Cradle To Cradle®
criteria for the built environment

The positive agenda of Cradle to Cradle establishes a new paradigm for redesigning in the built environment. Cradle to Cradle consists of a philosophy, quantifiable principles, and implementation tools that together comprise an innovation platform for enhancing the quality of materials, energy and biodiversity. This platform generates social, economic and eco-effective benefits, which go beyond the conventional sustainability approach of using eco-efficiency to minimize environmental impacts. Cradle to Cradle is well known through earlier published works but most practitioners in the built environment are still unfamiliar with how to apply its principles. The framework here provides an introduction to the philosophy then translates the three basic Cradle to Cradle principles into criteria that can be quantifiably applied and evaluated. It further describes implementation criteria, which allow the innovative integration of defined financial, contract, and design application tools. Definitions of Cradle to Cradle energy in relation to climate change gases are also provided.

Cradle to Cradle *metodoak beste paradigma bat ezartzen du, eraikitako ingurua berriro diseinatzeko aukera ematen duena. Berekin dakartza filosofia bat, kuantifikatzeko moduko printzipio batzuk, eta inplementazio-tresna bat. Horiek guztiek materialen kalitatea, energia eta biodibertsitatea hobetzeko berrikuntza-plataforma bat eratzen dute. Plataforma horrek onurak eragiten ditu gizarteari, ekonomiari eta eko-eraginkortasunari dagokienez, eta kontzeptu horiek gainditu egiten dute ingurumenaren gainerako eraginak txikiagotzeko erabilera eko-eraginkorrean oinarritzen den iraunkortasunaren ikuspegia.* Cradle to Cradle *metodoa oso ezaguna da aurretiaz argitaratutako lanei esker, baina eraikuntzan parte hartzen duten profesional gehienak oraindik ez daude ohituta horrelako printzipioak ezartzen. Artikulu honek, alde batetik, filosofia aurkeztu eta* Cradle to Cradle *metodoaren oinarrizko hiru printzipioak azaltzen ditu, modu kuantitatiboan ebalua eta aplika daitezkeen irizpideen bitartez. Beste alde batetik, inplementazio-irizpideak deskribatzen ditu eta, horrela, finantza-, kontratazio- eta diseinu-jardueretan aplika daitezkeen tresnak modu berritzailean integratzeko aukera ematen du. Halaber, definizioak ematen dira* Cradle to Crade *energiaren eremuan, berotegi-efektuko gasekin (BEG) lotuta.*

El método *Cradle to Cradle* establece un nuevo paradigma que permite un rediseño del entorno construido. Implica una filosofía, unos principios cuantificables así como una herramienta de implementación; todos ellos conforman una plataforma de innovación para la mejora de la calidad de los materiales, la energía y la biodiversidad. Esta plataforma genera beneficios sociales, económicos y eco-efectivos, conceptos que superan la perspectiva de la sostenibilidad centrada en el uso eco-eficiente para minimizar los impactos medioambientales. El método *Cradle to Cradle* es bien conocido gracias a los trabajos publicados anteriormente, si bien la mayoría de los profesionales implicados en la edificación aún no están acostumbrados con la puesta en práctica de este tipo de principios. Este artículo, por una parte, presenta la filosofía y traduce los tres principios básicos *Cradle to Cradle* a criterios que pueden ser aplicados y evaluados cuantitativamente. Por otra parte describe los criterios de implementación, lo que permite una integración innovadora de herramientas de aplicación para actividades financieras, de contratación y diseño. Al mismo tiempo se aportan definiciones en el ámbito de la energía *Cradle to Crade,* relacionadas con los gases de efecto invernadero.

Douglas Mulhall
Michael Braungart
Erasmus University, Rotterdam

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1. **INTRODUCTION**

The conventional approach of government and industry has been to minimize the environmental impacts of their activities by being "less bad" as products go from "Cradle to Grave." Despite pronouncements about the importance of being "sustainable," this approach is often regarded by managers as involving extra costs for stakeholders without many quantifiable benefits. Bluntly stated; sustainability is a necessary but expensive reality.

However, the "Cradle to Cradle" Design Protocol® has taken a fundamentally different approach that generates benefits for stakeholders by going beyond the "grave" and beyond conventional interpretations of "environment".

Cradle to Cradle® (C2C)[1] is a paradigm-changing innovation platform developed in the 1990s by Michael Braungart, William McDonough *et al.,* based on research at the Environmental Protection Encouragement Agency in Hamburg Germany, for designing beneficial economic, social and environmental features into products, processes and systems. Cradle to Cradle® is primarily an entrepreneurial and innovation concept that starts by determining the intended benefits of a product or service instead of focusing on minimizing negative environmental impacts.

[1] Disclaimer: These criteria are designed as a basis for planners, architects, and other building professionals to apply Cradle to Cradle® in the built environment, especially to buildings and to materials and products that move through them. The criteria can be used as guidelines for planning and specifications, but are not intended as specifications. It is important that building professionals determine the technical characteristics and regulatory limitations associated with each site prior to applying these criteria.

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[1] Various iterations of "Cradle to Cradle" and "C2C" are registered marks of McDonough Braungart Design Chemistry.

To enhance quality and add value for stakeholders, C2C promotes innovation partnerships along the entire chain of a product, including manufacturing, distribution, use, disassembly, recovery and reuse.

By characterizing hundreds of products and thousands of materials for their human and environmental health attributes, as well as defining systems to safely and fully cycle materials into new products, C2C has already provided a practical yet inspirational scientific and business model for improving quality.

This innovation and value model makes C2C potentially attractive to planners, builders and manufacturers for integration into products, processes, buildings, materials recovery systems, and purchasing.

The basic C2C design protocol is not described at length here because it has been described in journals, cover stories and documentary films published and broadcasted since the 1990s. The book "Cradle to Cradle"[2] is well known and translated into at least a dozen languages. The C2C protocol for Certification of products is published on the websites of EPEA.com and MBDC.com.

However, many planners are not yet familiar with how to integrate into the built environment C2C features. There is a tendency when encountering well-known phrases such as "safe materials" and "species diversity," to respond with "yes we do that already". But most buildings and area plans don't already do that. Methods are still not well established for designing sites so they contain defined materials, or are species-positive.

A rapid acceleration occurred from 2008 to 2010 in the numbers of planners, architects and engineers introducing C2C concepts into planning and construction. A priority expressed by government agencies is to translate C2C into renovation and new construction of buildings. Those requests resulted in these Cradle to Cradle® Criteria for the Built Environment.

To begin, it is important to describe basic C2C criteria for buildings, and how planners, architects and engineers can apply and measure those criteria.

2. DEFINITION. WHAT IS A CRADLE TO CRADLE® BUILDING?

Various guidelines for C2C in the built environment were established since the 1990s through published declarations such as the Hannover Principles and more recently in The Netherlands the Floriade Venlo Principles and Almere Principles.

However, those extensive documents are only effective if they can be translated into measurable results. The first step to doing that is by studying and implementing the three defining Cradle to Cradle® Principles;

— *Waste = Food*. Everything is a Nutrient for Something Else.

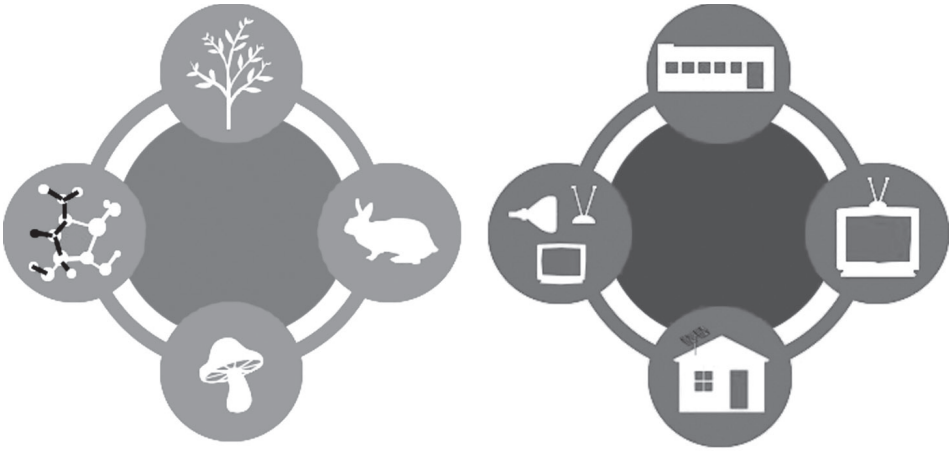
— *Use Current Solar Income.* Energy that can be Renewed as it is Used.

— *Celebrate Diversity.* Species, Cultural, and Innovation Diversity.

Those principles define and support two types of metabolisms for every product and process; Biosphere metabolisms for products designed to support biological processes, and Technosphere metabolisms for products designed to provide a

[2] Cradle to Cradle. Remaking the Way We Make Things. William McDonough & Michael Braungart, North Point Press NY, 2002.

Figure 1



Biosphere metabolism

Technosphere metabolism

Source: Own elaboration.

technical service and whose materials are continuously recycled[3].

The three principles integrated with Biosphere and Technosphere metabolisms constitute the special combination that is Cradle to Cradle®. Whenever experts might be uncertain about the various literature published on "what is Cradle to Cradle" it is always possible to return to the three principles and two metabolisms to grasp the essentials of C2C, and this is why the Cradle to Cradle® Criteria for the Built Environment are based on those aspects.

The C2C Design Protocol and Framework developed by McDonough and Braungart further define those principles and metabolisms. They also describe how C2C adds quality and value for stakeholders. Added quality and value often distinguish C2C from conventional interpretations of sustainability.

Because the various C2C principles and protocols were only developed near the turn of the millennium, a 100 percent Cradle to Cradle building does not exist yet, also due to the time required for a conservative building industry to adopt new concepts and products. However it is still possible

[3] For more information on Biosphere and Technosphere metabolisms refer to Section 3.1 Michael Braungart *et al.,* Cradle-to-cradle design: creating healthy emissions - a strategy for eco-effective product and system design, Journal of Cleaner Production (2006), doi:10.1016/j.jclepro.2006.08.003.

to describe and construct a building that uses C2C innovations and C2C-defined products and materials already existing in the marketplace.

In that context, it can generally be said that a building has an excellent chance of achieving C2C if it fulfills the three basic C2C principles and the C2C Defined Metabolisms. Those can be roughly condensed into this general definition:

> "A Cradle to Cradle building contains measurable elements that add value and celebrates innovation and enjoyment by; measurably enhancing the quality of materials, biodiversity, air, and water; using current solar income; being deconstructable and recyclable, and performing diverse practical and life-enhancing functions for its stakeholders."

Relevance. This definition can be applied to buildings whether they are residential, offices, factories, stadiums, or healthcare facilities. However, the definition also applies to materials and products such as furnishings that move through buildings, because often things that move through buildings have equal or greater impacts on their stakeholders than the structures themselves.

Criteria and tools for applying the Principles and Definition are described in the next sections.

2.1. **The principle criteria**

The purpose of this summary is to provide planners with guiding criteria for developing a building with measurable C2C features. The focus of these criteria that distinguishes them as C2C is to *maximize beneficial impacts* instead of just minimizing negative ones. These principle criteria are in no order of priority, although 'State Your Intentions' is normally done at the beginning of the process.

2.1.1. State Your Intentions

Design is the first signal of human intention. State your intentions for the building by describing your Goals and Milestones in relation to the three basic Cradle to Cradle Principles; i.e. where you want to be by a given date.

Examples. Do you want the building to contribute air and water that are cleaner than when they were taken from the outdoor environment? Do you want the building to be deconstructable? Do you want to demonstrate that the ingredients in building materials are defined and safe?

Criteria based on the defining C2C Principles

C2C Principle. Everything is a Nutrient for Something Else

2.1.2. Define Materials and Their Intended Use Pathways

a) Use materials whose quality and contents are measurably defined in technical or biological pathways from manufacturing through use and recovery.

b) Use materials whose impacts are measurably beneficial for human health and the environment.

Examples. A defined product would be a chair whose component parts come from known renewable sources or known recycled materials, whose composition is known to 100 parts per million, whose materials are safe for contact with human

skin and lungs, and can be disassembled into materials that each can be recycled for use in other products or decomposed as beneficial nutrients for biological systems. A "Beneficial" ingredient would be an ingredient added to coatings that allows them to actively clean the air.

2.1.3. Integrate Biological Nutrients

Measurably recycle biological nutrients and water by integrating biomass production into buildings, landscaping, and spatial plans to generate more biomass, soil and clean water than before development of the site.

Examples. Biological nutrients from grey water, biodigestion, and internal and external landscaping. Air-cleaning vegetative walls designed to metabolize pollutants. "Green roofs" that retain moisture, capture CO_2, metabolize particulates, and provide oxygen. "Topsoil manufacturing" that uses biodigestion and composting to produce humus and capture CO_2.

2.1.4. Enhance Air and Climate Quality

a) Measurably improve air quality to be healthier for biological metabolisms than before it entered the building and provide a comfortable climate for occupants.

b) Contribute to enhancing outdoor climate by contributing air that is healthier for biological metabolisms, and using climate change gases as resources through carbon management.

Examples; (a) Air quality can be enhanced by integrating C2C materials across products such as exposed window frames, floors, wall materials, HVAC systems, wall and floor coverings, indoor plants and green walls, furnishings, office equipment, and mold inhibitors. (b) Active carbon management is achieved with vegetation and renewable energy. Climate change gases such as methane and CO_2 are resources that can be used to produce biomass. See later sections for details on energy and CO_2.

2.1.5. Enhance Water Quality

Measurably improve water quality so the water is healthier for biological metabolisms than before it entered the building.

Examples. Water quality improvement can be achieved by integrating water recycling systems with nutrient recycling, rainfall capture and storage, indoor plants and green walls. See also "integrate biological nutrients".

C2C Principle. Use Current Solar Income

2.1.6. Integrate Renewable Energy

Integrate renewable energy (current solar and gravitational income) into buildings and area plans so the building and site generate more energy than they use. Use exergy as a way to guide energy effectiveness.

Examples; Use energy efficiency to introduce renewable energy rather than reduce fossil fuel use e.g. high-efficiency LEDs combined with direct current from photovoltaic cells. See "Energy in a C2C Building".

C2C Principle. Celebrate Diversity

2.1.7. Actively Support Biodiversity

Integrate measurable species diversity so the area supports more diversity than before development.

Examples. Species diversity applies to plants, animals and insects and is quantified by counting numbers and varieties supported by a building. The concept of "natural" or "native" species has to be evaluated in each case because in many regions the natural environment has been transformed by humans, and returning it to an earlier "natural" state might be impractical.

2.1.8. Celebrate Conceptual Diversity with Innovation

Conceptual diversity can be demonstrated measurably by focusing on special beneficial features of a building and integrating innovative components that are beneficial for the well-being of occupants and the environment.

Examples. Conceptual diversity can be quantified by measuring how innovations increase; the variety and prevalence of C2C-defined materials in a building, the percentage of energy used that is renewable according to C2C definitions, and the amount of beneficial air, water, topsoil and biodiversity contributed to the outside environment. "Buildings like trees" is a guiding C2C innovative approach. Some of this can be achieved through biomimicry e.g. coatings that metabolize pollutants. Systems integration that combines such enhancements can also be considered a C2C innovation.

Stakeholder value criteria

These criteria are designed to make sure C2C adds value and benefits for stakeholders instead of only providing benefits for the general environment or population. Benefiting stakeholders is essential for making C2C practical for building owners, operators & occupants.

2.1.9. Add Value and Enhance Quality for Stakeholders

Describe what the C2C features of a building do practically for the users.

Examples. Cleaner indoor air enhances productivity. Recycling water reduces water fees. Building integrated photovoltaics can be less expensive than other claddings while providing energy security in regions with irregular power supply. Design for disassembly of HVAC systems supports inexpensive replacement during the life of the building. Natural lighting cuts energy costs.

2.1.10. Enhance Stakeholder Well-Being and Enjoyment

Enjoyment is part of a C2C building because an ugly unenjoyable world is not part of C2C. By implementing each of the basic criteria, a C2C building enhances enjoyment by enhancing well-being. Spatial and aesthetic features that are less quantifiable can also enhance enjoyment and support diversity by demonstrating how well a building serves diverse stakeholders.

Examples. Make areas safe for children. Make meeting areas accessible. Provide ready access to outdoors and fresh air.

2.2. **Implementation criteria**

Importance of Integration. Tools described here are intended to enhance and accelerate implementation of the principle C2C criteria. Some of these tools are used in other building systems and are often not unique to C2C. It is their integration more than any one factor that makes them uniquely C2C.

2.2.1. Do an Inventory

Know what you already have. Prior to a site being developed or renovated, an inventory is done preferably with stakeholders to determine what C2C features already exist and what stakeholders want to preserve, especially for renovations.

Integration

2.2.2. Integrate Innovative Finance

To maximize C2C benefits use financial innovations that integrate capital and operating costs.

Examples; (a) Total Cost of Ownership financing, (b) power purchase and energy-to-grid agreements (c) service concepts for products.

2.2.3. Integrate Innovation Partnerships

Partner with C2C-experienced organizations, especially in supply chain partnerships. To enhance innovation it is beneficial to improve on examples already in the marketplace. This avoids "reinventing the wheel".

Examples. Many companies have already developed C2C products in the built environment, ranging from coatings to carpets, insulation, furniture, and structural materials.

2.2.4. Integrate Diverse C2C-Experienced Contractors

The developer makes use of contractors and suppliers who use C2C methods and materials.

Examples. Some engineering firms and architects are C2C-trained by authorized C2C training personnel. Various product companies provide C2C-defined products. C2C materials experts are available.

2.2.5. Integrate Systems and Application Tools

Each of the criteria described here can be achieved most effectively by integrating systems, components and C2C application tools. The level of systems integration can determine the success of C2C in a building.

Systems Integration Examples: To improve the quality of biodiversity, air and water, integrate Heating Ventilation and Air Conditioning (HVAC) systems with C2C-defined coatings, furnishings, floor and wall coverings, and plants that metabolize pollutants.

Examples of C2C Application Tools (in alphabetical order);

— *Actively Beneficial Qualities* e.g. coatings that clean the air.

— *Defined Product Recycling.* This involves developing dedicated sorting, disassembly and recycling of high quality materials that are more economic to recover on their own than if they are mixed with other material streams. This also enables materials upcycling.

— *Defined Use Pathways.* These describe the use of materials in their pathways from sourcing to manufacturing, use, disposal and reuse, recycling or decomposition.

— *Defined Use Periods*. Many "green" criteria require products to be "durable" to last as long as possible. However this approach is often

counter-productive because when products last longer than they are optimally useful they perpetuate obsolete technologies, reduce benefits for users, and generate unnecessary loss of revenues for business. The "durable" approach can also make recovery of materials more difficult. Because of this, C2C emphasizes designing materials or ingredients according to the intended use period of the product, to promote practical recovery of materials so they can be used in new products.

— *Design for Assembly, Disassembly*, & *Reverse Logistics.*

— *Materials Pooling.* This occurs where diverse industries develop a pool of defined materials to achieve economy of scale, commercial flexibility, and improved quality.

— *Preferred Ingredients Lists (P-Lists*). These are lists of positively defined ingredients that are designed to be used in materials according to their defined use in Biosphere or Technosphere pathways.

2.2.6. Integrate Diverse Uses with Features that Apply C2C Criteria

To maximize effectiveness, the building and site perform diverse functional uses while contributing energy and supporting biodiversity as well as beneficial climate, water, and air components.

Examples of integration. Integrate functional uses such as Recreation, Shopping, Dining, Manufacturing, & Modular design with C2C features such as cleaning air and water, and producing energy.

2.2.7. Integrate Natural Light with Innovative Artificial Light

Wherever practicable for the "intended use" of the building, natural light is made available to the maximum number of occupants and integrated with artificial light to provide a consistent quality of light.

Examples; skylights, fiber-optic transmission of daylight; locating work spaces near windows. *Artificial light.* Design innovative light solutions e.g. Use sensors to adjust artificial lighting for changes in natural lighting conditions. Design glare-free indirect indoor lighting. Use outdoor green-spectrum lighting on migratory routes.

2.2.8. Integrate Renewably Powered, Healthy Mobility

Support the use of current solar income for mobility in transport to, from and in the area.

Examples. Collaborate with vehicle manufacturers to use C2C criteria such as design for disassembly and materials for improving vehicle interior air quality when acquiring service vehicles for the building. Provide solar-powered charging stations for electric cars.

2.2.9. Protect Occupants from Environmental Hazards

a) The building measurably protects occupants from adverse normal elements e.g. harmful noise, biological threats such as mold and infestations, precipitation, and outside pollution.

b) The building can adapt to natural extremes by using innovative technologies to protect occupants

from extreme events such as earthquake, tornado, hurricane, sandstorm, flood, heat, cold and radiation.

2.2.10. Consider Aesthetic Opinions of Stakeholders

Provide intended occupants and viewers of a building with the opportunity to judge its beauty and enjoyable. This requires involving intended occupants and viewers in the design process.

Examples. While aesthetics are difficult to quantify, the act of involving stakeholders in the process can be quantified through consultations, creating interactive websites, and creating physical participation space where stakeholders can see plans for the building.

Energy in a C2C Building

Buildings are leading users of energy and are becoming generators of energy. Most conventional building criteria focus on reducing the amount of energy used by a building. However, Cradle to Cradle focuses on maximizing the amount of energy that can be produced by a building while also using efficiency to support introduction of renewables instead of just minimizing the use of non-renewables.

Most conventional building criteria for energy overlook materials. Energy is generated by materials. Power generation and distribution, HVAC systems, and climate change gases are all made from materials, yet conventional building approaches do not consider what goes into those materials, how those materials affect occupants, and how those materials can be recycled.

Cradle to Cradle approaches energy primarily as a materials resource issue instead of an energy issue. This introduces new perspectives such as integrating building surfaces into energy generation and use. *Example.* Some buildings save energy capital costs by integrating photovoltaic tiles with building exteriors. This improves payback time because solar tiles replace normal building tiles.

C2C Energy Defined

Cradle to Cradle (C2C) energy is energy that is generated and applied effectively, using current solar or gravitational income, and material media that are defined as biological or technical nutrients. The definition is qualified and quantified by the following criteria together*:*

1. **Energy Sources**. Use current solar or gravitational income, or other defined C2C sources. Primary examples of current solar income use, conversion and storage include natural light, solar thermal, photovoltaic, photosynthesis, photochemical, wave and wind energy, thermal mass storage, and heat exchange. Secondary solar uses include respiration, currently renewable biomass-derived energy from composting, biodigestion, thermolysis, hydrothermolysis, pyrolosis, gasification, and fuel cells. Gravitational income examples; kinetic energy from inertia or weight e.g. descending waterways.
2. **Material media.** For generating, converting and using energy, use

materials that contain defined biological or technical nutrients at each stage.

3. **Energy Effectiveness**. Generate and use energy in definably effective ways, using exergy as a way of measuring effectiveness.

Buildings and CO_2

From the C2C perspective, carbon dioxide is a resource. Surprisingly, many methods used to calculate "carbon footprint" of buildings do not include the beneficial use of carbon by, for example, vegetation.

Traditionally, emphasis is put on the large negative role of buildings adding CO_2 to the atmosphere. However from the C2C perspective CO_2 is a chemical resource that is part of biological and biochemical processes. If buildings integrate those processes as well as becoming net producers of renewable energy and users of renewable materials, they will be beneficial participants in the CO_2 cycle, in a similar way that trees are.

Examples. Biodigestion, production of topsoil for landscaping, green roofs & walls and algae tanks that use CO_2 as food, and solar thermal conversion more effective than many water heating technologies. Those elements can be integrated to develop a beneficial CO_2 footprint.