

# Towards a sustaining architecture for the 21<sup>st</sup> century: the promise of cradle-to-cradle design

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## Summary

*Cradle-to-cradle design is an ecologically intelligent approach to architecture and industry that involves materials, buildings and patterns of settlement which are wholly healthful and restorative. Unlike cradle-to-grave systems, cradle-to-cradle design sees human systems as nutrient cycles in which every material can support life. Materials designed as biological nutrients provide nourishment for nature after use; technical nutrients circulate through industrial systems in closed-loop cycles of production, recovery and remanufacture. Following a science-based protocol for selecting safe, healthful ingredients, cradle-to-cradle design maximizes the utility of material assets. Responding to physical, cultural and climactic settings, it creates buildings and community plans that generate a diverse range of economic, social and ecological value in industrialized and developing countries.*

## Résumé

*Les méthodes de conception qui envisagent un produit depuis sa production jusqu'à la valorisation de ses résidus constituent une approche écologiquement intelligente de l'architecture et de l'industrie qui créent des matériaux, des bâtiments et des modèles d'établissement parfaitement sains et stimulants. Contrairement aux méthodes dites « de bout en bout », elles considèrent les systèmes humains comme des cycles de substances nutritives où chaque matériau a un rôle à jouer dans le maintien de la vie. Les matériaux étudiés comme des substances nutritives biologiques servent de nourriture à la nature après usage ; les substances nutritives techniques circulent dans les systèmes industriels selon des cycles de production, de valorisation et de reconditionnement à boucle fermée. Respectant un protocole à fondements scientifiques pour sélectionner des ingrédients présentant une totale innocuité et bons pour la santé, les méthodes de conception qui envisagent le produit depuis sa production jusqu'à la valorisation de ses résidus renforcent le potentiel des ressources en matériaux. Adaptées au contexte physique, culturel et climatique, elles créent des bâtiments et des projets d'intérêt collectif générateurs de valeurs économiques, sociales et écologiques, dans les pays industrialisés comme dans les pays en développement.*

## Resumen

*El diseño "cradle to cradle" (múltiples ciclos de vida) es un planteamiento ecológico inteligente de la arquitectura y la industria que crea materiales, edificios y patrones de asentamiento totalmente sanos y reparadores. Diferente de los sistemas "cradle to grave" (ciclo de vida único), el diseño "cradle to cradle" considera los sistemas humanos como ciclos nutrientes en los que cada material puede sustentar la vida. Los materiales diseñados como nutrientes biológicos proveen alimento para la naturaleza después de ser utilizados. Los nutrientes técnicos circulan en sistemas industriales en ciclos cerrados de producción, recuperación y remanufactura. Siguiendo un protocolo establecido sobre bases científicas para seleccionar ingredientes seguros y sanos, el diseño "cradle to cradle" aprovecha al máximo la utilidad de los valores materiales. De acuerdo al medio físico, cultural o climático, crea edificios y planes comunitarios que generan una amplia gama de valores económicos, sociales y ecológicos tanto en naciones industrializadas como en países en desarrollo.*

As the global flow of advanced architectural materials grows with the expanding global economy, and as even traditional dwellings built with local materials begin to put pressure on natural resources in developing countries, environmental policy makers, business leaders and governments worldwide are increasingly embracing energy and material efficiency to mitigate the impacts of architecture.

But perhaps eco-efficiency's moment has past. "Doing more with less" played a valuable role in slowing ecological destruction in the late 20<sup>th</sup> century, but it is not up to the challenges presented by the kind of growth and global change expected in the 21<sup>st</sup>.

Certainly, eco-efficient measures such as the European Union's national targets for energy and material efficiency are laudable attempts to sus-

tain human health and economic growth. But using less fuel to heat energy-efficient highrises or sending less building material to landfills does not address the deep flaws of contemporary architecture and industry; it simply limits the negative impact of poor design.

The result, an easing of ecological stress, has been an important step towards a more just and healthful world. But it is yesterday's step. The time has come to adopt a truly hopeful strategy that will solve rather than merely alleviate the problems associated with buildings and construction, a strategy that will transform architecture into a celebration of a human ecological footprint with wholly positive effects.

Yesterday's ecological footprint

To move towards a sustaining, life-supporting human footprint, it is worthwhile to take a close look at the ideas and practices informing sustainable architecture today. The realization that conventional, modern architecture is not sustainable over the long term is not new. Constructing and maintaining new buildings rivals the global economy's entire manufacturing sector in material and energy use. For over a decade UNEP and other international bodies, along with an expanding network of NGOs, have been striving to shift the priorities of governments, businesses and architects towards more environmentally sound practices.

But how effective are the typical approaches to design for sustainability? Most are aimed at using energy and material more efficiently, a strategy that grows from the idea that decoupling material use from economic growth can sustain architecture and industry over the long term. This would seem to be a critical insight. A report by the World Resources Institute projects a 300% rise in energy and material use as world population and economic activity increase over the next 50 years. As long as economic growth implies increased material use, it warns, "there is little hope of limiting the impacts of human activity on the natural environment." But, the report continues, if industry can become more efficient, using less material to provide the goods and services people want, economic growth can be sustained – and thus decoupled from resource extraction and environmental harm.<sup>1</sup>

The same study found, however, that despite 25 years of dematerialization by five of the world's

most potent economies, waste and pollution in those nations had increased by as much as 28%. Though many European nations in the past ten years have achieved significant reductions in waste, they are merely reaching for sustainability, which is, after all, only a minimum condition for survival.

It is true that efficiently constructed buildings can cut waste, and that lighter materials can minimize resource consumption. But while designers may make material substitutions – super-efficient glass, triple glazing, recycled plastic – the chemistry of materials in efficient buildings tends to be the same as that in their more gluttonous contemporaries. And that still presents a serious threat to human health.

### Materials and human health

Indeed, *none* of the materials used to make contemporary buildings is specifically designed to be healthful for people. Even a cursory inventory begins to suggest some of the challenges facing architects.

Consider the ubiquitous use of polyvinyl chloride. Better known as PVC or vinyl, it is commonly used for windows, doors, siding, flooring, wall coverings, interior surfaces and insulation. Many PVC formulations contain plasticizers and toxic heavy metals such as cadmium and lead. Plasticizers are suspected of disrupting human endocrine systems, cadmium is known to be carcinogenic, and lead is a neurotoxin.

Equally common are the volatile organic compounds, some of which are suspected carcinogens and immune system disruptors, which are released from particleboard, paints, textiles, adhesives and carpets. Design flaws that trap moisture in buildings and add mould to the substances fouling indoor air, as well as the products developed to fight mould, appear to be generating a permanent breeding ground for resistant microorganisms. The widespread presence of wood preservatives and lead rounds out this formidable array of harmful materials.

Energy efficient buildings, which are designed to require less heating and cooling, and thus less air circulation, can make things worse. A recent study in Germany found that air quality inside several highly rated energy efficient buildings in downtown Hamburg was nearly four times worse than on the dirty, car-clogged street.<sup>2</sup> For all the care taken to save energy by keeping out the elements with better insulation and sealed windows, no one considered the long-term effects of sealing *in* the chemically laden carpets, upholsteries, paints and adhesives used to finish the interiors.

The effects are hard to ignore. When buildings with reduced air-exchange rates are common, so are health problems. In Germany, where tax credits support the construction of energy efficient buildings, allergies affect 42% of children aged six to seven, largely due to the poor quality of indoor air.<sup>3</sup>

Eco-efficient buildings also have a cultural impact. Following the old modernist aesthetic, they tend to be steel and glass boxes short on fresh air and natural light, their internal ecosystems

divorced from their surroundings. Whether located in Frankfurt or Indonesia, they are the same. Architecture critic James Howard Kunstler has called such structures “intrinsicly despotic buildings that [make] people feel placeless, powerless, insignificant, and less than human.”<sup>4</sup>

Are these the kind of buildings we want all over the world? Can't we do better?

### Cradle-to-cradle design

We can. Cradle-to-cradle design raises an entirely different agenda. Rather than seeing materials as a waste management problem, as in the cradle-to-grave system, cradle-to-cradle design is based on the closed-loop nutrient cycles of nature, in which there is no waste. By modelling human designs on these regenerative cycles, cradle-to-cradle design seeks, from the start, to create buildings, communities and systems that generate wholly positive effects on human and environmental health. Not less waste and fewer negative effects, but *more positive* effects. Imagine, for example, buildings that make oxygen, sequester carbon, fix nitrogen, distill water, provide habitat for thousands of species, accrue solar energy as fuel, build soil, create microclimate, change with the seasons, and are beautiful.

One need not simply imagine such places. By clearly understanding the chemistry of natural processes and their interactions with human purpose, architects can create buildings that are delightful, productive and regenerative by design. This represents a radical shift: from inanimate, one-size-fits-all structures into which we plug power and largely toxic materials, to buildings as life-support systems embedded in the material and energy flows of particular places. The presence of such buildings around the world suggests that human activity can indeed create footprints to delight in rather than lament.

This is not just wishful thinking or “concept” design. The cradle-to-cradle philosophy is driving a growing movement devoted to developing safe materials, products, supply chains and manufacturing processes throughout architecture and industry. It is being adopted by some of the world's most influential corporations, including BASF, the world's largest chemical company; Shaw Industries, the world's largest carpet maker; Ford Motor and its major suppliers in the auto industry; and a host of prestigious designers and manufacturers of textiles, furniture and other objects. Even in nations as vast and influential as China, organizations such as the China-US Center for Sustainable Development are adopting this new paradigm to develop healthful buildings, safe industrial processes and sustainable community plans.

Here's why. Cradle-to-cradle design is animated by ecological intelligence. In the natural world – a grand, evolving system based on hundreds of millions of years of research and development – the processes of each organism contribute to the health of the whole. One organism's waste is food for another, and nutrients and energy flow perpetually in closed-loop cycles of growth, decay and rebirth. Waste equals food. Understanding this natural system allows architects and designers

to recognize that all materials can be seen as *nutrients* that flow in natural or designed metabolisms.

Nature's nutrient cycles comprise the *biological metabolism*. The *technical metabolism* is designed to mirror the Earth's cradle-to-cradle cycles; it's a closed-loop system in which valuable, high-tech synthetics and mineral resources circulate in an endless cycle of production, recovery and reuse.

By specifying safe, healthful ingredients, designers and architects can create and use materials within cradle-to-cradle cycles. Materials designed as *biological nutrients*, such as textiles for draperies, wall coverings and upholstery, can be designed to biodegrade safely and restore soil after use, generating more positive effects, not fewer negative ones. Materials designed as *technical nutrients*, such as infinitely recyclable textiles, can provide high-quality, high-tech ingredients for generation after generation of synthetic products. And buildings constructed with these nutritious materials, and designed to respond to local energy flows and cultural settings, encourage patterns of human settlement that are restorative and regenerative.

### Waste equals food: from

dematerialization to rematerialization  
Cradle-to-cradle design yields an entirely new relationship to materials, energy and the making of things. Where eco-efficient designs aim to dematerialize – minimizing the negative effects of toxic materials and polluting fuels – cradle-to-cradle design seeks the *rematerialization* of safe, productive materials in systems powered by the sun.

Rematerialization can be understood as both a process and a metaphor. In the industrial world it refers to chemical recycling that adds value to materials, allowing them to be used again and again in high-quality products. As a metaphor growing from this process, it suggests a design strategy aimed at maximizing the positive effects of materials and energy and participating in the Earth's abundant material flows.

Nylon 6 provides a good example of rematerialization. This widely used polymer can be chemically recycled into the raw material caprolactam, which can be used to make generation after generation of high-quality carpet fibre. In effect, the process virtually eliminates waste – very little energy or material is lost. Given the hundreds of millions of pounds of carpet fibre that each year are sent to landfills or incinerators or recycled into products of lesser value, the significance of rematerializing nylon 6 is enormous. And it suggests an effective new model for material flows.

The model is changing real-world business. Shaw Industries, for example, has examined the material chemistry of its carpet fibre and backing to assess the healthfulness of its dyes, pigments, finishes and auxiliaries – everything that goes into carpet tile. Out of this rigorous process has come the promise of a fully optimized technical nutrient. Shaw now guarantees that all its nylon 6 carpet fibre will be taken back and returned to nylon 6 fibre, and its safe polyolefin backing returned to safe polyolefin backing.

Rematerialization makes conventional recycling



The roof of 901 Cherry (offices of Gap, Inc.) recreates the native habitat of grasses and wild flowers. Its form derives from the surrounding landscape.  
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look obsolete. Most recycling is actually downcycling, a loss of value over time with materials losing value. When various plastics are recycled into countertops, for example, valuable materials are mixed and can't be recycled again. New ultra-light composite materials are hybrids from the start; they can't even be recycled once. And when metals such as copper, nickel and manganese are blended in recycling, their value is lost forever.

The key to effective rematerialization is defining material chemistry and tracking material flows. A materials passport – a tracking code created with molecular markers, for example – makes that possible. The passport guides materials through industrial cycles, routing them from production through reuse, defining optimum uses and intelligent practices. With a passport, valuable construction materials can be rematerialized into valuable construction materials, not recycled into hybrids of lesser value heading inexorably towards the landfill.

When conceived as nutrients, high-tech materials can be safely and effectively used in every phase of construction. Cradle-to-cradle geopolymers, for example, are a promising replacement for concrete, which leaches harmful chemicals on building sites and in landfills. Made from local earth and high-quality plastic, geopolymers are far more stable than concrete and require far less embodied energy to produce. Design for disassembly allows building materials made of geopolymers to be used again in new buildings. Or they can be returned to technical cycles and used in other high-quality products. Another material designed as a technical nutrient, a polystyrene foam engineered by BASF, is being developed as a structural material for low-cost housing in developing countries.

Safe biological nutrients can be used throughout interiors, generating healthful effects during production and use and even after they wear out.

A textile we designed, woven of wool and ramie and processed with completely safe chemicals, provides an attractive, healthful upholstery fabric and can nourish the soil when it wears out. At the Swiss mill where the fabric is produced, the trimmings serve as garden mulch. The water leaving the factory is as clean as the water flowing in.

Rematerialization and cradle-to-cradle design can be applied with high-tech or low-tech methods to new or existing buildings. Harmful materials in existing buildings can be replaced with healthful ones. Old buildings can also be restored with new designs and technologies that harvest the sun's energy – examples include the Audubon Society's century-old headquarters in Manhattan and the venerable Field Museum in Chicago – or flexibly refitted for a variety of new uses.

**Intelligent materials pooling**  
Rematerialization on a large scale can be achieved through a nutrient management system we call intelligent materials pooling. This system, designed to effectively manage flows of polymers, rare minerals and high-tech materials for industry and architecture as well as local, low-tech flows of natural resources, calls for cooperative networks geared to optimizing materials' value.

In an intelligent materials pool, multiple companies share access to a supply of a high-quality material such as nylon 6 or copper. In effect, partners draw materials from the pool to create products and replenish it with materials they have recovered after a defined period of use. Sharing resources and knowledge, information and purchasing power, partners in a materials pool ideally develop a shared commitment to generating a healthy system of material flows and to using the safest, highest-quality technical ingredients in all their products.

From a strategic perspective, the process begins with an agreement by several companies to phase

out an environmentally dangerous material such as PVC. Out of this shared commitment comes a community of companies with the market strength to engineer the phase-out and develop innovative alternatives. Together they specify preferred materials, establish defined-use periods for products and services, and create an intelligent materials pool.

**Design and the laws of nature**  
Cradle-to-cradle architectural materials realize their full potential within cradle-to-cradle buildings. The context of material use is always the larger design, and the larger design always unfolds in the overarching context of the natural world.

Cradle-to-cradle building design is thus the process of discovering beneficial, fitting ways for humans to inhabit the landscape. In every landscape, nature is our guide. We study landforms, hydrology, vegetation and climate, trying to understand all the natural systems at play in each place we work. We investigate environmental and cultural history, study local energy flows, and explore the cycles of sunlight, shade and water. Out of these investigations comes an "essay of clues" – a map for developing healthy and creatively interactive relationships between our designs and the natural world.

The sun is the key to the whole show. When sunlight shines upon the Earth, biology flourishes and we celebrate its increase – the growth of trees, plants, food and biodiversity. This is good growth. When human activity supports ecological health, that's good growth, too. In fact, we can create buildings that make the energy of the sun a part of our metabolism, allowing us to tap the effectiveness of natural systems and apply architecture to positive purpose.

At Oberlin College, William McDonough + Partners (WM+P) designed a building like a tree: a building powered by the sun, enmeshed in local

nutrient flows and beneficial to the landscape. Built in northern Ohio, the Adam Joseph Lewis Center for Environmental Studies was designed to ultimately generate more energy than it consumes. Solar power is collected with rooftop cells and sunlight pours through southwest-facing windows into a two-story atrium, illuminating the public gathering areas. Wastewater is purified by a constructed marsh-like ecosystem that breaks down and digests organic material and releases clean water. The upholstery fabrics will feed the garden, and the carpets will be retrieved by the manufacturer and reused for new, high-quality carpets.

Lit by the sun, refreshed with fragrant breezes, in tune with its place through local flows of energy and matter, the Oberlin building's ecological footprint strongly confirms that the human presence in the landscape can be positive, restorative and 100% good.

### Cradle-to-cradle economics

Cradle-to-cradle design also makes extraordinarily good sense economically and socially. This is especially visible in the workplace. When designs for large-scale factories and offices are modelled on nature's effectiveness, they generate delightful, productive places for people to work. This not only encourages a strong sense of community and cooperation, it also allows efficiency and cost-effectiveness to serve a larger purpose.

Consider the corporate offices for Gap, Inc. in San Bruno, California. Aiming to enhance the qualities of the local landscape, WM+P designed an undulating roof covered in flowers and grasses that mirrors the local terrain, re-establishing several acres of the coastal savannah ecosystem that had been destroyed by human intervention over the past century. The living roof also absorbs storm water and provides thermal insulation, making the landscape an integral part of the building's energy systems.

Other features maximize local energy flows. A raised-floor air system allows evening breezes to flush the building, while concrete slabs beneath the floor store the cool air and release it during the day. The windows are operable and the delivery of fresh air is under individual control. Daylighting provides natural illumination. This is an open design with common spaces.

The building's advanced integrated systems are so effective, it was recognized as one of the most energy efficient buildings in California. By aiming to maximize positive effects, the design outperformed buildings that set efficiency as their highest goal.

The building's high performance is replicable. The Herman Miller furniture factory in Holland, Michigan, like the Gap building, was designed to

foster a spirit of community among employees while enhancing the local environment. An effective, celebratory design achieved both – and more. Not only did the building's site plan include extensive constructed wetlands that rebuild soil fabric, provide habitat and purify storm water, but its design, which maximizes fresh air and sunlight, generated increased worker satisfaction and productivity gains of 24%. Corporations locating in developing countries might take note: designing for human and environmental health supports economic productivity.

### Cradle-to-cradle planning

The benefits of cradle-to-cradle design are not limited to individual buildings. In Chicago, where Mayor Richard Daley is on a quest to make the city the greenest in America, cradle-to-cradle principles are providing an inspiring reference point for a host of citywide initiatives. Building on years of innovative environmental programmes, the City of Chicago is now developing community plans and cradle-to-cradle systems that will make it an international model for cities seeking designs that allow industry and ecology, human settlements and the natural world to flourish side by side.

Among many other initiatives, Chicago has agreed to buy 20% of its power from renewable sources by 2006, which is spurring the local development of renewable energy technology. Indeed, some renewable energy companies have moved into the city's new Chicago Center for Green Technology, an ecologically-intelligent facility built on a restored industrial site. Looking ahead, we see Chicago becoming a hub of green manufacturing and transit, energy effectiveness, environmental restoration and cradle-to-cradle material flows – all of which adds up to flourishing human communities that generate an abundance of ecological, economic and cultural wealth.

Cradle-to-cradle systems can generate this wide spectrum of wealth worldwide, in industrialized and developing nations alike. In rural China the people of Huangbaiyu, led by local entrepreneur Dai Xiaolong, are developing a Cradle-to-Cradle Village that aspires to be powered by the sun, with all materials maintained in closed-loop technical and biological cycles.

Significantly, the Cradle-to-Cradle Village is not an idea being imposed on Huangbaiyu by the Chinese government or by an international aid agency; it was generated by Mr. Dai's enterprising leadership, which has drawn support from Tong Ji University in Shanghai, the China-US Center for Sustainable Development, and WM+P. Mr. Dai's plan is based on investing in and growing Huangbaiyu's existing capacity to become more economically self-reliant and regenerative. The

chairman of the Tianyuan Eco-Cattle Farm, a successful business with subsidiary companies that include a brewery, breeding farm, organic fertilizer factory and trout fishery, Mr. Dai is well versed in nature's cradle-to-cradle systems and is applying them to the Huangbaiyu community development plan.

This plan is centred on the building of a compact settlement which will make maximum use of Huangbaiyu's available agricultural land, generate optimal conditions for closed-loop material flows, and provide services and amenities that cannot be effectively furnished to a dispersed population. Local workers will employ straw bale construction to build the village's 300 homes, taking advantage of an essentially free local material with proven insulating capacity. A community well will provide clean running water, a resource typically in short supply. Human and animal waste will be collected at centralized locations and used to produce biogas, which will in turn be used for heating and cooking. There will be street trees, public parks and a village school. The people of Huangbaiyu will be steadily employed in a variety of local enterprises, from sustainable forestry to farming to working in the biogas facility or a wood products plant. The enduring cycles of nature, it is hoped, will generate a wide spectrum of community wealth.

A diversity of sustaining cradle-to-cradle visions could come to fruition in many places. From high-tech Chicago to rural China, from Japanese temples to American factories, the principles and practices of cradle-to-cradle design are already creating hopeful changes in the world. Ultimately, we believe intelligent design can lead to ever more buildings, communities, cities and nations that honour not just human ingenuity but harmony with the exquisite intelligence of nature. When that becomes the hallmark of good design, we will have entered a moment in human history when the things we make will truly be a regenerative force.

### Notes

1. Matthews, Emily, et al. (2000) *The Weight of Nations: Material Outflows From Industrial Economies*. World Resources Institute, Washington, D.C.
2. Bujanowski, Anke, Michael Braungart and Christian Sinn (1998) *Primitives Produktdesign. Müllmagazin*, 2, pp. 24-26.
3. Braungart, Michael, Anke Bujanowski, Jürgen Schädling and Christian Sinn (1997) *Poor Design Practices – Gaseous Emissions from Complex Products*. Hamburger Umweltinstitut e.V., p. 9.
4. Kunstler, James Howard (2001) *The City in Mind: Notes on the Urban Condition*. Free Press, New York. ◆