Beyond sustainability in the built environment

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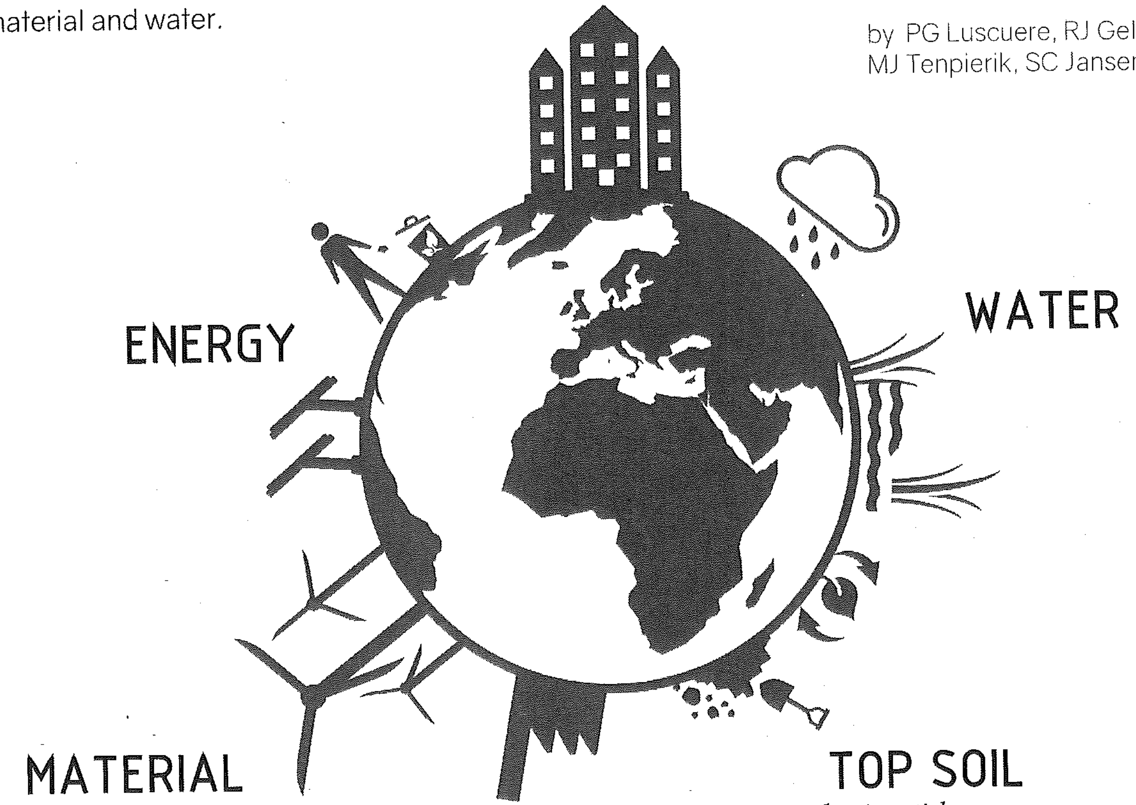
BEYOND SUSTAINABILITY

IN THE BUILT ENVIRONMENT

This article describes a vision on 'beyond sustainability' for the built environment. In this vision we do not only aim for less environmental impact, but the ambition is to achieve a positive footprint. In the first part an overview of all aspects and natural resources is described. This part is followed by three sections summarizing the developments and challenges on the use of natural resources of energy, material and water.

by PG Luscuere, RJ Geldermans, MJ Tenpierik, SC Jansen



1 Beyond sustainability: overview

Natural resources and challenges

The sustainability challenges we are confronted within the built environment are all related to the physical consumption of natural resources: energy, water, materials and top soil[i]. Extraction and conversion processes lead to depletion and harmful emissions, and as such to challenges in terms of ecology, economy and equity[ii].

The Matrix of Figure 1 depicts biodiversity, health effects and climate change as the most relevant ecological challenges we are confronted with, whereas scarcity of materials and natural resources is seen as primary economic challenges. In terms of equity, the unfair distribution of resources or the deliberate dumping of our toxic waste in countries with little regulations, stand out.

Energy Transition

At this moment (January 2016) the world population is reaching 7.4 billion: more than seven times the number of people at the start of the industrial revolution[1,2]. During the same timeframe the primary energy consumption per capita has nearly tripled[3,4] whereby the pressure on our, nearly entirely fossil based, energy supply has risen 23-fold. This leads to the present 70 GJ per year per person[3], the equivalent of 2.2 kW or 3 hp. Fossil fuels are being depleted, peak-oil has passed and the oil-addicted industry and governments are trying all they can to exploit their investments for yet a little longer or to savor the extra time of non-dependency from foreign nations.

One of the most logical alternatives is solar energy: it is abundantly available and it provides us with 5,000-10,000 times our current need[4]. Moreover, it is clean, free, and everlasting (at least for the foreseeable future). In approximately 10 years' time Germany has installed a staggering 50 GWp of Photo Voltaic Power[6], the peak equivalent of some 50 nuclear power plants, predominantly by (groups of) individual citizens. This is a substantial contribution of roughly one fourth of the required transition towards 76% renewable energy in 2030,

[i] Top Soil being the top few centimeters of fertile soil on which most of our food production depends.
[ii] Equity in social context, like fairness.
[iii] This matrix relates four natural resources to three value areas in our society: Ecology, Economy and Equity. Examples of non-sustainable developments are given as well as possible solutions. It can be used to structure discussions on sustainability ambitions.

Values / Re-cources	Ecology				Economy		Equity		
	Biodiversity	Health Effects	Climate Change	Scarcity	Cost / Benefits	PR Metaphor	Social Responsibility	Fairness	
Energy	SO2, Acid rain	NOx, PM 2.5	CO2	Fossil fuels	Pay Back Time *******	'Net Positive'	Energy Positive Buildings	'Supergrid'	Coal Powered Electricity ************
	Solar-, Wind-, Environmental-, Geothermal Energy and Highly Productive Biofuels (Algae)								
Water	Contaminated Water	Hormones & Medicines	Rising Sea Level	Fresh Water	Life Cycle Analysis *******	'Clean'	Cleaner Discharge as Intake	Geo-Political Governance (lack of)	Child Labor ***********
	Local Cleaning (Reed filters), use of Algae, Nutrition Regeneration				Total Cost of Ownership *******				Resource Depletion *************
Materials	Waste *)	Hazardous Emissions	Chlorofluorocarbons	Virgin Materials		'Healthy'	Actively Cleaning Buildings	'Securing' Resources	'Externalising' Costs *************
	Non-Toxic, -Carcinogenic or –Mutagenic Substances, From Down- to Re- and UpCycling				Life Cycle Costing *******				
Top Soil	Loss & Degradation	Contamination	CH4 - Emissions	Phosphate	Hard & Soft Costs and Benefits	'Fertile'	Positive Contribution to Top Soil Production	Displacing Arable Land by BioFuels	Rampant Environmental Pollution
	Apply Green Roofs & Walls, Close Cycles, Recovery of Nutrients, Large Scale Eco-Rehabilitation Projects								
*) Toxic-, Carcinogenic-, Mutagenic, etc.					Environmental Challenges / Solutions / model v11, PG Luscuere, December 2015				

Figure 1: Matrix Resources-Values[iii]

and a fine example of the power of democratization of renewable energy generation as described by J.Rifkin[7].

Nearly Zero Energy?

Energy has been the most popular studied resource, as we were – and are – confronted with the limitations of our fossil fuel dependency as well as its related sensitivity to price fluctuations and geo-political interests. Subsequently, we are unpleasantly surprised by global climate change as a – highly likely – consequence of our large-scale fossil fuel driven economy. Thus far, solutions were sought in terms of: reduction of consumption, replacement by renewable sources and improvement of efficiencies i.e. steps we know as the 'Trias Energetica'. The focus has gradually evolved from energy reduction via low energy buildings to 'nearly zero energy buildings'. This approach aims at minimizing the negative aspects of building and living, instead of maximizing its potential positive aspects, and is as such hardly sustainable.

Positive Footprint: energy

If we were able to realize buildings that generate more renewable energy than they consume, including the initially invested 'embodied energy' in production, transport and construction, one could speak of a positive footprint (regarding energy). This is a real paradigm shift; the (group of) building(s) couldn't be big enough from an energy point of view. It would be energetically beneficial to its environment and to society.

Improvement Potential using Exergy

To generate an energetic positive footprint we need to use the full potential of the available energy sources. At this moment that is not yet the case; the improvement potential of our energy conversions is still very big.

The focus up until this moment was on reduction of the demand and on production from renewable sources. At a system level the focus was aimed at energy efficiencies, only taking into account the first law of thermodynamics. This approach does not consider the quality of different forms of energy. It thereby fails to identify the true effectiveness of the used energy carrier in different energy systems, as well as its improvement potential. Exergy on the other hand , which is based on the second law of thermodynamics, takes into account the ideal conversion of one form of energy into another. Hence, exergy identifies the real thermodynamic performance and improvement potential. Burning high-value fossil fuels for low temperature heating is energetically highly efficient but exergetically disastrous. Simply analyzing energy flows can be very misleading indeed, see Figure 2.

Resource Depletion

Our fossil energy sources are exploited to the point of depletion while at the same time causing potential climate change. The other resources: water, materials and top soil face similar challenges. Water gets contaminated in different ways, sometimes to the point it can hardly be cleaned, several materials are expected to be depleted in the coming decades [8,12,13,] and of all available top-soil approximately 50% has been lost during the last 150 years[9]. Such linear processes – referred to as 'Take, Make, Waste' by Michael Braungart and William McDonough in their

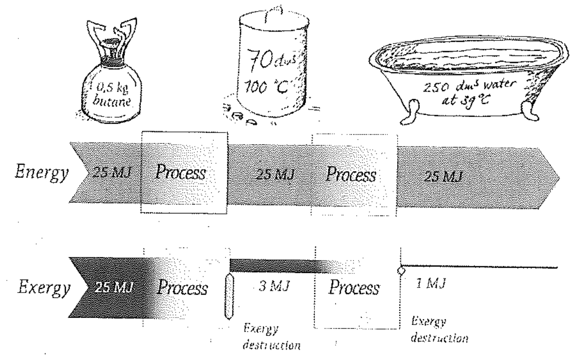


Figure 2: Energy and Exergy Analysis of gas and heat. The amount of Energy is constant for all three examples whereas the Exergy content is reduced dramatically as indicated.

book on Cradle to Cradle®[10] – do not relate well to a finite planet, as illustrated in a striking manner by Annie Leonard in her video-animation 'The Story of Stuff'[11]. That is why circularity is key; we must be able to endlessly renew all our natural resources. Energy, water, materials and top soil should all be renewable or from renewable sources.

Renewable energy is abundantly available in the form of solar energy. Some material resources are also renewable, but most resources used in industry and the built environment are non-renewable. The amount of those resources at our disposal is limited and we are consuming them in an irresponsible rate, like we have done with our fossil fuels. For example, at the current rate – taking into account a 3.1 % per annum increase – the existing world mineral reserves[iv] of Copper will be depleted by as early as 2035[12]. Based on recent sources[8,13] and given a general 2 % increase per year, one can calculate the

depletion of about 12 elements, among which quite common ones such as: Lead, Tin, Chromium, Zinc and Copper, in the coming 20 years.
The depletion of resources is more imminent and potentially more disruptive than the fossil energy depletion alone. In this context circularity is a means to achieve renewability, whether it concerns water, top soil, materials or energy.

A growing economy, or rather: a growing production of goods requires materials to answer to the increased demand. As most technological materials are finite, or only renewable in extremely long cycles, we have to find new abundant renewable alternatives alongside the extraction of materials from our waste. Furthermore, it is imperative that either the regenerative capacity of the earth allows for sufficient food production or that the production of renewable materials does not compromise food

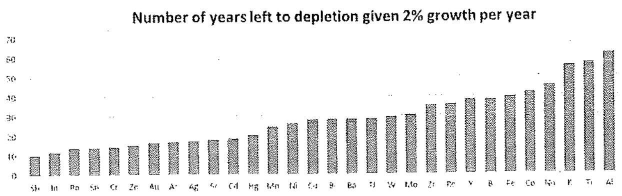


Figure 3: Number of years left to depletion of mineral reserves (Luscuere after USGS8 and Diederen[13])

production. In a way, technological materials that are fully recyclable and capable of functioning in continuing cycles can be considered renewable. Besides this, rare technological materials for which no substitutes exist need to be reserved for specific essential processes. Harmful materials and recycling processes must be avoided, just as hybrid materials that thwart the continuation of pure – biological or technological – flows ('monstrous hybrids' as they are called by Braungart en McDonough).

The relation between resources

It is essential to consider the interrelationship of all resources. Systems for the production of energy from renewable sources also require materials, many of which are finite.
Well-known examples are the so-called 'Rare Earth Metals'. Water may be a carrier of materials as well, in the form of impurities or salt for example. All these materials can be 'nutrients' for a material's cycle. For the biological material cycle a relation exists with top soil: the amount of renewable materials to be produced depends on the ecological capacity of the earth to (re)generate top soil. This underlines the importance to study the flows of energy, water, materials and top soil in an integrated way.

From Recycling to Upcycling

[iv] A mineral reserve is defined as that part of a known mineral deposit that can be extracted legally and economically.

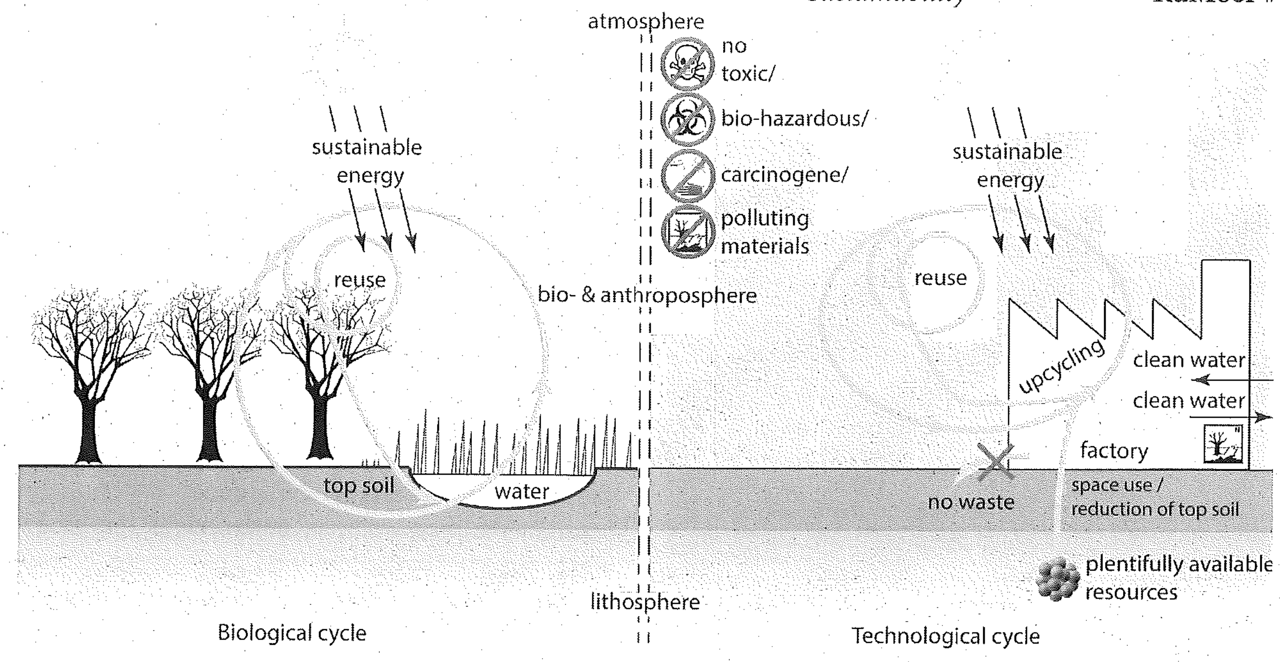


Figure 4: Biological and technological material cycles in our society

In the traditional linear economy, minerals are mined, processed to products and finally wasted in landfills or burnt in incinerators. In order to safeguard the availability of these materials, not only for the coming decades but surely also for our progeny, we will have to come up with more effective ways to recycle or even upcycle materials. And there is plenty available: not in our mines but in our present and historic waste.
The term 'upcycling' often gives rise to confusion. People argue this contradicts the second law of thermodynamics, in which entropy is ever increasing. The flaw in this reasoning is that it is not forbidden to feed energy to the system. In this way it is for instance possible to combine Carbon dioxide (mostly seen as a nasty climate change propelling waste product) with Hydrogen (originating from renewably powered electrolysis) to produce Methane. The latter is better known as natural gas, but now acquired through a very short-cycled renewable process as opposed to the fossil version.

Waste as a resource

Waste does not exist in nature. As in the C2C® principle of Waste = Food[10], all biological materials end up as intake for other processes. It is challenging to consider CO_2 as a resource instead of a harmful greenhouse gas. Multiple applications can be found for CO_2. In The Netherlands for example, where 'waste' CO_2 from industrial processes is captured

and used to fertilize greenhouse agriculture.
The word 'waste' is thus an abomination; it disregards the value of the constituent elements and components. In order to understand the true value of this we should approach waste as a resource. One kilogram of gold can be obtained from 200-1,000 ton of ore, depending on the richness of the mine. In 2009 one could find one kg of gold in 3.3 ton of used mobile phones, alongside 471 kg of Copper, 10 kg Silver, 0.4 kg Palladium and 10 grams of Platinum[14]. This richness in our 'waste' can best be described by using Exergy as a metaphor: the Exergy of waste or 'Ex Waste'.

Ex Waste

Following the mobile phone example: the constituent substances of a mobile phone represent more value than the caloric value of the device when burning it. The ways in which the substances are mixed, however, often withhold us from harvesting them in a clean and reusable state. For this we are dependent on logistics and technologies that may or may not be developed yet and will be continuously improved in the future. In the Ex Waste concept such contextual elements are taken into account. Ex Waste integrates different 'embodied values', depending on the inextricable preconditions surrounding the given waste stream. The Netherlands, for example, has an intensive livestock industry, producing more manure than can be processed naturally. Therefore manure is often seen in The Netherlands as an environmental burden or even a liability, whereas in neighbouring countries this manure is highly valued (in original or processed conditions). Ex Waste thus uses Exergy as a metaphor rather than an analogy, stressing the quality capacity, including thermodynamic principles but not solely depending on them.

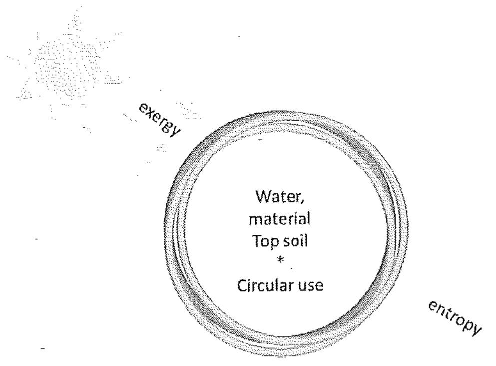


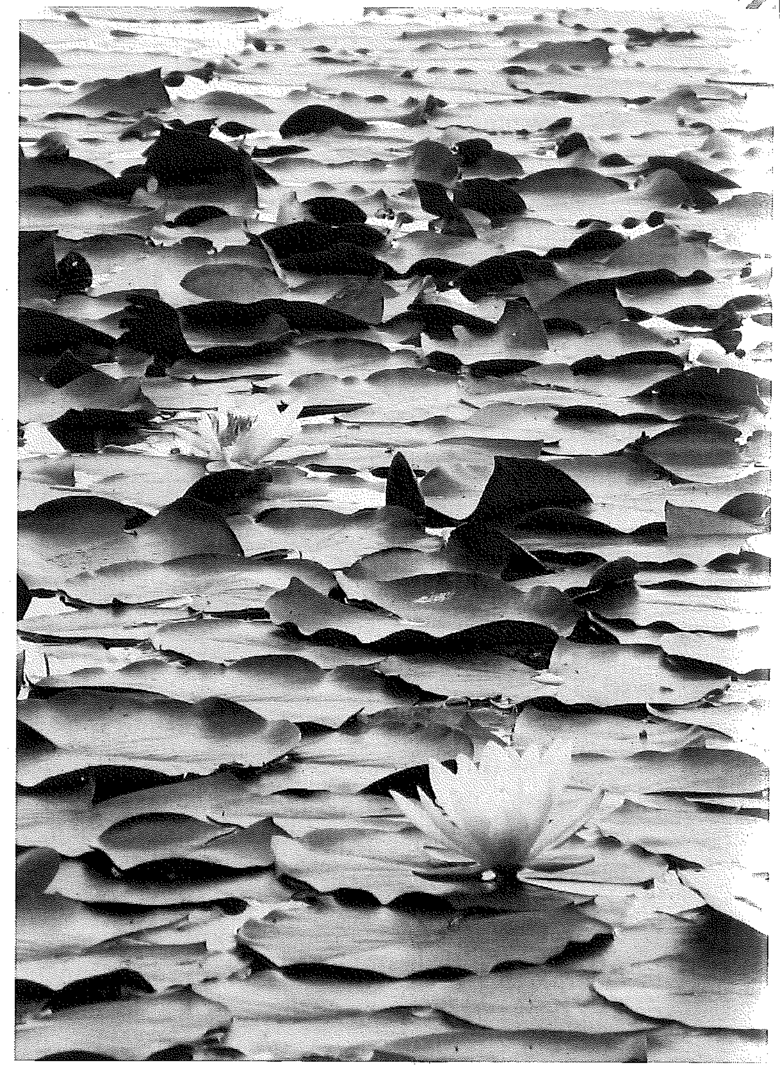
Figure 5: Sustainable energy powering the circular use of natural resources.

Widening the Concept of a Positive Footprint

The positive footprint concept can be applied to all four resources in the Built Environment:

1. Energy: Produce more renewable energy than the building consumes, including the embodied energy.
2. Water: Install water treatment that allows for better quality water out as in.
3. Top Soil: Take measures to produce more top soil during the anticipated life time of the building as what is destroyed during construction.
4. Materials: Bring materials in a biological or technological cycle so that they can be reused indefinitely.

Several energy positive buildings have already been realized[15], albeit without taking the embodied energy thoroughly into account. Biological water purification techniques are applied successfully in modern office buildings[16] and impressive results are achieved with regard to decentralized water purification in places with high concentrations of contaminants, such as hospitals[17]. Urban greening can help to form top soil[18], and phytoremediation interventions can help restore contaminated top soil . At multiple continents large-scale eco-remediation operations are successful[19]. Biological materials are renewable by definition: they grow. Unfortunately this quality is sometimes undermined: trees are being cut down for wood at a far greater rate than they are replanted[20]. Furthermore, dramatic efficiency improvements can be achieved in the cultivation of biological materials by choice of different crops[21] and harvesting techniques. Technological materials are presenting us with far more serious challenges. For several chemical elements the depletion of their mineral reserves will be reached in the two decades



to come (see Figure 3). Without a doubt prices will rise significantly on the mid to long term, whilst showing large fluctuations due to uncertainties. The only sustainable way forward is developing improved recycling and upcycling techniques.
For each of the resources the question is if, and if so, how the objective of a positive footprint can be met. This provides us with some challenging research questions.

New Business models

As a result of the abovementioned developments new business is emerging: design and development of new materials, components and products – that can be restored in the original constituent parts – as well as processes and services that enable full recyclability. The associated investments lead to new business models in which the ownership of renewable materials remains with the producers. The materials are provided for a defined period of time in what is -in fact- a material lease construction. At this moment track and trace systems and 'circularity passports' are being developed to safeguard the value of materials now and in the future, for example in the Horizon 2020 project: 'Buildings as Material Banks'.

Social values and health effects

A positive footprint for energy, water, materials and top soil relates to the users of these resources: all of us, here and there, now and later. Therewith it is first and foremost a social transition. But what this entails exactly, and how to anticipate it, is not immediately clear. In any case, the social aspects will have to be better integrated in the business – or: value – models of the construction sector. An instrument such as 'social return on investment' can be of assistance to secure the social added value of propositions and interventions. This ranges from e.g. stakeholder involvement, procurement policy and transparency to health, comfort and environmental effects. Traditional market mechanisms and earning models fall hopelessly short in this respect.
A lot is going on in this area, at various levels of interest. An example is the immense increase of decentralized generation of renewable energy, as described by Rifkin[7], which is in fact a democratization of energy generation. While existing structures are based on centralized generation and decentralized consumption, the emerging trend is decentralized generation of a substantial part. This transition increasingly takes shape through local cooperatives, which simultaneously promotes the social coherence in a neighborhood.
The fossil fuel industry encounters problems in terms of overcapacity, net problems and reserve capacity. Criticism from this industry regarding the 'subsidization' of renewable energy sources ignores the externalized hidden costs that the fossil fuel industry has forced upon society during its entire existence. An estimation of these costs can be found in a working paper from the International Monetary Fund: it amounts to 5.3 E12 $/y[22,23,24]. This equals 9 Million € per minute.
Furthermore, many materials that are used in our society contain harmful substances for our health. Emissions in our indoor environments and exposure to fine particulate matter by industry, building activities and traffic shorten our statistical life expectancy[25]. Such observations may sound quite technical but are of course based on real life experienced negative effects (health problems, nuisance in smell, noise, visual discomfort etc.).
Reduction of these hazardous elements in materials is an important step towards a sustainable society.
Functions and applications in the built environment are often very suitable to contribute positively to our living environment. For example, plants, trees and mosses are able to intercept or even metabolize fine particles, coatings exist with air cleaning properties, and harmful contaminants can be eliminated by positive micro-organisms[26].
Competition between energy and material cycles on one hand, and the production of food on the other should be prevented at all costs. A well-known example is the production of 1st generation bio-fuels, such as corn. Violent protests broke out in Mexico after the price of tortillas quadrupled in 2007, supposedly as a result of increased demand for corn from the USA for bio-fuel production[27]. Such price increases will first and foremost harm the poorest people on earth, leading to famine and increased poverty. Circularity as a concept can help to avoid an increase in the demand for such bio-fuels, whilst safeguarding sufficient arable land for food production.
Other aspects related to the concept of circularity and renewability are potential positive effects on employment and working conditions on the one hand, and increased flexibility for building owners and occupants on the other.

Beyond Sustainability and Cradle to Cradle®

Some of the ideas in this paper are consistent with or inspired by ideas from Cradle to Cradle ®. Up until now no building can claim a C2C-status, but a building that has positive footprints regarding all four resources, while honoring the mentioned ecological, economic and social challenges will be well on its way.
The built environment uses a lot of energy, but recent developments and future performance requirements of buildings aim at energy neutral buildings. A building is energy neutral when the annual energy demand is equal to the amount of energy generated from renewable resources – onsite or nearby. Depending on the available roof and façade area for

2 Beyond Sustainability: Energy

generating renewable energy it is already possible to develop 'energy positive buildings', i.e. buildings that produce more energy than they consume. As mentioned in the main article the use of the exergy concept plays an important role in the development of energy-plus buildings, since exergy supports the maximum use of the potential of our resources. However, building energy-plus is not enough when aiming for a sustainable built environment.

What is the sustainability performance of energy-plus buildings?

Different solutions can lead to energy neutral or energy-plus buildings, as is illustrated in a simplified way in figure 6. The question can then be asked: which solution is optimal from an overall sustainability point of view?

On a yearly basis they may have the same net energy use, but in order to be truly beneficial in a larger perspective there are more aspects to consider: Firstly, there is a short term (day-night) and long term (summer- winter) mismatch in time between the energy demand and the energy generated. This mismatch needs to be considered for a sustainable future with no backup from fossil fuels. Much research is currently being done on energy storage technologies, smart grid solutions and 'demand side management', all aiming to solve the mismatch problem.

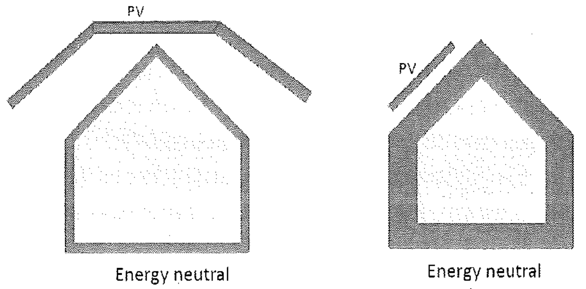


Figure 6: An energy neutral building can be achieved with different solutions. Which one is better?

Furthermore, the solutions illustrated in figure 6 are essentially different in two important aspects: the use of materials and the use of space. To convert, store or distribute energy materials are needed, and to harvest renewable energy space is required. In figure 7 the relation between energy system and the other resources on earth, including materials, water, top soil and space, is shown.

Material use

In performance assessment of buildings also the material use starts to be evaluated, mostly by looking at the 'embodied energy', i.e. the energy required for producing, transporting and maintaining a certain product. In addition, Life Cycle Assessment (LCA) methods are used, assessing the environmental impact of a product. However, current evaluation methods do not yet consider the circular use of a product or material[28]. Evaluating a product according to a life cycle – being truly circular – can lead to another performance outcome than in evaluation according to the more common 'take – make – waste' paradigm. In the latter approach a product ends in an 'end of life scenario' such as incineration. Instead, a circular evaluation ends with the 'new life' scenario of a product or material, and considers the energy required to achieve this. This paradigm shift is very important since it is in line with the nature of our planet, which receives energy from the sun while materials must be used in a circular way, as is also shown in figure 5.

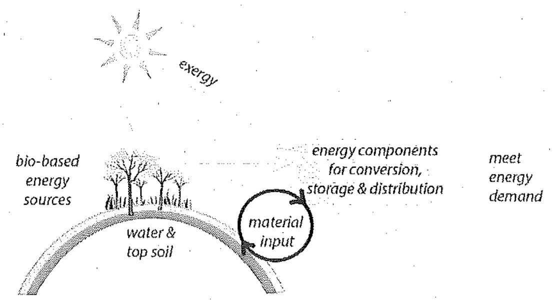


Figure 7: Scheme of the relation between energy system, resources on earth (water, material and top soil) and the use of space.

Use of space

Last but not least the factor 'space' is obviously essential. Generating energy from renewables usually requires space: for solar panels, for wind, for biomass. The use of space is directly related to the available top soil on our earth, biodiversity and ecosystems, all being the natural capital of our planet which enables life on it. If the aim is to design buildings with a positive footprint, the factor 'space' for energy systems needs to be considered. More simply stated: if you need your entire roof for energy production, there is no place for a green roof to increase biodiversity or grow vegetables.

To conclude...

Energy systems of buildings should meet not only

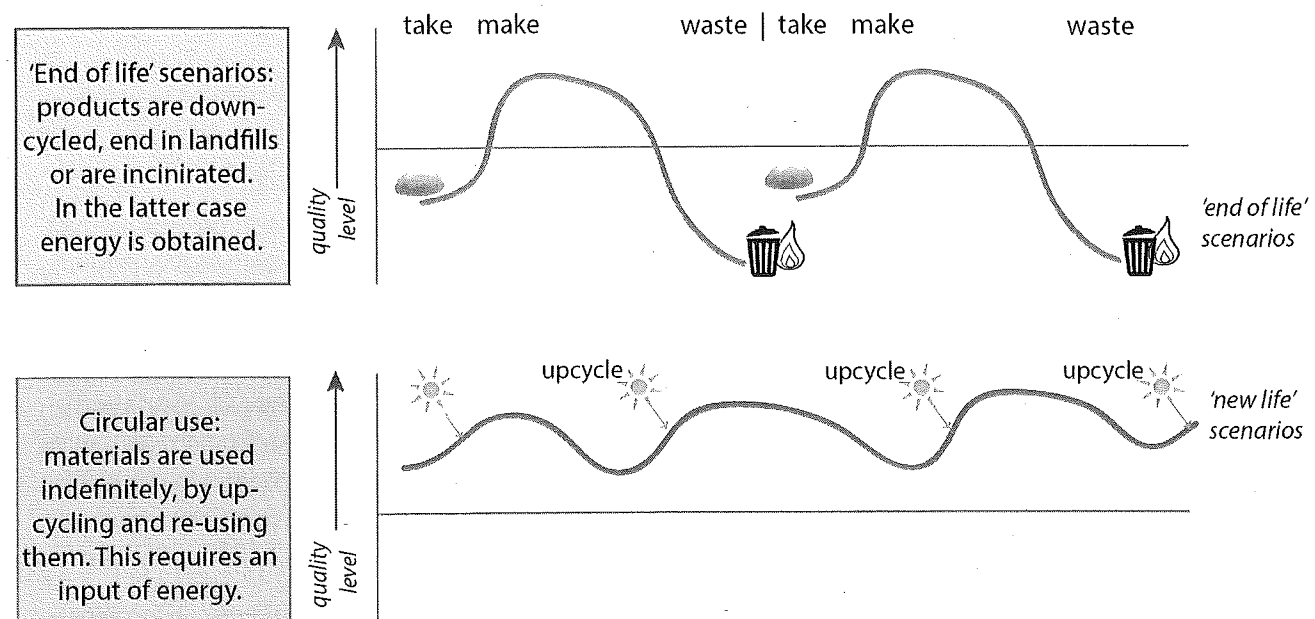


Figure 8: A 'take – make – waste' scenario versus a circular life cycle.

energy criteria but also consider the use of materials and space. Circularity of materials and use of space may be regarded as boundary conditions. Developing buildings that perform well on all resources is an interesting challenge for architects, engineers, clients and users.
Potential advantages of materials and products that function in a circular model are increasingly acknowledged: less waste and resource-depletion on the one hand, for example, and more focus on quality – of design, material use and producer-customer relation – on the other. But how this works for a complex assembly of materials, products, and services, such as a building, requires more study. Think of the technical capacity of building parts to

3 Beyond Sustainability: Materials, circular flows in buildings

enable circular flows, this asks for better track & trace systems of the used materials. If circularity is a criterion, knowing the qualities and quantities of materials in a building is a prerequisite. In the current build-use-demolish paradigm, however, we get away with rather rough estimations, and corresponding waste management strategies are usually limited to low-grade applications. For a more regenerative approach, radical changes are thus inevitable.

Cradle-to-Cradle® (C2C) puts forward the idea of buildings as material banks (temporary storage of materials that comprise the building assemblies), completely altering the way material flows need to be managed. This notion sheds a new light on the quality of building materials and building design. The basic conditions remain straightforward: touching upon pure, healthy material use, and anticipated disassembly and reuse routes. Just as important are the interdependencies between material properties (the intrinsic quality) on the one hand, and the contextualized building-design properties (the relational quality) on the other. Figure 9 displays the intrinsic and relational properties deemed crucial in facilitating circularity of materials and products in/through buildings[29]. Figure 10 visualises a basic inventory matrix linking building 'layers' to biological or technical regeneration routes. The service system, one of these layers, is highlighted. The building layers follow the so-called shearing layers of change[30], in the adapted version of McDonough & Partners, indicating average associated material turnover rates in a building's performance cycle. The layers can be further unravelled in sub categories, up to the smallest units of change relevant for the regeneration routes. Figure 11 displays the regeneration routes, as proposed by C2C[10] and Circular Economy[31]. Biological routes are labelled

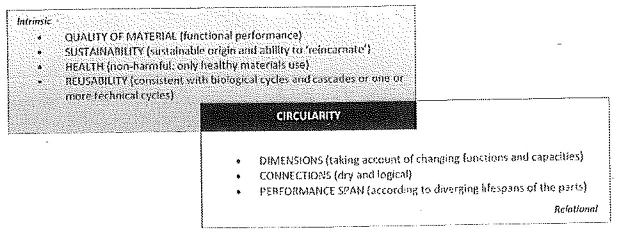


Figure 9: Circular potential at the intersection of intrinsic and relational aspects

as bio-cascades (reuse in gradually lower grade biological applications) and bio-feedstock (providing direct nutrients for the soil), whereas multiple technical routes can be distinguished: maintenance, redistribution, refurbishment, remanufacturing, and recycling. From here, an intriguing research field unfolds, touching upon a myriad of technical, organisational and financial questions of circular opportunities and challenges.

Water is one of the four important resources needed for life and for human activities. To deal with the worldwide rising demand for potable water and to resist the effects of climate change, a paradigm shift in our way of thinking is imperative. Our water supply must be brought in line with circular principles.

Among others four large system theories have discussed circularity in relation to water: Cradle-to-Cradle®, Regenerative Design, Biomimicry and Blue Economy. These theories have three important

GROUP (turnover rate)	SUB CATEGORY EXAMPLES	PART	Bio-cascade	Bio-feedstock	Maintenance	Redistribution	Refurbishment	Remanufacturing	Recycling
SERVICE SYSTEM (4x)	Piping & wiring HVAC units Sanitary equipment etc.	COMPONENT PRODUCT MATERIAL							
SETTING (3x)									
SKIN (2x)									
STRUCTURE (1x)									
SITE (0x)									

Figure 10: Example inventory matrix of building layers, material turnover rates and regeneration routes

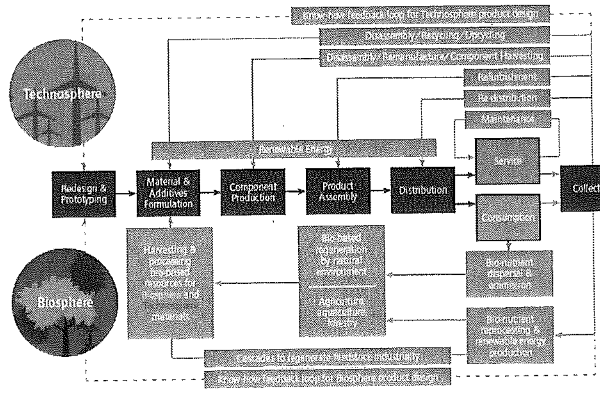


Figure 11: Material flows in a circular economy (Source: EPEA & Returnity Partners)

4 Beyond Sustainability: Water

principles when it comes to water[32]. These principles, which are all founded on the idea of creating positive footprints, are: 1. (innovative) reduction measures; 2. (innovative) discharge measures; 3. improvement of water quality. 'Improvement of water quality' in this context for instance means that companies that use water for their (production) processes must ensure that the water that leaves their premises is cleaner than the water that went into their premises. An example of an urban area in Amsterdam with a lot of attention for water quality is the office area 'De Ceuvel'[33]. Important aspects concerning 'innovative discharge measures', are green urban solutions like parks, public and private gardens and wadies. This greenery minimises peak loads on the sewer system during heavy rain fall, ensures water infiltration into the soil and improves the environment in the city.

One way of including water related aspects into the design of buildings is the use of the so-called New Stepped Strategy: 1. reduce the demand; 2. reuse waste flows; 3. use sustainable sources for the remaining demand[34]. Demand reduction foremost aims at reducing the need for potable water. Potable water should only be used for those purposes for which this water quality is really needed, like food preparation or water consumption by people and animals. A sustainable source of water for instance is rain water. After filtering, rain water is very suitable for diverse uses like flushing toilets, washing cars, watering gardens and maybe washing clothes. Because there is a time difference between the supply of rain water and the demand for water, storage is needed.

However, particularly step 2, reuse of waste flows, strongly links to circularity. We can distinguish reuse of water of the same quality, cascading and upcycling. An example of reuse of water of the same quality is a water-based cooling system in which the water after cooling down is reused within the same system. This in fact is a closed water circuit and therefore by definition circular. Cascading means reuse of water in (an)other function(s) for which water of lower quality can be used. An example is the use of shower water for flushing the toilet, if

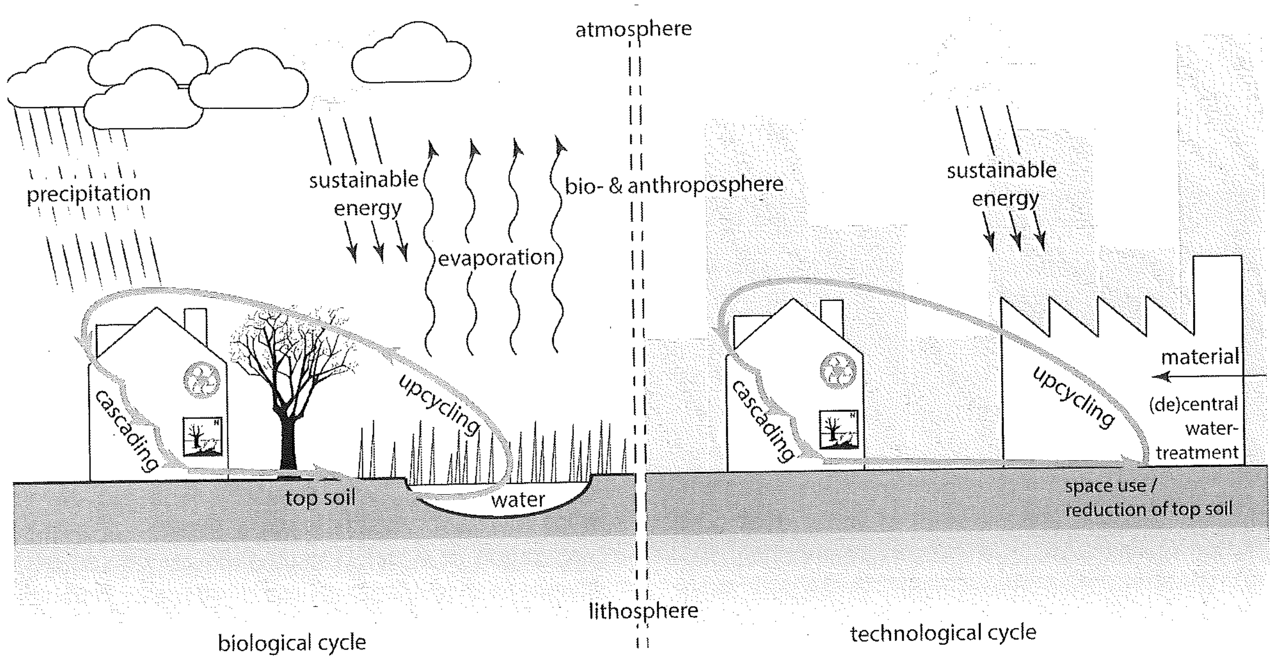


Figure 12: Circularity in the biological and technological water cycles.

necessary after filtering with a membrane filter as was done in the urban area Vauban in Freiburg[35]. Upcycling is the reuse of water after first having improved its quality. Such quality improvement typically takes place in a municipal water treatment plant or in infiltration zones in the dunes but can also take place inside neighbourhoods or even inside buildings (e.g. helophytes, lagoons, algae purification). Particularly water treatment areas in neighbourhoods can be interesting because these may increase the quality of the environment in the city by adding vegetation and water and may create temporary water buffers in case of high-intensity rain fall.

A good example of a building in which waste water is being reused is the office building Covent Garden in Brussels[36]. This building contains a cascading water flow in its atrium with various plants which act as the last step in a biological water treatment system for its own waste water. The water that is purified in this water flow up till grey water quality is reused within the building. By separating different qualities of water and by treating waste water in-house, this building is largely self-sufficient when it comes to water. Furthermore, the atrium with all its greenery is a pleasant space for people to reside in. This building nicely shows how water treatment can become part of the architecture of the building and at the same time minimises the need for fresh water from the utilities.

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5 Beyond Sustainability: Referencing

[1] World Health Organization: http://www.who.int/gho/urban_health/situation_trends/urban_population_growth_text/en/

[2] Worldometers: http://www.worldometers.info/world-population/

[3] http://ourfiniteworld.com/2012/03/12/world-energy-consumption-since-1820-in-charts/

[4] Welt im Wandel, Energiewende zur Nachhaltigkeit. Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen. ISBN 3-540-40160-1. http://www.wbgu.de/fileadmin/templates/dateien/veroeffentlichungen/hauptgutachten/jg2003/wbgu_jg2003.pdf

[5] http://www.peakoil.net/publications/peer-reviewed-articles

[6] BEE Plattform Systemtransformation 2012 Das BEE Szenario Stromversorgung 2030 Björn Pieprzyk:http://www.bee-ev.de/fileadmin/Publikationen/Studien/Plattform/BEE-Dialogkonferenz_Szenario-Stromversorgung-2030_BEE-Pieprzyk.pdf

[7] J Rifkin, The Third Industrial Revolution. ISBN: 978-0-230-34197-5

[8] Mineral Commodity Summaries 2015, US Dept. of the Interior, US Geological Survey: http://minerals.usgs.gov/minerals/pubs/mcs/2015/mcs2015.pdf

[9] WWF: https://www.worldwildlife.org/threats/soil-erosion-and-degradation

[10] M Braungart, W McDonough, Cradle to Cradle: Remaking the Way We Make Things, 2002. ISBN: 0-86547-587-3

[11] Story of Stuff: https://www.youtube.com/watch?v=9GorqroigqM

[12] P Mobbs: http://www.fraw.org.uk/mei/current/ecological_limits.shtml

[13] A Diederen, Global Resource Depletion, Managed Austerity and the Elements of Hope, 2010. ISBN: 978-90-5972-425-9

[14] The Encyclopedia of Earth: http://www.eoearth.org/view/article/150977/

[15] MN Fisch, Energy Plus. Buildings and districts as renewable energy sources. ISBN: 978-3-00-041246-2

[16] http://openbuildings.com/buildings/covent-garden-profile-3744

[17] Pharmafilter: http://www.pharmafilter.nl/en/

[18] http://www.thehenryford.org/rouge/teachers.aspx (21st Century Ford Rouge Factory –Environmental Innovations at the Rouge)

[19] https://www.youtube.com/watch?v=YBLZmwlPa8A

[20] MF Ashby, Materials and the Environment. ISBN: 978-1-85617-608-8

[21] http://www.bioenergy.wa.gov/oilseed.aspx

[22] International Monetary Fund, WP/15/105, How large are Global Energy Subsidies?

[23] JP van Soest en F Rooijers, Overheid stimuleert het gebruik van fossiele energie. NRC, 2015 05 23, O&D p. 9.

[24] The Guardian: http://www.theguardian.com/environment/2015/may/18/fossil-fuel-companies-getting-10m-a-minute-in-subsidies-says-imf

[25] European Environmental Agency, Loss of statistical life expectancy attributed to anthropogenic contributions to PM2.5, 2000 and 2020. http://www.eea.europa.eu/data-and-maps/figures/loss-of-statistical-life-expectancy-attributed-to-anthropogenic-contributions-to-pm2-5-2000-and-2020

[26] Bioorg: http://www.bioorg.eu/

[27] L Sherriff (2007), "Bio-fuels trigger tortilla price bubble", The register, 1 Feb. 2007: http://www.theregister.co.uk/2007/02/01/tortilla_bubble/

[28] NL Agency (december 2011), "Usability of Life Cycle Assessment for Cradle to Cradle purposes". Publication-nr. 1AFVA1106

[29] Geldermans, B., Rosen Jacobson, L., Zuidema, R., Doepel, D., Welink, J-H. Materialen & Circulair Bouwen, vervolgonderzoek Pieken in de Delta project REAP+, 2015

[30] Brand S., How Buildings Learn – What happens after they are built, Viking Press, New York, 1994

[31] Ellen MacArthur Foundation, Towards the Circular Economy – Economic and business rationale for an accelerated transition, EMF, 2012

[32] Dijk, S. van, Tenpierik, M. and Dobbelsteen, A. van den (2014), "Continuing the building's cycles: A literature review and analysis of current systems theories in comparison with the theory of Cradle to Cradle", Resources Conservation and Recycling 82: 21-34.

[33] Metabolic (2015), Metabolic – De Ceuvel, retrieved from the internet on 19 oktober 2015, <http://www.metabolic.nl/projects/de-ceuvel/>.

[34] Dobbelsteen, A.A.J.F. van den (2008), "Towards closed cycles – new strategy steps inspired by the Cradle to Cradle approach", In: Proceedings of the 25th passive and low energy architecture international conference, UC Dublin, 22-24 October, Dublin.

[35] Hasselaar, B.L.H., Graaf, P.A. de, Luising, A.A.E. en Timmeren, A. van (2006), Integratie van decentrale sanitatie in de gebouwde omgeving, TU Delft, Delft.

[36] Art & Build Architect (2007), Covent Garden Brussels 2007, brochure,retrieved from the internet on 20 oktober 2015, < http://www.artbuild.eu/projects/environment/covent-garden>.