. From article titled, "'Factor Ten' and the Nonviolent Overthrow of Bad Engineering," by Andrew Kean (www.rmi.org)

In recent years, RMI's Integrative Design, Energy and Resources, and Built Environment teams have redesigned about $20 billion worth of facilities on these lines. Our clients are happy to learn how to do such radically efficient designs, but we are not so thrilled because we keep seeing the same design errors over and over. If the designs had been properly done in the first instance, such improvements would not be necessary. Indeed, the incorrect methodologies that underlie much of the inefficiency we observe are clearly set out in all the leading engineering textbooks! Rather than correcting these errors in minute particulars, it would be far better to change engineering pedagogy and practice so such errors are ultimately extirpated. And to this end, we have hatched the ambitious 10xE project and invite engineers and teachers with experience or interest in whole-system design to join us![3]

The Built Environment

From the destructive construction process to contributions to deforestation, global warming, and water cycle interruption, the impact of buildings on our planet is both substantial and undeniable. However, as outputs from a hodgepodge of disciplines, the built environment also offers an abundance of opportunities for Factor Ten Engineering and subsequent resource savings.

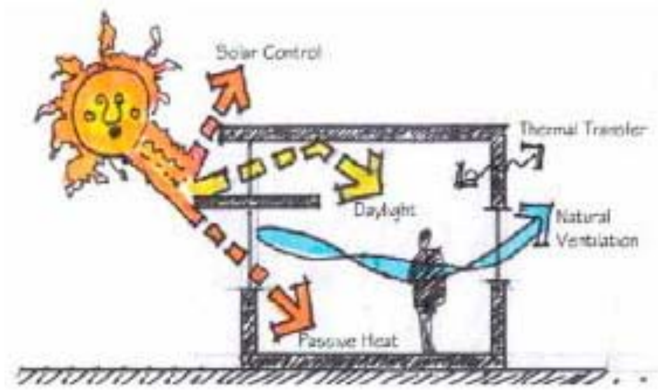

Figure 5. Concepts of climate-responsive architecture.

[3] Imran Sheikh, 10xE Research Fellow, Factor 10xE Press Release, RMI, 2006.

With buildings, whole-system design refers not only to sustainable features but also to other design criteria such as aesthetics, cost, and schedule. The result of the integrated design process is a new generation of refined architecture with radically optimized energy and water efficiency, appropriate natural materials, and superior indoor environments.

Energy efficiency and the use of renewable energy in buildings create win-win solutions, as lower operating costs correspond to reduced atmospheric pollution. Integrated design for energy optimization on a new building starts with climate-responsive architecture in which nature provides as much lighting, ventilation, cooling, and heating as possible. Following are case studies of several buildings and communities that exemplify the concept of integrated design in architecture.

Building Case Studies

Natural Energy Laboratory of Hawaii Authority

The Natural Energy Laboratory of Hawai‘i Authority has a new visitor center in Kona, Hi. – the Hawai‘i Gateway Energy Center, designed by Ferraro Choi Architects of Honolulu. This 3,600-square-foot building houses multi-purpose space for displays, outreach, conferencing, and education, as well as for administrative offices. Annually, it actually produces more energy than it uses. This unique facility (see Fig. 6) uses 43-degree (F) seawater pumped from 3,000 feet below sea level to passively condition the building. Outside air is drawn over cooling coils and moved through the space employing the solar powered stack effect, generated entirely as a result of the building design. The system’s cooling and ventilation capabilities exceed ASHRAE standards. The condensation water surrounding the coils is used for landscaping and toilets. Waterless urinals were also installed. A 20-kilowatt photovoltaic array provides a renewable source of electricity.

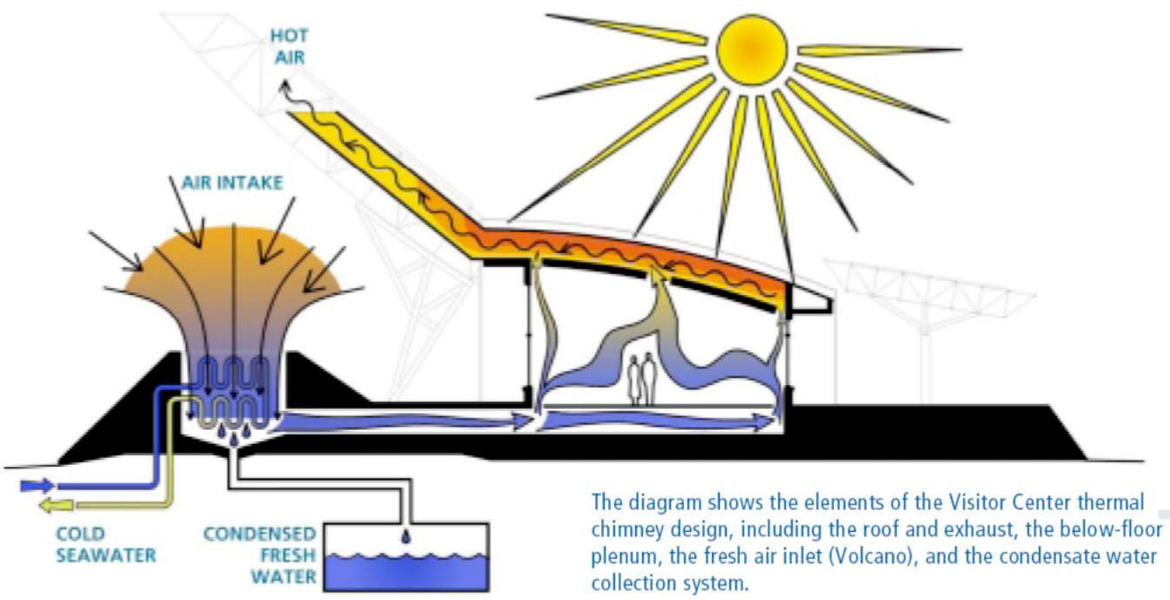

Figure 6. The Deep Seawater cooling system at the Hawai’I Gateway Energy Center. Figure by Ferraro Choi Architects.

The calculated peak demand for the visitor center is approximately 10 kilowatts, thus the center is a net exporter of power. The project (see Fig. 7) is entirely naturally lit during daylight hours, which was achieved through north-south orientation of the fenestration.

Figure 7. Southern view of the Hawai‘i Gateway Energy Center. The design team included Ferraro Choi and Associates (architect), Lincolne Scott, Inc. (mechanical/electrical/energy), Libbey Heywood, Inc. (structural), R. M. Towill Corporation (civil), LP&D (landscape), Triodetic Space Frames (space frames), Bolton, Inc. (contractor), Engineering Economics, Inc. (commissioning authority), and RMI/ENSAR Built Environment Team (LEED management).

Curitiba Schools, State of Paranà, Brazil

The State of Paranà in Brazil is developing new schools with the use of standard architectural plans for construction in Curitiba and elsewhere in Paranà. These schools are affordable to construct, use local building materials and techniques, and can be located and built in a timely manner. RMI/ENSAR provided energy analysis and design consulting for the facility including energy modeling, daylighting design, natural ventilation strategies, and material specification. The LEED Rating System has been used as a tool during the design process. This project would be in a LEED Gold category if it attempted certification. In terms of energy performance, the school has a high level of thermal comfort (without mechanical systems for heating, cooling, or ventilating) and operates at a 75% reduction in energy cost.

Figure 8. Before retrofit.

Figure 9. After retrofit.

Missouri Department of Natural Resources

The Missouri Department of Natural Resources, in Jefferson City, Mo. recently developed a stellar example of what can be achieved with green strategies in its new 120,00-square-foot Lewis and Clark State Office Building, designed by BNIM Architects of Kansas City. The previously developed site was restored to emphasize native prairie plants and ecosystems, and to minimize storm water run-off. The elongated east–west orientation allows the preferred north and south glazing and the building is organized around a central four-story atrium (Fig. 10). The building envelope has high-performance glazing, vertical fins, and horizontal light shelves that allow considerable daylight with appropriate sun control. The project also utilizes cutting-edge approaches to electric lighting and controls, building envelope design, and HVAC systems. This project clearly helps achieve its mission to protect and restore natural resources. Wood certified by the Forest Stewardship Council directly addresses deforestation issues.

Figure 10. Missouri Department of Natural Resources

Figure 11. FSC certified wood installed at Missouri DNR

Community Case Studies

Eco Village, Leesburg, Virginia

Eco Village, a sustainable community being developed near Washington D.C. will be home to over 600 people. The project, which includes 50 dwellings, also incorporates a multi-use community building, which provides local employment and educational opportunities. RMI/ENSAR is the prime architect responsible for the master planning, sustainability guidelines, conceptual and preliminary designs, and all design/construction review. Buildings constructed to date have demonstrated excellent energy performance and are consistently more efficient than the building base case, modeled after other local buildings.

Figure 12. Single-family home in Eco Village

Ladera Ranch, Irvine, California

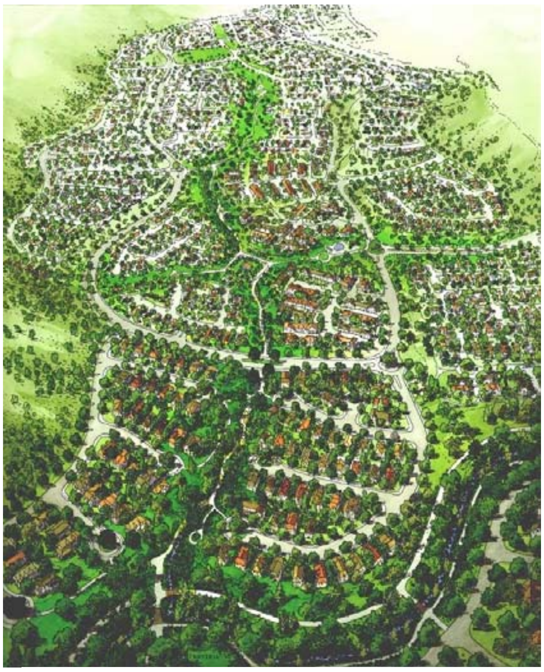

Figure 13. Bird’s eye view of Ladera Ranch

Ladera Ranch is a planned community development located in Orange County, CA. that was completed in 2004. The community is organized into six villages defined by physical features and public amenities that will accommodate approximately 8,000 housing units (both single and multi-family units), 870,000sf of commercial space, and 1,600 acres of open space. RMI/ENSAR provided sustainable consulting services including developing criteria for the “Green Development Program” plus training and coordination for energy analysis. The LEED system was used as a tool in the development of the program, although was adapted to be more applicable to residential issues.

Figure 14. Sketch of Ladera environment.

Development of Eco-Cities

The aforementioned communities embody the concept of whole system design by integrating green design with the appropriate infrastructure and social services. Rather than looking for isolated problems with distinct solutions, Ladera Ranch and Eco Village recognize links between sustainability, economic growth, and human health, and are therefore able to address multiple interests with fewer resources. As noted by Amory Lovins of Rocky Mountain Institute, "Successful societies require that each action they take answers many needs simultaneously."[4] This is even more of a necessity in the developing world where "such whole-system thinking is at a premium, because the new pattern of scarcity . . . – abundant people but scarce nature – has arrived there early and with a vengeance. ***For the developing world, most acutely, the relevant question will be: How many problems can be simultaneously solved or avoided, how many needs can be met, by making the right initial choices? And how can those choices be linked into a web of mutually supporting solutions, creating a healthy economic, social, and ecological system that develops both better people and thriving nature?***"[5]

A successful example of integrated development that does in fact develop both better people and thriving nature comes from the city of Curitiba, Brazil.[6] With a population of 2.1 million in 1990 (expected to grow to 3.1 million by 2020) Curitiba is representative of many Brazilian cities, yet only in size. Since the 1970's Curitiba has (unlike other Brazilian cities) shunned mega projects in favor of hundreds of multipurpose, financially responsible, community supported projects. Ranging from the revitalization of the central historic district to the implementation of a cost and time effective express-avenue transportation system to the purchase of centrally located land for low-income housing, Curitiba does it right in many ways. The key however, is the exclusion of typical engineering practices in favor of a weighted design decision process, which treats transportation, land-use, hydrology, poverty, waste flows, health, education, jobs, income, culture, and politics as equal components.

Figure 15. Tube stations in Curitiba.

---

[4] Amory Lovins, Natural Capitalism, p287, 1999.
[5] Ibid, p288.
[6] This case study is articulated in detail in Chapter 14 – Human Capitalism, from Natural Capitalism.

One stellar example of thoughtful integrated design is Curitiba's bus system. Double or triple length buses carry up to 270 passengers minimizing fuel per seat mile as well as per seat trip as triggered light signals also minimize travel time. In addition to high capacity vehicles, the city streamlines boarding procedures via above ground "tube stations" (see Fig. 15) where citizens board and disembark buses without needing to climb stairs or pay fares (as they pay upon entering the "station"). Additionally, the ten private operating firms are compensated based only on miles covered so there is plenty of incentive to serve all communities. And lastly, the system is entirely self-financing from flat-rate, unlimited transfer fares, effectively using shorter commutes by the middle class to subsidize longer commutes by the poor. The system is one of the best managed in the world – and the Curitiban citizens appreciate and respect it.

In Curitiba, "Resources are used frugally. New technologies are adopted. Broken loops are reclosed. Toxicity is designed out, health in. Design works with nature, not against it. The scale of solutions matches the scale of problems."[7] Proper scaling is not only well articulated in Lovins's *Natural Capitalism* but also in one of RMI's newer publications, *Small is Profitable,* which focuses on the benefits of distributed power generation.

Utility Planning and Distributed Generation

Small is Profitable explains that although some distributed technologies like solar cells and fuel cells are still made in low volume and can therefore cost more than competing sources, their increased *value*—due to improvements in financial risk, engineering flexibility, security, environmental quality, and other important attributes—can often more than offset their apparent cost disadvantage. The book introduces engineering and financial practitioners, business managers and strategists, public policymakers, designers, and interested citizens to those new value opportunities. It also provides a basic introduction to key concepts from such disciplines as electrical engineering, power system planning, and financial economics. Its examples are mainly U.S.-based, but its scope is global.[8]

Specifically, RMI found that distributed resources—both supply sources such as solar cells and fuel cells and demand-side resources such as energy efficiency and peak demand response programs—can provide significantly higher economic benefits than typical utility planning processes and tools recognize. These benefits come from financial risk management, electrical grid impacts, power quality/reliability, and environmental quality impacts. In more practical terms, RMI has codified its insights on how to incorporate renewable, distributed, and demand-side resources into the integrated planning process with its Energy Resource Investment Strategy (ERIS) methodology. The ERIS methodology is an extension of the Integrated Resource Planning (IRP) approach that was adopted by many utilities in the early 1990s.[9]

RMI has recently been actively applying this methodology with private utilities in Hawaii and Missouri, public utilities in California and Nebraska, as well as with the cities of San Francisco, Sacramento and Palo Alto. The typical results of our analysis using the ERIS methodology is that a

---

[7] Ibid, p.307.
[8] Lovins et al. "Small is Profitable," Excerpt from Executive Summary, 2002.
[9] See J. Swisher, G. Jannuzzi and R. Redlinger, 1998. *Tools and Methods for Integrated Resource Planning: Improving Energy Efficiency and Protecting the Environment*, UNEP Collaborating Centre on Energy and Environment, Denmark. http://uneprisoe.org/highlights.htm#irp

portfolio of renewable and distributed resources, including both supply and demand-side technologies, can provide comparable quantity, quality and reliability of energy services as conventional, central supply. Moreover, the distributed resource portfolio can slow the increase in customer energy bills, despite rising fuel costs, and reliably reduce the economic and environmental risks of increased exposure to volatile power, fuel, and emissions markets.

Closing Thoughts

Sustainable architecture and factor ten engineering are wholly dependent on whole-system design. While high performance buildings are a good start, high performance communities are even better! While essential to design buildings within the political and economic constraints of the community, it is also necessary to consider the context and possible adaptations a project can contribute to local transportation and utility services. In closing, think about the following RMI design guidelines – both practical and sometimes obvious, these principles are essential to generating whole-system designs.

- ⇒ Downstream before upstream
- ⇒ Demand before supply
- ⇒ Application before equipment
- ⇒ People before hardware
- ⇒ Passive before active
- ⇒ Quality before quantity
- ⇒ And lastly, ***capture multiple benefits from single expenditures***