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Shady Attia

Regenerative and Positive Impact Architecture

Learning from Case Studies

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This book is dedicated to perplexed minds that have only two choices.

This book is dedicated to architects, designers and building engineers who want to create positive impact architecture and built environment.

This book is dedicated to owners and developers who want to make profitable, healthy and energy positive buildings.

This book is dedicated to contractors who are confused about materials' sustainability and green construction technologies.

This book is dedicated to those who will take the third choice.

Foreword I

Shady and I met each other for the first time in 2012 at the Cradle to Cradle in Design and Business Seminar at the University of Twente in the Netherlands. At that time, he was thinking about the idea to translate the first Cradle to Cradle book into Arabic. This was of course a fantastic idea, but he luckily chose to go another path and surprised me with something much more spectacular. With this ground-breaking work, he is operating at the front of a totally new built environment. I am very grateful for his courageous decision to pay such a massive contribution to the discussion and implementation of regenerative architecture with a positive impact.

Since the Cradle to Cradle exhibition at the Biennale Architettura 2016 in Venice, I have realised even more that we are standing at the beginning of the regenerative architecture paradigm. Many architects still think that if they want to be good, a little less bad is enough—staying within concepts of resource efficiency and carbon neutrality. For decades, Cradle to Cradle advocates to go beyond conventional sustainability. We are capable to do more than simply reducing our ecological footprint and become neutral. If products and buildings become waste and have a negative influence on human health or the environment, it is simply a mark of bad design and poor quality. As a matter of fact, just to make products and buildings less bad will not safeguard our future. Ineffective resource management and thoughtless design created many socio-environmental challenges for humans and nature. Change these root causes by using the intelligent design of nature: beyond sustainability, but design for abundance.

Hence, we need a positive agenda to define our future. It is about using another language that creates other goals, designs and content. Shady understands perfectly that such a new approach towards architecture can only be implemented through integrating this positive language thoroughly. The book elaborates the theoretical development of sustainability towards the recent "regenerative architecture" paradigm shift very clearly. Besides, it connects theory with practical case studies in a way that it increases the know-how on what architecture with a positive impact exactly means. Therefore, this book is a useful support for architects and building professionals, which offers helpful analysis, tools and practical recommendations to increase the positive impact and regenerativeness of architecture. Since design lies at the core of solving current and future challenges by rethinking it all from the start, this book provides a framework that can help designers during their early design process.

Despite the many challenges we are facing, Shady is optimistic but addresses the need to consequently integrate regenerative Cradle to Cradle principles into the design of buildings. We need to become more aware and open to the fact that buildings can celebrate innovation by defining materials as part of biological and technical spheres to actively improve the quality of biodiversity, air, and water, all while being energy positive. Moreover, buildings can function as healthy material banks, where materials maintain their status as resources which can be used over and over again. With this book, I sincerely hope that more and more people in the built environment sector become inspired to develop and implement those principles. In fact, we need all the possible support to make this paradigm a successful one, so it will be realised in the right way. I wish you all the best on the path ahead.

Hamburg, Germany
July 2017

Michael Braungart

Foreword II

I am glad to introduce Shady Attia's new book on regenerative architecture and positive impact architecture. This book *Regenerative and positive impact architecture: learning from case studies* fits my interest and views that he knows very well. I first met Shady as an invited jury member in his architectural studio at Liege University in 2014. During the jury, I provided critical feedback to his students, keeping in mind the difficulty of changing the conventional design paradigm and embracing the regenerative paradigm. I liked the jury. It had a friendly but very constructive atmosphere that only Liège University can generate. I am glad he managed to summarise what seems very complex into common sense, if I dare to say "farmers" common sense.

Back in 1984, when I was an architecture student, my graduation project got the best mark at St.-Luc ESASL Brussels. The project was in Meknes, Morocco, where sustainability was natural to me enabling local skills and materials. The project addressed the lack of drinkable water and energy and the low agricultural productivity. I was inspired by the local *medina* and palaces relying on simple rules that create freshness, ventilation, security, privacy and tremendous comfort without relying on artificial and sophisticated means, but rather on transversal learnings and experience of generations.

I believe never achieved anything as complete as that graduation project. Indeed, I was thrilled to see such approach in Shady's studio…32 years later.

I always adopt this attitude of combining simple solutions for sustainable architectural design, which is now supported by sophisticated assessment methods and tools. My Lateral Thinking Factory consulting firm adopts the most advanced C2C engineering together with Drees & Sommer project management firm. As an accredited C2C architect, I worked on complex buildings such as PLEA Award winning Berlaymont EC Headquarters and Council of Europe Agora Building in Strasburg which includes Aquaponics Farming, a new applied Circular Economy venture achieved through BIGH (Building Integrated Greenhouses) or even being part of Circular Emerging Cities Integrated Lab in Addis Ababa. Thus, the potential is enormous, and there is so much to do!

Thank you Shady for helping us understand that it is all going in the same direction. It is important to achieve a positive impact architecture that considers not only its surroundings, but also involves all stakeholders into account. A win-win approach that the most business-minded developers understand … because it also makes an economic sense and will continue to do so.

This book can help architects and building designers to get informed about regenerative design and not to fear regulations, certifications and responsibilities … if it makes sense on numerous fronts, you will get through … no need to be perfect, just bring innovation to a point where it is experienced with positive impact.

This book is useful for architects and professionals in the construction sector because it provides a detailed performance assessment of 4 state-of-the-art buildings and quantifies their environmental performance. Also, this book provides a framework that can help designers during their early design processes with simple measurable solutions. As we need real-life testing, this book informs designers how to create a regenerative architectural design following a transversal and multidisciplinary approach.

I look forward to see the development and implementation of those principles. The more numerous we are, the more we share and the more we will be able to embrace the regenerative paradigm and create change and transformations that start from small projects to large cities. This book provides valuable and interesting knowledge for everyone who embraces this common sense.

Brussels, Belgium Steven Beckers
July 2017

Steven Beckers C2C accredited architect, co-founder of the Lateral Thinking Factory, the Building Integrated Greenhouses, Implementation Centre for Circular Economy and the Local Solutions Development Group Ethiopia and University Lecturer.

Preface

In this book, I tried to unearth the truth behind common perceptions of sustainable architecture. For more than 40 years, the energy efficiency reductionism paradigm has been held up as the solution to building's environmental impact. It is time to think not just about sustaining the world's badly damaged ecosystems and human communities, but about regenerating them instead.

In my own professional work as an architect and sustainability consultant, I have concentrated primarily on the use of green building rating systems, examining building resource consumption (energy, water and air) and building materials end life. Therefore, I selected four case studies with a positive impact and performed a systematic assessment to develop common rules for an environmentally enhancing and restorative relationship between architecture and the ecosystems.

Architects are under the obligation to learn about regenerative buildings and inform their clients and building users about their positive impact. Many times, clients distance themselves from sustainability issues and architects hesitate about sustainability until the contractor makes the decision for them. In this context, inaction and indecision is dangerous. Therefore, we need to learn about regenerative and circular design so that form follows performance. In parallel, we should not underestimate the learning curve to design, build and operate regenerative and positive impact buildings.

Contemporary architecture has to often confine itself to visual impact, reducing it to a mere image. Architects should move from designing architectural artefact to design performing architectural systems. We need to create healthy living and working environments with a positive impact on clients and users and the environment. The concept of regenerative architecture can help to reverse the climate change phenomena under the rules of capitalism. We have the knowledge and technologies to make a positive impact built environment and regenerate local communities. It is high time that the learned lessons presented in this book to become embedded in the teaching of architecture, building construction and urban planning at universities and technical schools all over the world.

Liège, Belgium Shady Attia
July 2017

Acknowledgements

This idea of this book was prepared based on the as an inaugural speech of Prof. Dr. Shady Attia inaugural speech at the chair of Sustainable Architecture and Building Construction at the Faculty of Applied Sciences at Liege University (Belgium).

Special thank is dedicated to architect Conrad Lutz (Green Offices), architect Michel Post (Iewan Social Housing), NREL team including Paul Torcellini and Shanti Pless and Venlo City Hall's architect Hans Goverde and Edward Timmermans. The work could not have been done without the support of Jerome Payet from EPFL, Corrine Gauvreau-Lemelin, Florence Delvenne, Dr. Sandra Belbooms and Prof. Angelique Leonard from the chemical engineering department, ULg. Also, special thank is dedicated to the meetings of the Cradle to Cradle inspired laboratory organised by Bob Geldermans and Peter Luscure at TU-Delft between 2010 and 2014.

The completion of this book would not have been possible without the contribution of several persons and entities that the author wishes to thank:

- Students of my architectural design studio who are committed with determination, to develop creative projects, responding to high didactic requirements.
- Speakers Herwin Sap, Professor and architect Wendy Broers of Zuyd University of Applied Sciences, Faculty Bèta Science and Technology Group Sustainable Built Environment.
- Jury members and external experts; Steven Beckers, architect and consultant and founder of Lateral Thinking Factory; Marny Di Pietrantonio, architect responsible for the technical department of the Passive House Platform (BE); Liesbeth de Jong, landscaper and expert of land use planning; Bob Geldermans, architect and head of research and climate design department, Faculty of architecture and the built environment, Delft University of Technology; Andromaque Simon, architect and expert in sustainable construction and certification of sustainable buildings BREEAM; Frédéric Castaings, expert in timber construction and

manager of forestry in the non-profit association Natural Resources Development; Muriel Brandt and Olivier Henz, architects and founders of ECORCE; and Lucien Hoffmann, director of the Environmental Research and Innovation Department at Luxembourg Institute of Science and Technology.

I would like to extend my thanks to *Architecture et Climat* at UCLouvain and in particular Prof. Andre De Herde for the development of the historical part and for comments on earlier versions of this book. The author thanks Josef Ayoub, Natural Resources Canada and the IEA SHC Task40/ECBCS Annex 52 team.

Finally, our gratitude is addressed to the University of Liège (ULg), the Faculty of Applied Science (FSA) and the Department of Urban and Environmental (UEE) Engineering, thanks to the quality of its members and their infrastructures.

Contents

Abbreviations

AIA	American Institute of Architects
ASES	American Society Energy Society
ASHRAE	American Society for Heating and Refrigeration and Air-conditioning Engineers
BIM	Building Information Modelling
BPS	Building Performance Simulation
BREEAM	Building Research Establishment Environmental Assessment Method
C2C	Cradle to Cradle
CD	Concept Design
CH	Switzerland
COTE	Committee on the Environment
CP	Construction Phase
DD	Design Development
DGNB	German Sustainable Building Council
DHW	Domestic Hot Water
DOE	US Department of Energy
EN	European
EPD	Environmental Product Declaration
EU	European Union
EUI	Energy Use Intensity
FSC	Forest Stewardship Council
GWP	Global Warming Potential
HDP	Health Product Declaration
HVAC	Heating, Ventilation and Air Conditioning
IDP	Integrative Design Process
IEA	International Energy Agency
IEQ	Indoor Environmental Quality
IPCC	International Panel for Climate Change
ISO	International Standardisation Organisation
KPI	Key Performance Indicator

LCA	Life-Cycle Assessment
LCI	Life-Cycle Inventory
LED	Low emitting diode
LEED	Leadership in Energy and Environmental Design
NL	The Netherlands
NRE	Non-renewable energy
NREL	National Renewable Energy Laboratory
nZEB	Nearly Zero Energy Building
NZEB	Net-Zero Energy Building
OSB	Oriented Strand Board
PE	Primary Energy
PLEA	Passive and Low Energy Architecture
PPA	Purchase Power Agreement
PV	Photovoltaic
PVC	Polyvinyl chloride
RSF	Research Support Facility
SD	Schematic Design
SHGC	Solar Heat Gain Coefficient
US	United States
USGBC	United States Green Building Council
U-value	Thermal conductivity
Vlt	Visible transmittance
VOC	Volatile Organic Compound
WWR	Window-to-wall-ratio
XPS	Extruded polystyrene

Abstract

Regenerative design holds great promise for a new era of sustainable and positive impact architecture, sparking considerable interest among architects, building professionals and their clients. Until now, there are no green buildings with an overall positive impact on environment and health. In this regard, the professional and scientific potential of regenerative architecture can only be fully realised by the setting a design framework that guides designers during projects design, construction and operation. This book introduces readers to key concepts of circularity in the built environment, highlight best practices, introduce opportunities to create value learn from real cutting-edge case studies. In this book, we present a novel framework for regenerative building design that can be applied to future constructions based on professional expertise and exposure, towards healthy, resource efficient and green buildings in the AEC industry. We compare four state-of-the-art buildings to address the critical principles, strategies and steps in the transition from the negative impact reduction architecture to the positive impact regenerative architecture, utilising life-cycle analysis. The case studies analysis and comparison can serve as an inspiring eye-opener and provide a vision for architects and building professionals in the fields of high-performance buildings, resource-centred thinking and regenerative architecture.

Keywords Green building · Sustainable building · Circularity · Resource efficiency · Carbon emissions · Life-cycle assessment

Chapter 1
Introduction

Abstract Looking today to the challenges for planning and design of sustainable built environment including, carbon emissions, climate change, human health, water problems, biodiversity, scarcity of resources, depletion of fossil fuel, population growth and urbanization; sustainable architecture will play a key role for the sustainable development of society as a whole. Cities and buildings can be seen as microcosms, a potential testing ground for models of the ecological and economic renewal of the society. In this context, this chapter provides an introduction to the book readers and shares with them the vision and key research questions that guided the research development in relation to sustainable urban and architectural development. The chapter presents the scope of research and the motivation behind writing this book. A discussion on the ecological and economic challenges in relation of the built environment and its environmental impact highlights the need for a paradigm shift.

1.1 Ecological and Economic Challenges and the Built Environment

The ecological and economic crises have been present for many years now. The economic system is showing its weak points in a dramatic fashion, unemployment is growing at a fast rate, the end of our fossil energy and other resources are apparent. There are more people who are becoming aware of the consequences of the climate change and the speed at which the biodiversity is diminishing is far beyond human imagination. Historically, buildings and architecture in particular had a central meaning for the sustainable development of the society. Remnants of the built environment of many cultures suggest that architecture played an important role in the social, economic and environmental life, but a review of the last century reveals that architecture tended to diminish in importance while other forms of discourse, such as the political, economic, technological, media had a more definitive impact on culture. Looking today to the challenges for planning and design of sustainable built environment including, carbon emissions, climate

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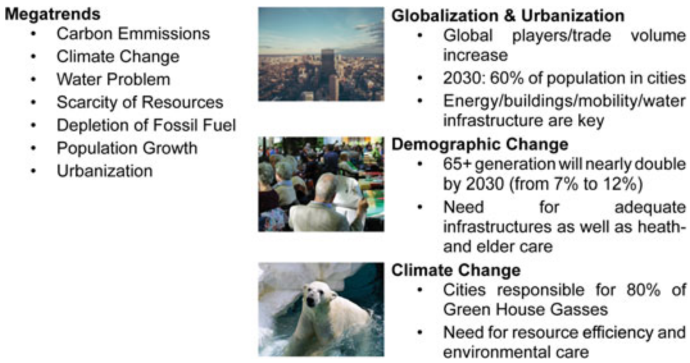

Fig. 1.1 Challenges for planning and design of positive impact built environment

change, human health, water problems, biodiversity, scarcity of resources, depletion of fossil fuel, population growth and urbanization (see Fig. 1.1); sustainable architecture will play a key role for the sustainable development of society as a whole. Cities and buildings can be seen as microcosms, a potential testing ground for models of the ecological and economic renewal of the society.

Building construction and operation contribute greatly to the resource consumptions and emissions of the society. In Europe, building acclimatization alone accounts for roughly 40% of the total energy consumption (Huovila 2007). When the effort required for construction, maintenance and demolition adds up, it is safe to assume that roughly half of the overall energy consumption can be attributed directly or indirectly to buildings. According to estimates nearly half of the all raw materials are employed in buildings, and a staggering 60% of all waste is the result of construction and demolition. The great significance of buildings and dwellings is evident in the way the building sector occupies in national economies. Private households spend roughly one third of their disposable income on housing (Eurostat 2012). In Western Europe, 75% of fixed assets are invested in real estate (Serrano and Martin 2009).

Thus, the resources (land, water, energy, materials and air) we need to provide for decent housing and high quality life in the built environment are in decline because they are being used, exhausted or damaged faster than nature can regenerate them. In the same time, our demand for these resources is growing. The industrialisation exhausted the planet's carrying capacity and destroyed ecosystem functions and services. Populating growth in many regions of the planet has brought with it the need for decent housing with low greenhouse emissions, while in those countries with consolidated urban development process it is the existing built environment that demands transformation. When setting out the issue of satisfying these needs, we must consider both local and global environmental limitations. However, during the last 50 years architects and building professionals have been mainly concerned by only reducing the environmental impact of the built environment (Meadows et al. 1972). Even today, the dominant operating paradigm to face the economic and ecological crisis remains the same reductions resource efficiency based paradigm.

In this context, it is not enough to aspire to mitigate the effects of human activity. On the opposite, we need to increase the carrying capacity beyond pre-industrial conditions to generate ecosystems functions and services to reverse the ecological foot print. This approach is promoted through the regenerative paradigm that seeks to develop renewable resources infrastructure and design building with a positive environmental impact.

1.2 Research Aim and Audience

Architects, building designers and owners seeking sustainable architecture in their practice require valuable information in order to make informed decisions. It is estimated that buildings design cost 1% of the life cycle cost but it can reduce over 90% of life cycle energy cost (Lovins et al. 1999). While during early design phases 20% of the design decisions taken subsequently, influence 80% of all design decisions (Bogenstätter 2000). However, effort spent to predict or reduce buildings environmental impact should be replaced by high quality regenerative design support metrics, indicators, tools, strategies and framework for net positive development. They need information on how to replace fossil fuel based system and components with passive or natural/renewable sources on the building and grid level. This information will need to be easily accessible, and, as shown in this book, based on a design framework (see Chap. 4) and well establish predicts and materials life cycle analysis. In this context, building professionals and in particular architects are challenged with a new reality and decision making stress that can be summarized as follow:

- To deal with sustainability issues, most architects follow a rather ad hoc, problem-solving approach at the end of the design process instead of designing from a sustainability perspective. However, sustainability principles should be inherently integrated in the architect's design process from the concept development phase on.
- The integration of sustainability in architectural design is complex due to multiple criteria that should be taken into account and the need for an interdisciplinary approach.
- Although the general principles of regenerative design are not new, there is a need to translate these principles to architects. No clear design framework, no hands-on guide or practical tools to support architects when designing buildings within a regenerative paradigm are developed so far.

Therefore, this book explores the resource efficiency and regenerative paradigms and presents a carrying framework for regenerative design. Based on four state of the art case studies, the book represents both paradigms and provides an overview and recommendations for regenerative building design. The purpose is to provide an understanding of both paradigms through practical examples, recommendations and lessons learned to demonstrate to building designers their adequacy in meeting the challenges of the design and operation of a positive impact built environment. Also, we explore the design principles and strategies of regenerative and positive impact architecture and systematic design approaches. The four case studies comparison is based on the life cycle analysis and evaluation of four state of the art green buildings through comparison. Comparison is the highest cognitive level analysis involving synthesis and evaluation. The first case study is the Research Support Facility (RSF) of the National Renewable Energy Lab (NREL) representing the reductionist paradigm. The second, third and fourth case studies are the Green Offices, Venlo City Hall and Iewan Social Housing that are high performance building representing the regenerative paradigm. The book explores the difference between two different dominating paradigms regarding their embodied energy and environmental impact.

1.3 Research Question

The comparison of four state of the art high performance buildings is valuable because it permits researches to measure constructs more accurately and as a consequence shape an effective theory-building of sustainable architecture. It helps us to answer the main research question of this book:

- Can the resource efficiency and impact neutrality paradigms help us to solve the economic and ecological crisis we are living?
- How can architects invent regenerative architecture and positive impact built environment?

The juxtaposition of the building performance analysis results allowed the research into a more creative, frame breaking mode of thinking. The result was a deeper insight into both paradigms. The significance of the comparison is based on documenting a paradigm shift and its increasing influence on the architectural and building design and construction practice. The results reported in this book are considered as an eye-opener and guidelines for building professionals including designers, owners and architects. The accurate and specific determination of regenerative and circularity characteristics of buildings can help designers to make fundamental choices in the design and construction of sustainable architecture. Choices that achieve thermal comfort, occupant's well beings enhance sustainability by working together toward a positive footprint. On the long term, this book can lead to reformulating and rethinking the definition of sustainable architecture while increase the uptake of positive impact buildings in practice and consequently lead to a paradigm shift.

The book is divided into 8 chapters. This chapter introduces the readers to introduce the research aim and questions. Chapter 2 explores briefly the historical background of sustainability in the architectural practice during the last century. Chapter 3 is fundamental, setting a definition for negative and positive impact built environment explaining the shortcomings of the linear construction process and benefits of circularity in the built environment. Chapter 4 explains the research methodology and the bases of the case study selection and comparison. The hypotheses and assumption underlying the life cycle assessment (LCA) are explained in Chap. 5. Then, Chaps. 6 and 7 present the four case studies and their comparison results. Finally, Chap. 8 provides an extended discussion and conclusion on the research major findings, learned lessons and a discussion on potential future implication on research.

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Chapter 2
Modern History of Sustainable Architecture

Abstract In order to understand the changes that accrued in the field of architectural, building design and urbanisation practices during the last hundred years we must follow the history of sustainability in the built environment. We can classify this history under five major phases that shaped the architectural discourse and practice we are witnessing today. Four out of five of those phases were influenced mainly by a major reductionist paradigm that defined sustainability for architecture and buildings design. The reductionist paradigm is seeking mainly the reduction of negative building impact through environmental efficiency. However, we are on a verge of a paradigm shift that operates from a different paradigm. This chapter describes the historical progress and different phases of the modern sustainable architecture and explore the sustainability paradigms associated with those phases.

2.1 Historical Background

From the beginning of the 20th century there have been five influential paradigms that shaped sustainability in architecture and the built environment. A review of the last 120 years reveals that the architectural discourse was influenced significantly by the economic and ecological crisis associated with industrialisation (see Table 2.1 and Fig. 2.1). This classification is not rigid and should not be interpreted as a rigid classification that creates borders it is a trial of categorization of thoughts that aims to provide a better understanding of the evolution and relation between sustainability and the creation of the built environment. Thus for thinking on sustainability we distinguish seven paradigms.

The first paradigm named Bioclimatic Architecture was dominated by ideas of Wright in 1906 on organic architecture (Uechi 2009), Corbusier and Breuer in 1906 on sun shading (Braham 2000), Atkinson in 1906 on hygiene (Banham 1984), Meyer in 1926 on the biological model (Mertins 2007), Neutra in 1929 on bioregionalism (Porteous 2013), Aalto in 1935 on health and precautionary principle (Anderson 2010) until formulation of the Bioclimatic Architecture paradigm by the Olgyay Brothers in 1949 and Olgyay (1953). Buildings of those architects showed a

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Table 2.1 Sustainability paradigms influencing architecture in 20th and 21th century

Paradigm	Years	Influencer	Paradigm
Bioclimatic architecture	1908–1968	Olgyay, Wright, Neutra	Discovery
Environmental architecture	1969–1972	Ian McHarg	Harmony
Energy conscious architecture	1973–1983	AIA, Balcomb, ASES, PLEA	Energy efficiency
Sustainable architecture	1984–1993	Brundtland, IEA, Feist	Resource efficiency
Green architecture	1993–2006	USGBC, Van der Ryn	Neutrality
Carbon neutral architecture	2006–2015	UN IPCC, Mazria	Resilience
Regenerative architecture	2016–Future	Lyle, Braungart, Benyus	Recovery

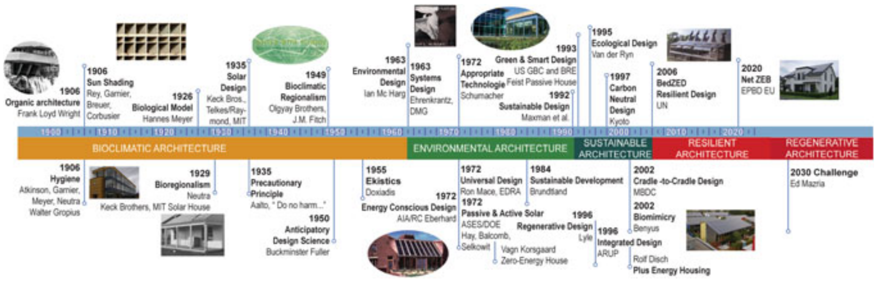

Fig. 2.1 Timeline of modern history of sustainable architecture

tendency of rationalism and functionalism while being fascinated by the beauty of nature. Bioclimatic adaptation, hygiene, safety and the notion of experimental and empirical design was not developed. Until the brothers Olgyay set up the first architecture lab in the 1950s combining academic research and practice. This was a major change that moved architecture into the scientific and empirical research world that is evidence based.

The second paradigm named Environmental Architecture was dominated by the ideas of McHarg in 1963 on design with nature (McHarg and Mumford 1969), Ehrenkrantz in 1963 on systems design (Ehrenkrantz 1989), Schumacher in 1972 on appropriate technology (Stewart 1974) and Ron Mace in 1972 on universal design (Thompson et al. 2002). Buildings of those architects showed a tendency of inclusiveness of environment and biology from the building interior to urban and planning scale.

The third paradigm followed the first energy crisis and was dominated by the ideas of the American Institute of Architecture (AIA) in 1972 on energy conscious architecture (Villecco 1977), the American Solar Energy Society (ASES) including the work of Balcomb in 1972 on passive and active solar architecture (Balcomb 1992), the Passive and Low Energy Architecture (PLEA) society in 1980 and

Herzog in 1980 (Herzog et al. 2001). Buildings of those architects showed a tendency of inclusiveness of solar and energy saving design strategies. The first ideas of energy neutral buildings and renewable energy integrated systems were introduced in several building prototypes and concepts. The use of empirical simulation and measuring based technique to quantify building performance was based on energy codes and standards that were created in this phase.

The fourth paradigm named Sustainable Architecture was dominated by the ideas of Brundtland (1987), ranging from Baker on sustainable designs (Bhatia 1991), Fathy's congruent with nature designs to build architecture from what beneath our feet (Fathy 1973) to Sam Mockbee. Along with many others, they expanded the purview of sustainable design by embracing aesthetics and human experience in addition to environmental performance.

The fifth paradigm named Green Architecture was dominated by the ideas of the US Green Building Council in 1993 on green and smart design, Van der Ryn in 1995 on ecological community design (Van der Ryn et al. 1991), ARUP in 1996 on integrated design (Uihlein 2014) and Feist in 1996 on Passive Haus Concept (Feist et al. 1999). With the emergence of this paradigm the greening of architecture proliferated globally with more complex and broader environmental considerations (Deviren and Tabb 2014).

The sixth paradigm named Carbon Neutral Architecture was dominated by the ideas of the Kyoto Protocol in 1997 on carbon neutrality (Protocol 1997) and UN IPCC report (2006) on climate change. The work of Bill Dunster on Zero Energy Development and Ed Mazria on the 2030 Challenge had a strong impact on architectural research and practice. With the EU 2020 nearly zero energy targets for 28 member states, energy neutral architecture became a reality embracing resilience, dynamism, and integration.

For the coming 20 years, we will be on the verge of the seventh paradigm named Regenerative Architecture. This paradigm will be dominated by the ideas of Lyle since 1996 on regenerative design (Lyle 1996a), Braungart and McDonough since 2002 (McDonough and Braungart 2010) on cradle to cradle design and Benyus on Biomimicry (Benyus 2002). We are on a verge of a paradigm shift that operates from a positive impact creation through environmentally effective sustainable buildings. Three of the presented cases studies, in this research, serve as showcases for a positive impact creation.

2.2 Towards a New Architectural Design Paradigm

Until the start of the 21st century, promoting sustainable architecture and green building concepts was a specialist niche issue, a storm in a glass of water in the margin of a linear economic mass production. This classification allows us identify the ideas and trends in the field of sustainability of architecture and the built environment. In the last hundred years, architecture was influenced by the sustainability discourse and many architectural and building innovations were tied to progress of ideas listed earlier. The influence of the seven phases was profound on architectural practice, driven by new construction technologies such as insulation materials, renewable systems and efficient heating and cooling technologies. Sustainability represented a vision for new practice and performance driven architecture and resulted in new production and performance calculation indices and methods. Several paradigms dominated the architectural and building practice. The most recent two are: ultra-efficiency and effectiveness. Being in a transitional verge between both paradigms the following chapter explain the difference between both paradigms.

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Chapter 3
Definitions and Paradigm Shift

Abstract Creating positive impact buildings requires setting clear definitions to accelerate the innovation process. A definition can increase the built environments' positive impact on people, planet and economy by designing regenerative and circular buildings. We are on the verge of paradigm shift that challenges the traditional and linear resource centred thinking. The impact reduction paradigm of the linear extract, make, use and dispose process is confronted with a new paradigm that is about maintaining products and services at their highest value, then recovering and regenerating them. In this chapter, we will explain both paradigms and bring ideas and definitions that can help the reader to adopt a new way of thinking into new design and construction models.

3.1 Negative Impact Reduction via Increased Efficiency

With the emergence of the ecological and economic crises during the last hundred years the architectural, engineering and construction community realized the negative impact of the industrialization of the built environment on the planet. Buildings are responsible for 40% of carbon emission, 14% of water consumption and 60% of waste production worldwide (Petersdorff et al. 2006). According to the European Union Directive, land is the scarcest resource on earth, making land development a fundamental component in effective sustainable building practice (EU 2003) (EEA 2002). Worldwide over 50% of the human population is urban. Environmental damage caused by urban sprawl and building construction is severe and we are developing land at a speed that the earth cannot compensate. Buildings affect ecosystems in a variety of ways and they increasingly overtake agricultural lands and wetlands or bodies of water and compromise existing wildlife. Energy is the building resource that has gained the most attention within the built environment research community. Building materials are another limited resource within a building's life cycle. In contrast to energy and water, materials circulate within a near closed-loop system. The regeneration period of most materials used in current building construction is extremely long since they were millions of years in the

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making. Water is a key resource that lubricates the building sector as much as oil does. Buildings require water during construction and during occupancy. The enormous negative impacts of ecology and the deteriorating ecosystem functions and services and the large ecological footprint, due to fossil fuel consumption and pollution resulted in large environmental deterioration.

As a result of these problems, the resources efficiency paradigm dominated the practice aiming to the reduction of the negative impact of the built environment. For example, the energy crisis in 1972 resulted in the development of energy efficiency measures in the built environment. The International Energy Agency (IEA), European Union (EU) and the American Society for Heating and Refrigeration and Air-conditioning Engineers (ASHRAE) legalized and published standards and performance targets for the energy consumption of buildings have improved by a factor of five to ten since 1984 (see Fig. 3.1) (EU-Directive 2005). The Club of Rome published its report Limits to Growth, predicting that economic growth could not continue indefinitely because of the limited availability of natural resources (Meadows et al. 1972). Factor Four idea is another outcome of the club of Rome that aims at doubling wealth while halving resource use (Von Weizsacker et al. 1997). In trying to achieve an environmental friendly built environment through reduction, the

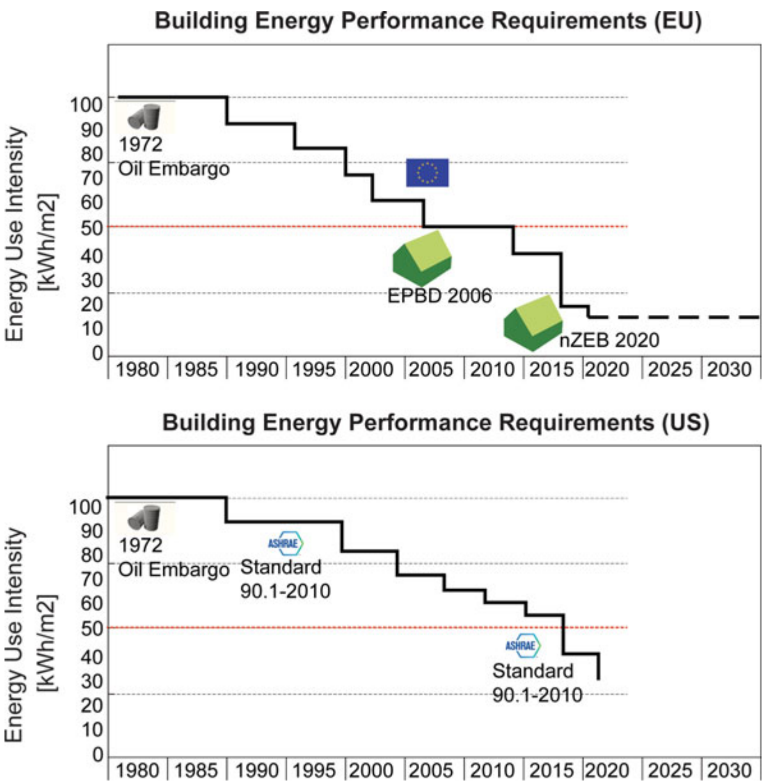

Fig. 3.1 Evolution of building energy performance requirements in the EU and US

sustainable architectural and building practice for a resource efficiency goals meaning to reduce the consumption and use resources efficiently. However, the changes that influenced the field emerged all from an efficiency paradigm focusing on the reduction of the use of depleting or polluting resources. Even the zero energy building and zero carbon building goals that seek maximum efficiency derive from the notion of neutralizing the resource consumption and define this as zero energy consumption (Marszal and Heiselberg 2009). In fact, the "break even" approach is very limited. Restricting the building impact boundaries to 'zero' or 'net zero' is misguided, the 'zero' goal limits achieving long-term sustainable building practices. If energy generated on-site prove to be an abundant resource, why then should we limit our objectives to zero? Moreover, the efficiency paradigm discourages the potential to reach fossil fuel independent buildings. The decline in the availability of oil, gas and coal and the danger of nuclear energy means that the cost of black fuels will become increasingly volatile. Peak oil will have a huge impact throughout the economy. Thus, the energy efficiency paradigm has reached its limit by proposing zero energy or zero emissions as the 'holy grail', because this reductionist approach operates within a black fossil fuel paradigm that does not recognize the importance of renewable, regenerative resources and building design mechanism that can reverse the climate change root cause.

With the advent of the 2013 IPCC report it became evident to the scientific and public community that the efficiency paradigm is failing to solve the problem. Even in architecture we witnessed several manifestations regar-ding its changing role and crucial character to our survival (see Table 1). The accelerated impact of climate change and the increasing negative impact of the built environ-ment are exceeding the planets capacity by six times (Stevenson 2012). The efficiency paradigm can no longer face the problem. We need to reverse the negative impact of the built environment and go beyond the efficiency paradigm.

3.2 Positive Impact via Increased Regenerative Effectiveness

From the discussion above we can conclude that the increasing population growth and ecological destruction requires increasing the ecological carrying capacity beyond pre-industrial conditions. We are looking for sustainable positive development that incorporate maximizing the viability of harnessing renewable resources and become independent from depleting and polluting resources. In order, to achieve positive building footprint we must move from the cradle to grave paradigm that aims to reduce, avoid, minimize or prevent the use of fossil energy to a regenerative paradigm that aims to increase, support, and optimize the use of renewable (Lyle 1996). As shown in Fig. 3.2, the previous efficiency strategies have been operating within a carbon negative or neutral approach that will never reach a positive and beneficial building footprint. Even the existing net balance approach assumes a fundamental dependence on fossil fuels. Therefore, we define

Fig. 3.2 Paradigm shift towards a beneficial positive impact footprint of the built environment

the positive impact of the built environment from a renewable self-efficiency paradigm.

A regenerative sustainable building seeks the highest efficiency in the management of combined resources and maximum generation of renewable resources. It seeks positive development to increase the carrying capacity to reverse ecological footprint (see Fig. 3.3). The building's resource management emphasizes the

Fig. 3.3 A regenerative sustainable building seeks the highest efficiency in the management of combined resources and a maximum generation of renewable resources

viability of harnessing renewable resources and allows energy exchange and micro generation within urban boundaries (Attia and De Herde 2011). Over the past years, regenerative positive development paradigm has been garnering increasing influence on the evolution of architecture. The progress is dramatic: plus energy plus, earth buildings, healthy buildings and positive impact buildings. This new way of thinking entails the integration of natural and human living systems to create and sustain greater health for both accompanied technological progress.

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Chapter 4
Design Principles of Regenerative Design

Abstract Designers should focus on applying design principles and strategies for regenerative and positive impact architecture. During early design stages, design teams need to be informed with a richer understanding of principles of regenerative design so that they can come up with design solutions and incorporate them into effective performance driven buildings. Therefore, in this chapter, we present the key design principles for regenerative design and more importantly we provide a design framework that serves as a logical frame for decision making during the design process. The design framework has been tested and acknowledged in association with detailed regenerative design strategies and design elements. We recommend designers to read this chapter that provides a step-by-step informed guidance for the selection of construction systems, the creation of architectural design elements and solutions and the selection of regenerative design materials and products. A series of illustrations and schemes are developed to help architects during the design process. The aim of this chapter is to enhance the understanding and provide a structured guidance based on measurable performance indicators and threshold when designing regenerative and positive impact buildings.

4.1 Introduction

Accelerating the embracement or uptake of sustainability principles, set by the EU, in the architectural design practice is essential. Bringing sustainability to the ideation or concept development phase; supporting the inherent integration of sustainability principles in the architect's design practice. Transforming the foundations of sustainable development or the triple bottom line principles illustrated in Fig. 4.1 into practical design principles is necessary to help architect to achieve regenerative and positive impact architecture. This task should start by understanding the essence and meaning of regenerative design.

The term "*regenerative*" refers to a process that repairs, recreates or revitalizes its own sources of energy or air, water or any other matter. It is a sustainable system that shapes the needs of a society on the integrity and balance of nature. The

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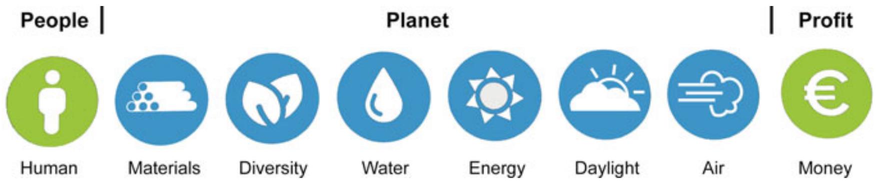

Fig. 4.1 People, planet and profit three bottom line of sustainable development

concept of a regenerative design is thus to create a virtuous circle, in which the consumption of resources (materials, water, air and energy) in a process is balanced by the creation of products (or by-products) and resources identical in quantity and quality, which are the consequences of an appropriate design. Applied to the field of architecture, the challenge of designing positive impact buildings is to integrate a number of constraints to ensure that the project as a whole will be able, on the scale of its own life, to reproduce and recreate all of its components and the resources it consumed to be built, to perform and to function.

4.2 Guiding Principles

The goal of regenerative design and sustainable development is a world that celebrates diversity, health and just with ecology, water, soil, air; and energy for the benefit of all. In the last ten years, there has been a progress made in measuring the environmental impacts of the building sector. It is possible to highlight the weight and the role of buildings in the final consumption of energy, carbon, water and in the consumption of raw materials. The model of sustainable building construction is gradually being imposed on those involved in the construction sector, the owners, design professionals, contractors and politicians. Consider, for example, the growing importance of the Environmental Product Declarations (EPDs) documents that provide product information on the environmental impact of building materials based on thorough life cycle analyses. Today, the guiding principles for sustainable architecture can be found mainly in criteria of:

(1) holistic building rating systems including LEED, BREEAM, Living Building Challenge or DGNB,
(2) specific building standards including the Passive House, Minergie, or Active House and
(3) building products and materials labels including the EPDs and the Cradle to Cradle Certified Product Standard.

For this book, we recommend five major guiding principles based on the Cradle to Cradle (C2C) certified product standard (MBDC 2014) as fundamental principles of regenerative design. The C2C concept is an international label that evaluates products and materials based on five parameters listed below. It is considered as one of the most progressive approaches that stimulates regenerative products development and optimizations. The C2C concept stimulates upcycling and upgrading products' residual value, by giving products a new function or application (McDonough and Braungart 2010 and 2013).

Safe and Healthy Materials: All manufacturers are required assess their use materials based on the hazards of chemicals in products and their relative routes of exposure during the intended (and unintended) use and end-of-use product phases. Harmful chemicals listed in the banned list of chemicals for technical and biological nutrients (MBDC 2012) should not be present in materials that may result in exposure to humans and the environment.

Materials Reuse: Each building product or material must be able to biodegrade safely as an organic nutrient or be recycled into a new product as a technical nutrient. All manufacturers are required to develop and implement strategies to close the life-cycle of their products with a goal of 100% recovery or re-use.

Renewable Energy and Carbon Management: The energy and carbon required for the production of a building product must be calculated. All manufacturers are required to increase the share of renewable energies in their manufacturing processes with a target of 100% of its use at the end of the production line. Manufacturers should carry out effective plans for transitioning to renewable energy use, and achieving a balance of carbon in the atmosphere and as food for building healthy soil.

Water Stewardship: Manufacturers are expected to treating clean water as a valuable resource and fundamental human right. Every product manufacturer has an important responsibility to care for this vital resource, and would be wise to effectively manage water resources.

Social Fairness: Manufacturers are expected to carry out their economic activities while respecting the health, safety and diversity of all living things and aspiring to have a completely positive impact on their communities. Social Fairness ensures that progress is made towards sustaining business operations that protect the value chain and contribute to all stakeholder interests including employees, customers, community members, and the environment.

Based on those five criteria, a framework for regenerative design needs to be developed allowing architects to embrace and integrate sustainability principles in an intuitive and innovative way in their design practice, starting from early design. The following section presents a framework on regenerative design. The clear identification of the framework will unlock this barrier for regenerative design and will allow architects to follow an integrated design approach within a regenerative paradigm.

4.3 Framework for Regenerative Building Design

Translation of the five guiding principles of regenerative design into a framework can inform and guide the design decision making of architects during the early design phases of regenerative design. The five guiding principles of regenerative

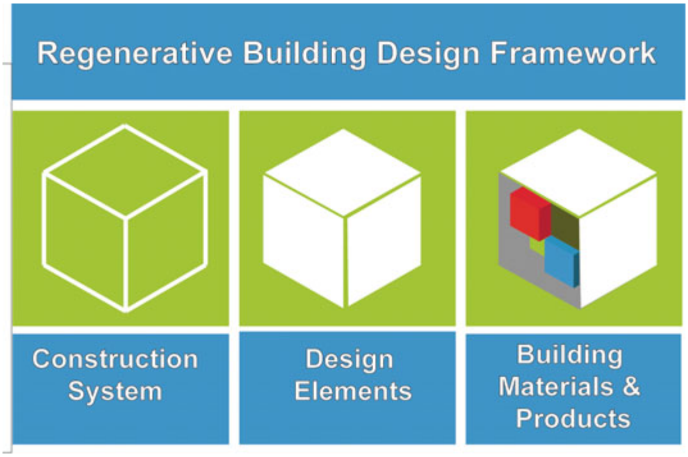

Fig. 4.2 The framework for regenerative building design is based on three key strategies

design addressing safe and healthy materials, materials reuse, renewable energy and carbon management, water stewardship and social fairness are theoretical design principles than needs to be translated into concrete architectural design strategies under the guidance of a logical thinking framework.

Based on our experience from different project analysis and our design studios we learned from the design process and from jury experts that regenerative design requires an architectural framework (Attia 2011, 2015, 2016a, b and 2017). This framework is an approach that can be used by architects for designing and evaluating regenerative and positive impact projects. The framework provides a logical planning and management for the thinking sequence to design positive impact buildings. This framework is a roadmap that is mainly based on three strategies (see Fig. 4.2) translated into architectural design decisions and leads to the selection, composition and integration of a flexible structural system, architectural design elements and regenerative building materials and products. The following sections describe those design strategies in details.

4.3.1 Regenerative Construction Systems

Regenerative design is fundamentally based on anticipating the multifunctional evolutions of the buildings use in the future. In a rapidly changing society, our buildings need to be able to adapt quickly to changes and new sociocultural and demographic issues. It is therefore essential to anticipate these changes and to integrate strategies allowing the building to adapt to a variety of uses over time. Today, huge quantities of building materials end up in landfills or incinerators long before they have lost any quality or use. Figure 4.3 shows the enormous potential of

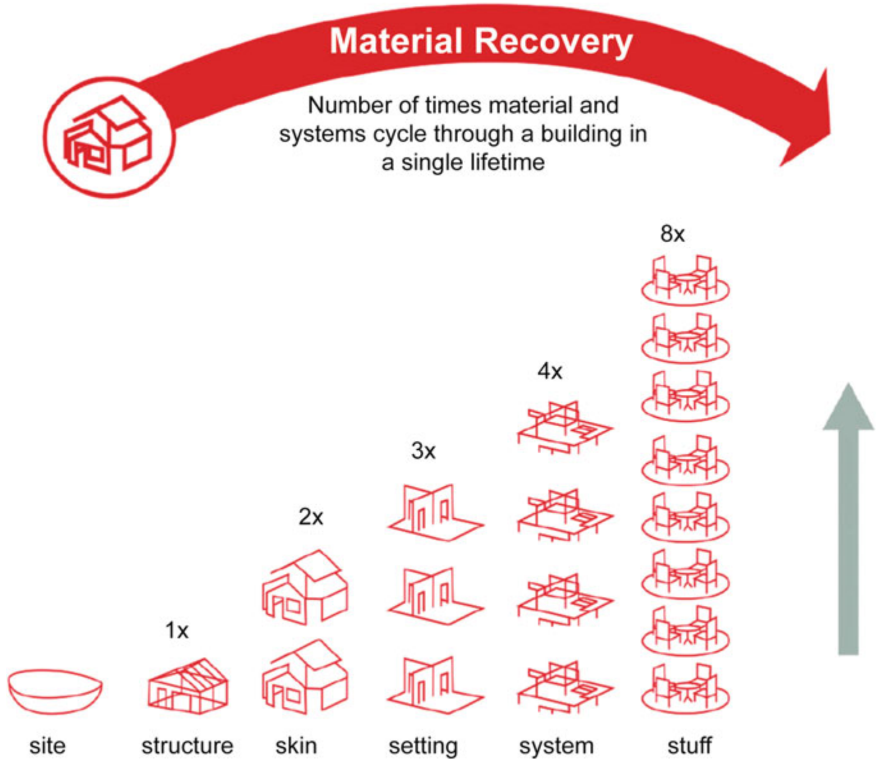

Fig. 4.3 Stweard brand—how buildings learn (1994)

materials to be recovered or reintegrated into consumption cycles. In the first place, it is essential to define a logical choice in terms of constructive and structural systems, such as columns, beams and slabs, in order to be able to upgrade the reuse cycles thereafter.

Flexible construction systems can make it easier to dismantle the structures and thus the recovery, upgrading, modification or transformation of building materials. The selection of flexible construction system allows future users to dismantle or disassemble a building in its elements and components, in order to increase the resilience of the building in terms of multi-functionality and flexibility of interpretation of spatiality and use. The modular design of construction systems allows the reuse of components and materials, while increasing the multifunctional capacity of building uses. We recommend designing modular construction systems that allow maximum spatial flexibility in the building (and thus uses) and that can be easily dismount into reusable building elements. There are examples of the implementation of these precepts in wood, metal, aluminium, concrete, even in masonry; Modular structures (such as containers) or thin steel structures are other avenues of investigation. As the first design strategy, building designers must select a flexible construction system that allows combing architectural design elements and regenerative products. A flexible construction system is the key to anticipate future modifications of buildings by addition, subtraction or replacement of envelope and façade layers.

4.3.2 Regenerative Design Elements

Once the construction system has been chosen, the following strategy is to reflect on the building spaces to increase the architectural design value. Depending on the geographical and climatic situation, certain elements may be more appropriate in order to guarantee architectural quality; this include atriums, courtyards, terraces, balconies, skylights, glazed facades, staircases, meeting rooms, open office spaces, common areas, foyer and roof gardens (see Fig. 4.4). The integration of regenerative elements provides quality and positive impact on users. The purpose of the regenerative design elements of a building is to improve the quality of air and water, increase biodiversity, use healthy materials, enable cultural and social diversity, enable functionality, mobility and generate energy. Identifying and selecting the appropriate regenerative architectural or technical design elements and integrating them into the design are essential to ensure the beneficial impact of an architectural project.

4.3.3 Regenerative Building Materials and Products

The final strategy of the regenerative design framework is to address building products and optimize the material selection process and integrate certified products into the building to increase its value. Each brick, board, piece of wood or glass in a building has a value. Instead of becoming waste, buildings must function as banks of valuable materials—slowing down the usage of resources to a rate that meets the capacity of the planet. C2C-certified products or similar eco-labels generate less waste and waste because they come from cycles beneficiaries of the biosphere or techno sphere. Choosing regenerative building products is a guarantee that building components are healthy, safe and beneficial for humans like the environment. These components or products are designed in such a way that their ingredients can be safely reintroduced into natural or industrial cycles and are assembled or produced with 100% renewable and non-polluting energy. Regenerative building materials and products are designed to protect and increase clean water resources (as a basis for social and environmental justice). The use of such products also generates chain partnerships with the aim of validating each intermediary within a production process. Mechanisms for recovery and reuse of materials but also waste or synergy of processes are born between the actors of these chains.

Fig. 4.4 **a** An atrium that is naturally daylit with a staircase and a green wall, Venlo City Hall, The Netherlands. **b** A planted atrium provides contact with nature, Alterra Building, Wageningen, The Netherlands. **c** An internal paneled windows wall providing view for office, Venlo Floriade, The Netherlands. **d** Outdoor space and hardscape for activities and well-being, Venlo Floriade, The Netherlands. **e** A protected terrace to connect the inside with the outside, Liege, Belgium. **f** A green roof and outdoor playground, Brussels, Belgium

This includes passing a passport to each material and creating a database in a building, reuse is facilitated in the future. Sustaining the value of the materials is the key to circular material use and ways to harvest this value is at the centre of the regenerative buildings. Integrating materials passports with reversible building design to optimise circular industrial value chains can lead to the reduction of waste generation and resource use. Tracing building materials and products will increase product life-spans, enable product and material reuse, recycling, recovery, with an upgrading cascading approach for recovered materials and products, and reduce generation of waste along product chains in different production processes as well as reduce the utilisation of feedstock materials and the emission of harmful substances.

4.4 Design Strategies for Regenerative Building Design

The regenerative design framework is based on three design strategies. Those three fundamental strategies should be applied at the start of the concept development phase and shall be used along the design process. Applying the following three strategies is a game changer, introducing a new design thinking paradigm where sustainability will be embraced inherently in the design process.

4.4.1 Design Strategy 1: Selection of a Construction System

The selection and sizing of the construction system should be based on the ability of designers to realize the modularity and the possibilities of assemblies of different materials and regenerative products. The construction system must be designed to facilitate the disassembly, handling and transport of a reversible architecture. From a sustainability perspective, particular attention should be given to expression and materiality, but also to the structural flexibility and adaptability of the construction and structural system. On the basis of the construction system concept, designer can then develop the entire envelope of the building. The envelope must meet the challenges of modularity and circularity and use of the façade elements (Fig. 4.3). The envelope must respect the hygrothermal requirement of high performance envelopes using positive impact materials. In addition, in order to facilitate the transport, storage and handling of the components, the sizing must be studied accordingly. In other words, it is up to architects to explore the structure and the envelope of the project enabling users to move from a perceived space to a built space. The construction system should allow the architectural, spatial, and technical transition between the inner and outer space (see Fig. 4.5).

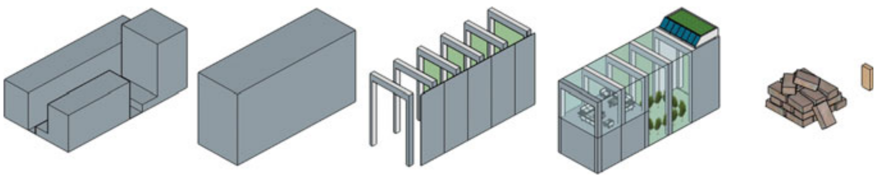

Fig. 4.5 The selection of construction system is the first step to move from the urban massing to the architectural spatial design

After defining a flexible construction system, the design team should address the whole building to finalize the project mass, plans and layout. The design should include the optimization of the envelope and the refinement of the architectural expression.

4.4.2 Design Strategy 2: Defining of Design Elements and Their Performance

Defining the design elements, described earlier in Sect. 4.2 and Fig. 4.4, depends on the ability to integrate them with the construction system and to achieve a series of architectural and building performance goals. At this stage, designers should identify the architectural design elements most likely to create a positive impact on their project and to size them as early possible. The spatial and technical feasibility of integrating regenerative design elements should happen at the right scale. More importantly, it must be coupled to the following performance indicators and performance goals.

4.4.3 Enhance Air Quality and Human Health

The human being is at the centre of the regenerative design. Providing high quality indoor environments and outdoor spaces for the activities of individuals and communities brings serenity and satisfaction to them. The design of naturally lit and ventilated spaces for living and working including gardens, meeting rooms, common spaces or even staircases stimulate productivity and well-being of building users. One of the desired performance goals in regenerative buildings is to improve indoor and outdoor air quality during the operation of the building. On average, indoor air quality in buildings is 4–8 times worse than outside, according to European studies. Therefore, the objective of positive impact buildings is to improve the quality of outdoor air as well as indoor air quality in order to create healthy, pleasant and safe indoor and outdoor air quality. Architects must develop buildings and cleaner environments by eliminating fine particles in the air, carbon emissions, and producing oxygen. Combining the air with the vegetation can be very effective indoors and outdoors. The use of plants increases biodiversity and above all make a contribution to make the city more beautiful. The purification of supply air can be mainly achieved by passing the air through green spaces. The use of green roofs, suspended gardens or vegetated walls provides additional lungs that purify air in urban areas. Clean air increases the well-being and productivity of building users. Natural ventilation and air circulation must be connected to natural or active air purification and filtration systems.

4.4.4 Energy Saving

Climate responsive and energy efficient design play an important role in regenerative architecture. Meeting the requirements of ultra-low energy building standards, such as the Passive House or Minergie or Active House Standard, is essential to guarantee a minimum consumption of energy and a maximum thermal comfort. For example, the Passive House Standard net heating energy requirements must be less than 15 kWh/m^2 annually, the airtightness must be less than 50 Pa and the minimum air renewal should not exceed 0.6 air changes per hour. Temperature overheating cannot exceed 25 °C for 5% of annual hours of operation of the building. In order to guarantee this performance, the envelope should be highly insulated and air tight. Walls should have a conductivity value $U \leq 0.1$–$0.15\ W/(m^2K)$ and for roofs and external slabs $U \leq 0.1\ W/(m^2K)$. Depending on the choice of the insulation materials, the sizing of the thickness to be implemented must be calculated and reflected in the design of the project. Special attention should be given to the design of the facades and the fenestration. Passive solar gains should be maximized on the south facades. Local rules of thumb for window-to-wall-ratio sizing should be respected for all openings in the different orientations. Shading devices must also be provided to prevent overheating. The conductivity value of a window must be $\leq 0.85\ W/(m^2K)$ with a value of $g > 0.5$. Double flow mechanical ventilation with heat recovery should be provided. The air vents and the air supply and extraction ducts must be integrated into the network of the technical ducts. The technical premises and raiser shafts should be provided, designed and drawn in plans and sections, including heating, air and heat exchangers. It is advisable to try to rely of free cooling or geothermal resources of the soil in order to passively cool or heat the air or water.

4.4.5 Renewable Energy Production

A regenerative building must produce more energy than it consumes. Building energy consumption should be estimated during early design phases to size and integrate renewable energy systems. Positive energy generation should be achieved to balance the consumption annually and generate preferably onsite more energy using mainly renewable energy. The choice of renewable energies (thermal or photovoltaic panels, geothermal or other systems …), their sizing and their spatial integrations must be managed with the building form and envelope. The area intended to accommodate the photovoltaic panels; their orientation and their positioning must be studied and represented in the drawings, diagrams and building models. The integration and sizing of the panels, whether architectural (roofs and facades of the building) or technical (to the HVAC system), should be apprehended on the basis of simple calculations based on the location of the building. Solar thermal systems should be also provided to cover the hot water needs and should be coupled to water storage tanks to ensure meeting the occupants' needs.

4.4.6 Water Management

A regenerative building separately collects the different wastewater streams and uses rainwater harvested locally. An optimal positive impact building, from the point of view of sewage management, would have in phytofilter or situ-treatment technology by a plant-based purification system (plant-based filtration). There are environmental friendly in situ treatment systems that treat both gray and black waters. They must be resistant to drought and occupants cannot use toxic or bleaching cleaning materials to keep plants alive. They can become part of a greenery landscape and increase biodiversity. Enhancing the water quality is a very important performance indicator in regenerative buildings. Therefore, all potential options for optimal water treatment and nutrient extraction from waste water must be investigated. Rainwater tanks can guarantees independence for the building during summer seasons. Their sizing and installation must be mastered for each project. In the case of sewage systems design, special attention should be paid to layout plans and the flooding scenarios.

4.4.7 Design with Nature

The introduction of vegetation in and out of buildings enhances the spaces and increases the environmental quality (biophilia, regulation of humidity, oxygen and acoustics) and external (increase in biodiversity and resistance to the effect heat island). Design with nature begins with a green infrastructure that connects buildings and their users to the ecosystem. Design with nature should be based on nature-based solutions that connect humans to flora and fauna in a balanced way. The nature-based solution promotes biodiversity and the biophilia and helps the built environment recover from the effects of heat island, air pollution, noise and degrading quality of life. The well-being of humans is based on the genetic connection to nature and the biophilia is an area that provides evidence of this connection. The introduction of nature-based solutions both indoors and outdoors is essential for water management, urban food production, air cleaning and human well-being. The nature-based solution includes urban agriculture, green roofs, green spaces, green facades, trees, gardens, parks, ecological networks and permaculture. Integrating such systems into a project is essential and requires careful design and technical studies during the design phase. The assumptions to be considered are, for example: root damage, artificial irrigation, structural overload, water storage and overflow management, and erosion, light penetration and solar orientation, choice and diversity of plants, consequences on insulation, etc. Each project must integrate the plant component in order to increase the quality of the architectural experience.

Finally, each project must integrate regenerative elements in order to increase the quality of the architectural experience. The following list contains a non-exhaustive list of examples of different regenerative elements to be integrated into the project according to their relevance in the architecture developed:

- Windows
- Roof gardens
- Solar panels
- Solar chimneys
- Greenhouses
- Ventilation chimneys
- Geothermal
- Storage space
- Parking facilities
- Garages
- Phytofilter
- Green Walls
- Bio-based insulation
- Green Roofs
- Trees.

4.4.8 Design Strategy 3: Choice of Regenerative Materials

The use of regenerative materials, whether of the biological or technological sphere, must be met without loss of quality. Materials with EPD, C2C certified materials or any other eco-certified products should be used in line with the previously mentioned regenerative design principles. Particular attention must be paid to the fire safety considerations, the embodied energy and carbon content and the structural, mechanical, hygrothermal and acoustic performance of the materials used. As far as possible, it is preferable to favor biosphere materials such as clay, wood, straw, bamboo or hemp (see Fig. 4.6). However, it is not necessary to exclude the products of the technosphere such as concrete, aluminum or steel. In the case of construction, the products resulting from the technosphere are sometimes unavoidable; e.g. for certain types of foundations, windows, special techniques or for specific safety devices (fire, bracing). Technoshpere materials are encouraged to be used if they serve the design for disassembly and reuse target and as long as these products are certified or have EPDs and the use of toxic substances is excluded, as are the effects of their production cycles on the environment. Figure 4.7 provides a list of key questions that need to be answered during the selection process of regenerative building products, components or materials.

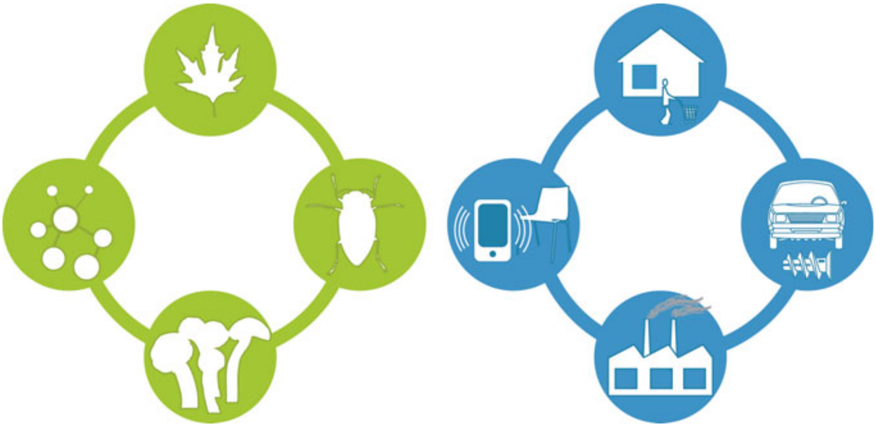

Fig. 4.6 Biosphere and technosphere (Mulhall and Braungart 2010)

Fig. 4.7 Key questions to be used when selecting materials for a regenerative building

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Chapter 5
Indicators and Metrics of Regenerative Design

Abstract In this chapter, we list the key performance indicators and thresholds for regenerative architecture and positive impact architecture. The aim of this chapter is to share with readers the insights of our assessment methodology and how we compared the four case studies. The chapter discuss the key influential parameters that need to be taken into account when assessing the environmental performance of buildings. The assumptions for our life cycle assessment and the used standards and system boundaries are described including the functional unit and indicators of comparison. We present the life cycle inventory and the weight share of material groups that was found four the four buildings. The durability of elements, replacement and repair scenarios are presented in order to inform the reader about the some quantitative and methodological information on the role of end-of-life in buildings.

5.1 Introduction

Figure 5.1 lists a series of environmental impacts related to buildings and suggests corresponding performance indicators that can be used to measure those impacts. The assessment of building sustainability is complex but has evolved in the recent 20 years from single criteria to multi-criteria evaluation. Moreover, it evolved from single life stage evaluation, which is mainly the operational or use stage, to multi stage evaluation including product stage, construction stage and end-of-life stage. Therefore, when assessing regenerative and positive impact building we should operate on a holistic level and on an operational level combing a cocktail of performance indicators.

In order to answer the research question, introduced earlier in the introduction chapter (see Chap. 1), in broad terms on the effectiveness of the efficiency paradigm versus the effectiveness of regenerative paradigm it is important to test our suggested design framework (see Sect. 4.2) based on case studies. Four specific case studies were selected to represent the two paradigms. We looked for selecting four appropriate high performance buildings with extraneous variations to define the

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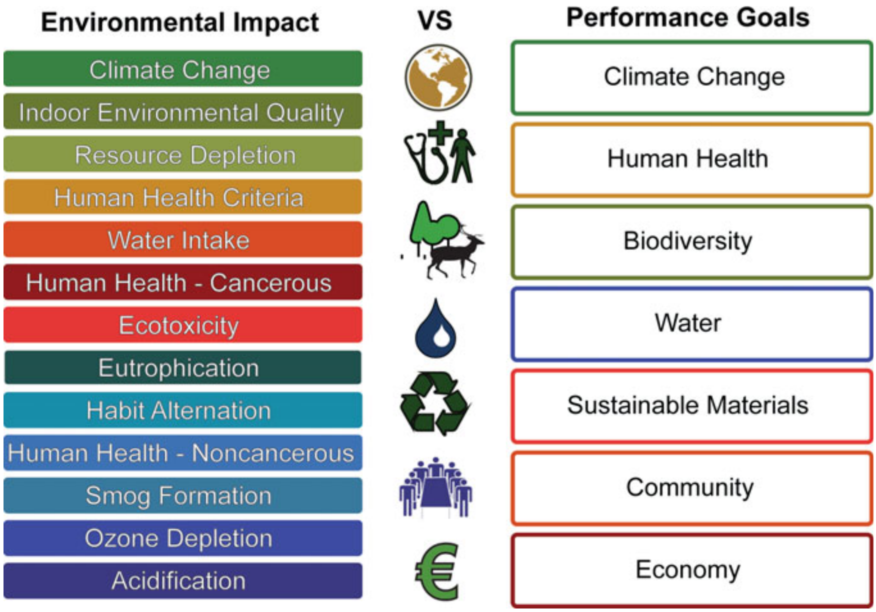

Fig. 5.1 Holistic vision of performance indicators of regenerative design and positive impact buildings

limit for generalising the findings. The four selected buildings provide examples of four types classified as state of the art high performance buildings in US, Switzerland and the Netherlands. The goal of the selection to choose cases which are likely to replicate. Indeed, the US case is LEED Platinum certified zero energy office building, the Swiss case is a MINERGIE-ECO ecological office building, the first Dutch case is the Venlo City Hall, a C2C inspired building and the second Dutch case is Iewan Social Housing project representing affordable self-built ecological living.

The comparison focused mainly on energy, water, indoor environmental quality (IEQ) and construction technology during the phase of construction, operation and demolition in order to avoid the overwhelming volume of data. The four cases were meant to be used as a source for a firmer empirical grounding to answer the research question. The analysis was carried out in two steps:

- Screening and analysing both building so that we can see the magnitude of impacts.
- Performing a detailed LCA especially for carbon emissions and primary energy.

For the first part of the study, multiple data collection methods were combined to compare the four cases studies. The data collection included literature reviews, interviews, observations, field studies and access to simulation models and monitored performance data. The author had the chance to interview the design teams and visit all four buildings during and after construction and perform a modelling analysis and post-occupancy evaluation.

5.2 Life Cycle Standards and System Boundary

The second part of the study comprised a life cycle assessment analysis. The interest in evaluating energy use, consumption of natural resources and pollutant emissions, especially for new and low energy buildings is increasing (Hernandez and Kenny 2010; Leckner and Zmeureanu 2011). One of the most important environmental impacts of buildings is materials and resources. According to the USGBC Projects Database, materials count for 35% of the total energy consumed during the building life cycle (Turner et al. 2008). A more recent study pointed out that embodied energy can be up to 60% of the building life cycle (Huberman and Pearlmutter 2008). Therefore, we opted for a life cycle assessment to compare the energy consumption, material embodied energy and CO_2 emissions according to ISO 14040 and 14044 standards (ISO 14040, ISO 2006a, b and ISO 14044; Vogtländer 2010) (see Fig. 5.2).

The CEN/TC 350 “Sustainability of Construction works” standard recommends consideration of four life cycle stages for buildings: product stage (raw materials supply, transport and manufacturing), construction stage (transport and construction installation on-site process), use stage (maintenance, repair and replacement, refurbishment, operational energy use: heating cooling, ventilation, hot water and lighting and operational water use) and end-life stage (deconstruction, transport, recycling/re-use and disposal) (Blengini and Di Carlo 2010; CEN 2005). Table 5.1 illustrates the life cycle subsystems conducted for this study. To facilitate the

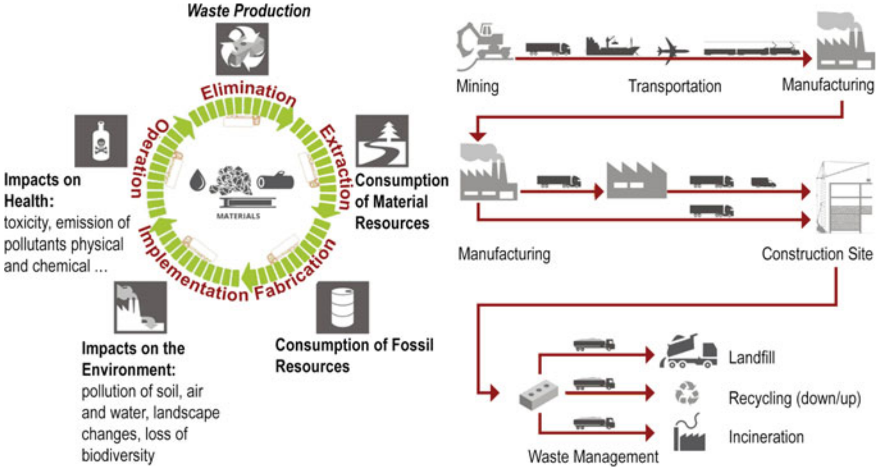

Fig. 5.2 Life cycle assessment stages and the end of life scenarios

Table 5.1 Life cycle phases and data sources

Life cycle phase	Subsystem	Case study 1	Case study 2	Case study 3	Case study 4
Product stage	– Shell and building services materials production – Analysis include gross amount, i.e. including the material loss during building process	– Quantities estimated from building drawings – Literature data (Guggemos et al. 2010) – Inventory information process for most materials has been collected from Ecoinvent database (PRé Consultants 2016)	– Quantities estimated from building drawings – Unpublished data from University de Lausanne (Lehmann 2011) – Inventory information process for most materials has been collected from Ecoinvent database with exception of wood and cellulose insulation for which specific data have been available (PRé Consultants 2016)	– Quantities estimated from building drawings – Inventory information process for most materials has been collected from Ecoinvent database with exception of concrete for which specific data have been available	– Quantities estimated from building drawings – Inventory information process for most materials has been collected from Ecoinvent database with exception of straw insulation for which specific data have been available (Orio architecten 2017; VastBouw 2017 and PRé Consultants 2017)
	– Transportation and building process – Distances from the production location for the main materials to the building location based on calculated weight – Type of transport and means of transport	– Information about the type of means of transport used for transporting individual types of building materials has been based on personal communication with design-build team – Distances have been calculated	– Unpublished data from University de Lausanne (Lehmann 2011) – Distances have been calculated – Information about the type of means of transport used for transporting individual types of building materials has been revised through a presentation of the architect	– Information about the type of means of transport used for transporting individual types of building materials has been based on personal communication with design and construction team – Distances have been estimated and calculated	– Information about the type of means of transport used for transporting individual types of building materials has been based on personal communication with design-build team – Distances have been calculated

(continued)

Table 5.1 (continued)

Life cycle phase	Subsystem	Case study 1	Case study 2	Case study 3	Case study 4
Construction stage	– Construction of building components and construction of the whole building – Energy consumption by construction machinery	– Assumptions about construction machinery have been made based on the literature – Calculated with the software application SimaPro	– Assumptions about construction machinery have been made based on consultation with architect – Calculated with the software application SimaPro	– Assumptions about construction machinery have been made based on the documentary video (Kraaijvanger 2016) – Calculated with the software application SimaPro	– Assumptions about construction machinery have been made based on the documentary video (Iewan 2015) – Calculated with the software application SimaPro
Use stage	– Energy use for HVAC – Energy use for lighting and plug loads	– Literature (US DOE 2012) and monitored data from NREL (Carpenter and Deru 2010) – Data concerning HVAC have been collected between 2010 and 2014 – A simple simulation model was created to assess the energy consumption and fuel breakdown and neutralize the climate variability	– Literature (Lehmann 2011) and monitored data from architect Conrad Lutz between 2010 and 2014 – A simple simulation model was created to assess the energy consumption and fuel breakdown and neutralize the climate variability	– A simple simulation model was created to assess the energy consumption and fuel breakdown and neutralize the climate variability	– A simple simulation model was created to assess the energy consumption and fuel breakdown and neutralize the climate variability

(continued)

Table 5.1 (continued)

Life cycle phase	Subsystem	Case study 1	Case study 2	Case study 3	Case study 4
End-of-life Stage	– Dismantling, demolition, recycling/ reuse/landfill – Type of waste disposal – Distances from demolition site to the final disposal sites – Type of transport and means of transport	– Literature data(Carpenter and Deru 2010) – Type of means of transport used for transporting building materials has been based on literature	– Literature (BAFU 2016) and unpublished data from University de Lausanne (Lehmann 2011) – Type od means of transport used for transporting building materials has been based on literature	– Type of means of transport used for transporting building materials has been based on literature	– Type of means of transport used for transporting building materials has been based on literature

comparison of resources for architects we classified our analysis under energy use (operational energy) materials (embodied energy).

5.3 Functional Unit, Year, Tools and Indicators

The functional unit to compare both buildings was 1 m^2/year. Figures 5.3 and 5.4 show two examples of the environmental impact of insulation and heating systems. For the calculation model we expected the occupancy for 100 years. Numerous

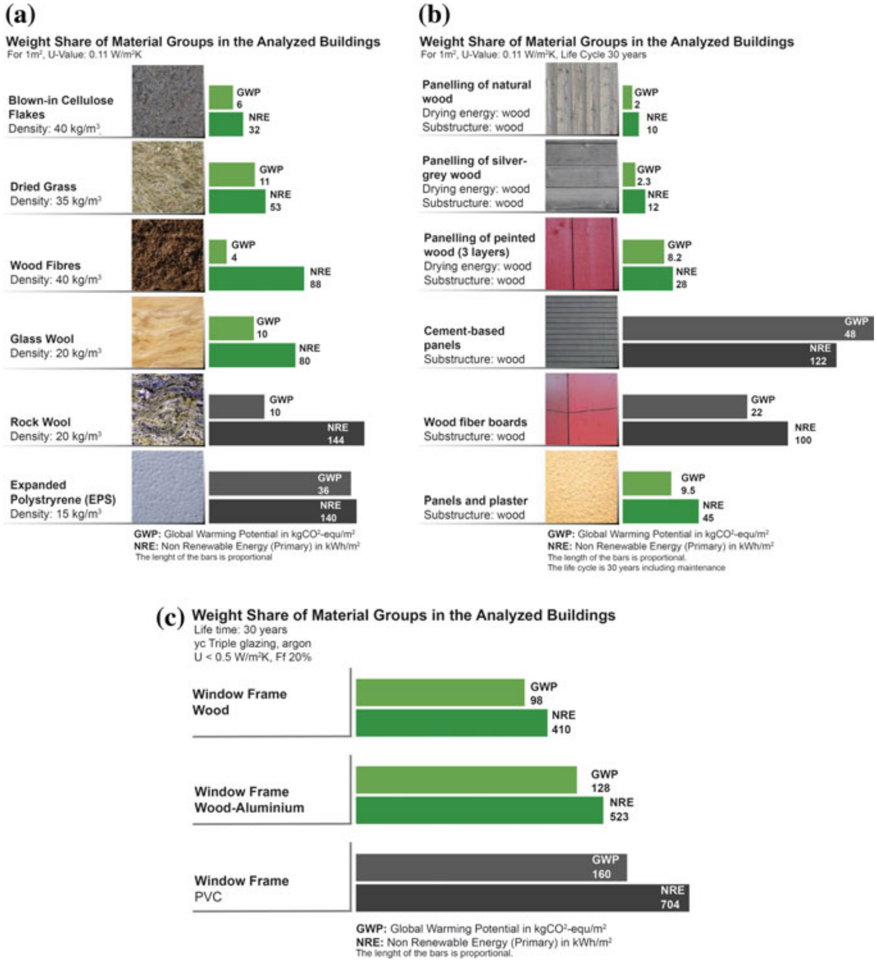

Fig. 5.3 **a** Weight share of material groups in the analyzed buildings for 30 years including maintenance based on the German Energy Agency calculations (dena-energies), graph adapted from Conrad Lutz (2017). **b** Weight share of material groups in the analyzed buildings based on the German Energy Agency calculations (dena-energies), graph adapted from Conrad Lutz (2017). **c** Weight share of window material groups in the analyzed buildings for 30 years including maintenance based on the German Energy Agency calculations (dena-energies), graph adapted from Conrad Lutz (2017)

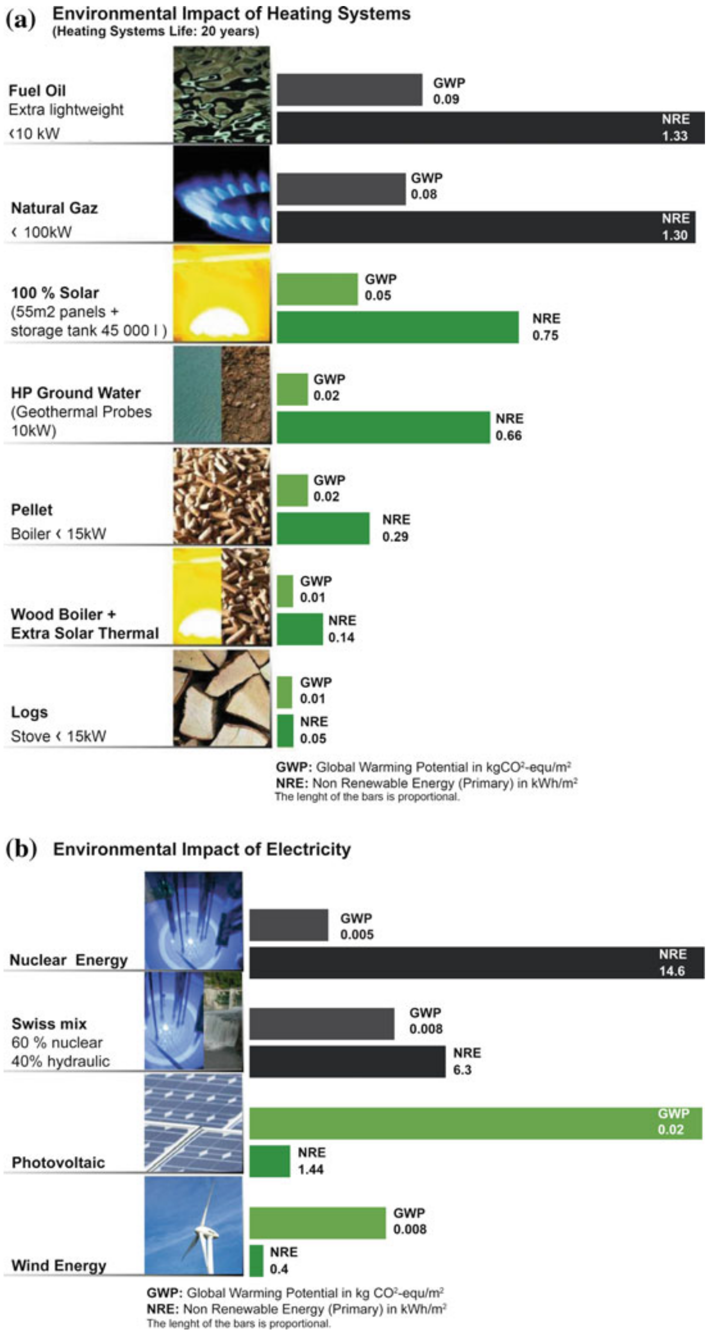

Fig. 5.4 **a** Environmental impact of different heating systems for 20 years of service life based on the German Energy Agency calculations (dena-energies), graph adapted from Conrad Lutz (2017) **b** Environmental impact of electricity in Switzerland based on LESO—EPFL Lausanne and IPEA—EIG Genève calculations, graph adapted from Conrad Lutz (2017)

examples of using LCA for 100 years can be found (Fay et al. 2000; Bribián et al. 2011; Pajchrowski et al. 2014). Also, global warming potential is available for different time horizons, and a choice of 100 years is usually assessed on this basis (Forster et al. 2007). The cradle to grave LCA was made on the basis of directly collected data from the design-build teams and integrated with literature data. An inventory dataset for materials was developed and completed using the Ecoinvent 2 database. The life cycle inventory was performed using the SimaPro 7 software applications. In order to calculate the environmental impact resulted from the biogenic CO_2 circulation, an approach of CO_2 storage in the buildings for 100 years was used. The negative values of the global warming indicator results were obtained for a cradle (forest) and positive ones for the final disposal stage of wooden waster (incineration and reuse). The LCA indicators were summarized in a group of three energy and environmental indicators as follow:

- Primary energy (PE), as an indicator of life cycle energy use
- Non-renewable energy (NRE), as the non-renewable part of PE
- Global warming potential (GWP), as an indicator of greenhouse emissions, including the contribution of biogenic carbon dioxide. Biogenic CO_2 is captured in biomass during the growth of a plant or tree and, consequently, in a biologically-based product.

5.4 Life Cycle Inventory

Within the scope of the LCA an inventory have been created, which referred to building materials of the four life cycle stages, mentioned earlier. During data collection, the expertise of architects and building engineers have been used extensively as described in Table 5.1. For the case studies, the as-built drawings were used to size most building features and their size and weight. The energy consumption was collected from monitored data between 2010 and 2016 and simulated in four models with the same legislative requirements (in US, Switzerland and The Netherlands) of envelope and HVAC systems to neutralize the climatic variability and estimate average operation energy using the Energy Use Intensity (EUI) Index. The main difference between both case studies is those relevant to the building material, envelope thickness and type of insulation and glazing. Also, the HVAC systems are very different and the fuel type has different associated carbon emissions. The simulation models helped in elaborating the building components and weights and later feed in the Ecoinvent data inventory.

Table 5.2 list data concerning the weight of major building materials for both buildings. Table 5.3 presents the basic assumptions related to the durability of elements subject to replacement and repairs. Flooring and finishing is carried out with the highest frequency but it was assumed that the previous finishing layers are not removed before subsequent painting. Doors and windows are subject to

Table 5.2 Weight share of material groups in the analysed buildings

Building material category	RSF		Green office[a]		Venlo city hall[a]		Iewan housing[a]	
	Amount (kg)	Share (%)	Amount (kg)	Share (%)	Amount (kg)	Share (%)	Amount (kg)	Share (%)
Concrete	32,500,000	79	788,650	73.4	65,000,000	96	745,900	54
Brick	–	–	10,890	1	–	–	–	–
Lime sandstone	–	–	–	–	1,200,000	2	230,450	17
Gravel	6,000,000	14.6	50,000	4.6	–	–	250,000	18
Ceramics	84,000	0.2	–	–	120,000	0.2	5150	0.4
Mineral binding materials	82,600	0.2	2000	0.1	220,000	0.3	3000	0.2
Wood and wood based materials	10,000	0.2	144,200	13.5	120,000	0.05	35,668	3
Insulation materials (biobased)	–	–	–	–	30,100	Flax	7500	0.5
Insulation materials (petrochemical)	110,000	0.3	55,000	5.1	45,000	0.1	200	0.01
Insulation materials (biobased)	–	–	–	–	Flax	Flax	Straw	Straw
Metals	1,904,762	4.7	12,600	1	250,000	0.4	3880	0.3
Glass	53,460	0.1	5680	0.05	500,000	0.7	31,080	2.2
Paints and preservatives	48,240	0.1	1340	0.1	22,000	0.01	8900	0.6
Cement plaster and gypsum board	229,680	0.5	2000	0.1	20,000	0.01	–	–
Clay plaster	–	–	–	–	–	–	61,000	4.4

[a]Annex 1.1 Lehmann 2011

Table 5.3 Durability of elements subject to replacement and repairs in 100 years

Building	RSF		Green office		Venlo city hall		Iewan housing	
Inventory element	Durability (years)	Number of replacements	Durability (years)	Number of replacements	Durability (years)	Number of replacements	Durability (years)	Number of replacements
Construction elements	100	0	100	0	100	0	100	0
Windows	25	3	25	3	25	3	25	3
Internal doors	30	3	30	3	30	3	30	3
External doors	30	3	30	3	30	3	30	3
Wood flooring/cladding	–	–	50	1	70	1	30	2
Heating installations	30	3	30	3	30	3	30	3
Ceramic tiles	20	4	20	4	–	–	20	4
Electric installations	50	1	50	1	50	1	50	1
Ventilation system	25	3	25	3	25	3	25	3
Roofing	50	1	50	1	50	1	50	1
Roof insulation	50	1	50	1	50	1	50	1
Walls insulation	60	1	30	2	60	1	30	2
Building facade	60	1	60	1	60	1	30	2
Painting internal walls	5	19	5	19	5	19	5	19
Painting external walls	25	3	25	3	25	3	25	3
Varnishing of floors	25	3	25	3	25	3	25	3
PV panels	30	2	30	2	30	2	30	2

replacement and are calculated within the use stage (see Fig. 5.3c). The assumptions include the calculated mass flows of materials and waste generated in 100 year period and resulting from the replacement and repair.

5.5 Limitations

Although ISO 14040 recommends that LCAs end with a set of mid-point environmental indicators, we proposed the narrow set of indicators listed above. Architects often express their need for practical and simple performance indicators that might simplify the decision making. The LCA scope was limited to the subsystems mentioned in Table 5.1. Also, we had limited quantitative information on the actual demolition process. Therefore, we referred to few studies that contain some quantitative and methodological information on the role of end-of-life in buildings in the US, Switzerland and The Netherlands (BAFU 2016; Thormark 2002, 2006; Werner and Richter 2007; Spoerri et al. 2009; Boschmann and Gabriel 2013; Spiegel and Meadows 2010; Müller 2006; Hatayama and Tahara 2016 and TNO 1999).

For this study, we excluded water installations and sewage installation including roof gutter systems from the study. Also, the damage categories such as human health, ecosystem quality, climate change, resources and impact categories (carcinogens, non-carcinogens, respiratory inorganics, ionising radiation, ozone layer depletion, respiratory organics, aquterrestrial ecotoxicity, terrestrial acidifica-tion/nitrification, land occupation, aquatic acidification, aquatic eutrophication, global warming, atic ecotoxicity) were excluded. Needless to say, the energy mix of both buildings was taken into account for calculations in regard to the electricity mix and will be elaborated in following case studies sections (see Fig. 5.4a).

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Chapter 6
Case Studies: Energy Efficiency Versus Regenerative Paradigm

Abstract In this chapter, we present an overview of the four case studies. We investigated the design, construction and operation aspects related to the four projects and their pre-set performance targets. This chapter is the foundation for our building energy modelling and life cycle assessment of the four case studies. Through walkthrough visits and interviews with different stakeholders we summarize the main characteristics of those projects before presenting the performance comparison and qualification results in Chap. 7.

6.1 Introduction

The selection of four case studies was based on their outstanding and ambitious environmental performance. The four buildings received several awards on regional or national level in Europe and the United States. The four projects represent the excellence in sustainable architecture and green construction in their countries and some of them obtained the highest green rating certification LEED Platinum and Minergie-P-ECO. The RSF (Caste Study 1) received the award of Excellence for Green Construction from the American Concrete Institute AIA. Also, RSF received the 2011 AIA/COTE Top Ten Green Project Award. The Green Office (Case Study 2) received the Watt d'Or 2008 and Prix Lignum Holzpreis 2009 in Switzerland. Venlo City Hall (Case Study 3) has won an Architizer A + Award for public building as a Cradle to Cradle inspired architecture. Iewan Social Housing (Case Study 4) was selected as an eco-village that represents social and sustainable housing. The project won the European Green Capital Award 2018. More interestingly, Case Study 1 represent the reductionist paradigm while Case Studies 2–3 represent the regenerative paradigm and are seen as pilot projects by the professional communities in three different countries and two different continents.

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6.2 Case Study 1: Efficiency Paradigm (Office Building)

The research support facility (RSF) is a state of the art office building to host researchers of the National Renewable Energy (NREL) Lab. The RSF in Golden, Colorado was designed and constructed between 2006-2010, after a process of proposals calls and selection. The vision of the selected project operates within the energy efficiency paradigm aiming to build an energy neutral office building or a NZEB. The design brief emphasized an integrative design approach to design, build and operate the most energy efficient building in the world. The call had a Design & Build acquisition strategy that connects the building to the electricity grid for energy balance through a power purchase agreement. The Design & Build Team comprises Haselden Construction, RNL Architect and Stantec as Sus-tainability Consultant and MEP engineering. The design process involved an integrative approach looking to:

1. avoid needs for energy by integrating passive heating and cooling and ventilation;
2. improve energy efficiency and
3. incorporate renewable energy and green power.

The building is located in latitude N 39.74 and longitude W 105.17 and is 151 m above sea level. The site receives 660 mm of rain per year with an average snowfall of 1371 mm. The number of days with any measurable precipitation is 73. On average, there are 242 sunny days per year in Golden, Colorado. The July high is around 30° and January low is −8 while humidity during the hot mon-ths, is a 58 out of 100. The building is a 20.400 square meter hosting 800 person. The building energy use intensity had to perform less than 80 kWh/m^2/year and additional 20 kWh/m^2 per year was allowed for a large data centre that serves the entire NREL Campus. The RSF facility had to perform 50% better that ASHRAE 90.1-2007 energy performance requirements. The project is a net zero energy building and obtained the LEED Platinum Certificate (V.2) and Energy Star Plus certification. The design brief also required maximum use of natural ventilation and 90% of floor space fully daylit.

With the help of building performance simulation (BPS) several passive design strategies were optimized. The building form and mass was shaped to host the main building functions influence by an energy saving approach. The RSF building has two wings sized and positioned to allow natural ventilation and lighting (see Fig. 6.1). The orientation of the two wings is elongated on the east-west axe to allow an easy control of solar access during summer. To achieve energy performance goals, the workspace layout is open, with low cubicle walls and light-coloured furniture that allow air to circulate and daylight to penetrate into the space. The aspect ratio is 13.5 and the window-to-wall-ratio is 25% with a low-e triple vision glazing (U-value 0.17, SHGC 0.22). The daylight glass is a low-e

Fig. 6.1 **a** Two wings optimized to allow natural lighting and ventilation, RSF, NREL, Golden, Colorado, US. **b** The South Wing is optimized for a window-to-wall-ratio of 25% and the east glazing surface is minimized. **c** PV array of mono-crystalline panels of 17% efficiency. **d** The South Wing is optimized for a window-to-wall-ratio of 25% and the east glazing surface is minimized. **e** Windows design was optimized to reduce the effective view glass and provide solar protection. **f** The open space office was optimized for maximum natural lighting and natural cross ventilation

double pane day lighting glazing (U-value 0.27, SHGC 0.38, Vlt 65%). The envelope comprises modular structural insulated panels of 2.5 cm exterior concrete with rigid foam insulation (polyi-socyanurate R-13) and an internal thermal mass of 15 cm interior concrete (see Fig. 6.1b and c).

Regarding active systems the building has a hybrid operating system. The vision glass is manually operable and gets automatically controlled depending on indoor and outdoor environment. A radiant heating and cooling system is installed in the roof slab. Natural ventilation is achieved during day through manual windows control and during night through automated control for night cooling and thermal mass activation. Mechanical ventilation is demand based and air is displaced through an under floor air distribution system. A heat recovery system is installed on outside air intake and exhaust from restrooms and electrical rooms. The whole building energy use is 283 continuous watts per occupant. Laptops of 60 W with 35 W thin screens are used in workspaces. The artificial lighting system is based on motion and daylight intensity sensors. Sensor controlled LED task light of 15 W are used for workstations lighting. A third party owned power purchase agreement PPA provided full rooftop array of 1.7 MW of mono-crystalline panels of 17% efficiency (see Fig. 6.1c). The current power purchased from a fossil mix (60% coal, 22, 22% from natural gas, and 18% from renewable energy resources (EIA 2014)) (see Fig. 6.1d, e and f).

The construction life-cycle stage included the full construction of the building. For the LCA data from a proprietary Athena Institute database was used for the construction of similar commercial structural systems (precast concrete, cast-in-place concrete, and structural steel), as well as layers of various envelope materials and interior partitions. Annual energy use was calculated using NREL monitoring results. The maintenance stage includes repair and replacement of assemblies and com-ponents of assemblies throughout the study building's service life. The primary source of information was the Athena report, Maintenance, Repair and Replacement Effects for Envelope Materials (2002). Standard recommendations are based on decades of building envelope experience, manufacturers' installation instructions, material warranties, and industry best practice. Generic industry associations' data and publications and North American industry practices were taken in consideration to model the end-of-life stage scenarios. A literature review and Internet search was conducted but little detailed information regarding construction and demolition waste management practices in Denver urban centre were found and further considered in this study. End-of-life scenarios are being forecast up to 100 years. A more comprehensive description of the production processes and tables for the other varieties can be found in (Guggemos et al. 2010). The detailed carbon footprint as well as environmental impact of the various processes for producing the concrete construction system is provided.

6.3 Case Study 2: Regenerative Paradigm (Office Building)

The vision of the selected project was to build the most ecological and regenerative office building. Approached by the French State the architect Conrad Lutz was asked to design and construct an ecologically optimal building with a positive impact. The Green Office building located in Givisiez, Switzerland was designed and constructed between 2005 and 2007. The building is located in latitude N 46.81 and longitude E 7.12 and is 99 m above sea level. The site receives 1075 mm of rain per year with an average snow-fall of 627 mm. The July high is around 25° and January low is −1 while humidity during the hot months, is a 69 out of 100. The building provides commercial of-fice spaces for companies working in the field of sustainable development. The building has three floors with a total area of 5391 square meter and is the first MINERGIE-P-ECO in Switzerland. The building energy use intensity had to perform less than 25 kWh/m^2/year and 10 W/m^2 for thermal air heating should not exceed. The design process involved an integrative approach looking to:

1. avoid needs for energy by integrating passive heating and cooling and ventilation with a focus on compactness;
2. improve energy efficiency and trace the impact of energy resources
3. Sequestration—the capture and storage of CO_2 in the construction material.

The high thermal insulation of walls, ceilings and floor and triple glazing was the architect's passive strategy to reduce the need for building heating. The value u-value of the roof is 0.10 W/m^{2}K, façade 0.11 W/m^{2}K, windows 0.5 W/m^{2}K and floors 0.10 W/m^{2}K achieved through wood fibre insulation. The building form is optimised to increase compactness and reduce the envelope surface area and reduce heat losses. The building resembles a cube with a volume of 5291 m^3 and comprises internal partitions that allow several companies to settle, share and grow. Natural light was optimized using daylight simulation for optimal natural lighting and avoidance of overheating during summer. The heating system is a pellet stove with under floor heating. Free cooling using an underground tube that works as passive ground–coupled heat exchanger (*puits canadien*) is used in summer through ventilation. The hot water is produced with solar thermal panels and the current power purchased from a renewable mix (60% wind, 37% hydro, solar 3% (Lehmann 2011)). However, the roof is prepared for electricity production and will get equipped with 270 m^2 Photovoltaic. The expected energy generation should exceed 30% of the building electrical energy needs and export the additional 30% to the grid. The plug loads are controlled buy electricity cut-off policy and all used equipment and appliances, including flat screens, are energy star rated (see Fig. 6.2).

The construction life-cycle stage included the full construction of the building. For the LCA, data from eco-ninvent database was used for the construction of similar commercial structural systems (timber and cast-in-place concrete), as well as layers of various envelope materials and interior partitions. Wood was cut in

Fig. 6.2 **a** Simple building mass in a shape of a cube, Green Offices, Givisiez, Switzerland. **b** Prefabricated façade and floor units made from timber and blown-in cellulose flakes. **c** The four floors were constructed in 10 days with a high assembly precision. **d** Under ground floor heating coupled to a biomass heating system. **e** Waterless toilets connected to a compost unit in the basement resulted into 75% reduction of potable water use. **f** The open office interior and furniture is painted with VOC free paints

Semsales Region. The raw wood was transported on a direct path to Givisiez, while the laminated timber made along the way to Burgdorf. The distances have been calculated from Switzerland's maps. Most material sources were located based on the architect's identification of products names and their manufacturer. Annual energy use was calculated using Green Offices monitoring results (Lehmann 2011). Today (2017), most materials are buried at the end of life of a building in

Switzerland. For Green Offices, the timber construction and cellulose insulation was assumed to be burned in a municipal incinerator for electricity generation, and the other district heating. In 100 years, the efficiency of energy recovery may be increased by reusing timber as chips or pellets in heaters. Concrete was assu-med to be buried in the ground, or be crushed for reuse as gravel under roads or under construction. Manufacturers indicated that glass panes are not recycled in Switzer-land, but buried with other construction waste. Generic industry associations' data and publications and Swiss industry practices were taken in consideration to model the end-of-life stage scenarios. A literature review and Internet search was conducted but little detailed information regarding construction and demolition waste management practices in the Swiss urban centres were found and further considered in this study. End-of-life scenarios are being forecast up to 100 years. A more comprehensive description of the production processes and tables for the other varieties can be found in (Lehmann 2011). The detailed carbon footprint as well as environmental impact of the various processes for producing the timber construction system is provided.

6.4 Case Study 3: Regenerative Paradigm (Office Building)

The City Hall of Venlo is a top example of a C2C inspired building. The building is designed and built following the C2C principles by the Dutch architect Hans Goverde and his design team of Kraaijvanger Architects Office in Rotterdam. The City Hall is located in Venlo, The Netherlands and was designed and constructed between 2010 and 2016 by Laudy/Ballast Nedam contractors. The building is located on latitude N 51.36 and longitude E 6.16 and is 21 m above sea level (Venlo City 2017). The average July high is around 20° and January low is 4 while humidity during the hot months, is 70 out of 100. The new city hall was designed a as an icon for the city of Venlo at a crossing point at the river Meuse. The program requirements consists mainly 12,757 m^2 for 900 workers, 620 offices and of a three floors public parking garage with 400 parking lots underground of 12,755 m^2 (Kraaijvanger 2017). The building is not certified by any rating systems and exceeds the national Energy Performance for Buildings Directive (EPBD) requirements. The building energy use intensity had to perform less than 85 $kWh/m^2/year$. The design was based on four design principles looking to:

1. enhance air and climate quality and building a living green façade that cleans the indoor and outdoor air of the building;
2. integrate renewables and generate more energy by the building than the actual building use;

3. define materials and their intended pathway through the use of appropriate products that can be recycled after being used and traced through a materials passport;
4. and enhance water quality and valorise the whole water use and disposal chain.

Air quality was one of the most influential design considerations in the City Hall that resulted in the creation of a healthy, pleasant and optimized indoor and outdoor quality. A green house is situated at the last floor of the building serving as a green lung. The green house is planted with plants and vegetation to purify the outdoor air before it enters to the building. The purified air circulates down entering different floors, after a piping system in the floors have achieved a comfort temperature. A void is crossing the building centrally from the top to the ground floor. On top of that void, a solar chimney is located on top of the roof allowing the used air to get drawn up naturally. The solar air chimney plays the role of natural air outlet in the summer and is closed in the winter. On several locations in the building, green interior wall are places to enhance indoor air quality and provide a pleasant indoor environment taking into the account of biophilia on well-being. Next, an external green wall of 2200 m^2 aims to enhance the outdoor air quality in a radius of 500 m, based on the calculation done by the technical university of Eindhoven. The green walls outside and inside are based on modular vertical garden unit for use as a wall façade. A Modulogreen® façade consists of a number of modules, designed for a variety of specific case requirements (C2C 2017b). Green walls are designed to absorb CO_2 and fine dust to improve air quality, using limited water, and are designed to have insulating and soundproofing properties. Tests in labs of Eindhoven University of Technology have proven that the façade filters 30% of nitrogen and carbon dioxide from the air (see Fig. 6.3a–c).

Energy efficiency was another important design goal targeting energy consumption 50% less of national requirements. Therefore, the building is highly insulated with optimized window-to-wall-ratio and solar protection for the east, west and north facades to reduce the heating demand and avoid overheating risks. The u-value of the roof is 0.5 W/m^2K achieved through flax insulation for most of the envelope area above ground. For the underground and surfaces with contact with water, styrofoam® extruded polystyrene (XPS) insulation was used for its high thermal resistance and the right compressive strength and insensitivity to moisture. Styrofoam was also used in the South façade. The building form was optimized to guarantee certain compactness in an urban dense context. In the same time, the building orientation and openings where designed to benefit as much as possible from natural light and ventilation to reduce the energy consumption to a minimum. Only A + Energy Labelled products were used in the new building. In parallel, 1000 m^2 of PV panels were installed to achieve energy neutrality by 2021. Thermal energy is produced by geothermal resource and 25 m^2 solar panels water heaters. An Aquifer Thermal Energy Storage system, provide the building with a sustainable system for heating and cooling with the help of the Maas River and the underground car park using geothermal heat pumps (Eurbanlab Showcasing 2015). The building is not connected to the natural gas grid and the renewable energy

Fig. 6.3 **a** Overall view of the Green Façade (Biosphere), Venlo City Hall, Venlo, The Netherlands. **b** Overall view of the South Façade (Technosphere) with solar protection. **c** The void crossing the building centrally and providing natural lighting in connection to the solar chimney. **d** Office spaces and flexible working areas. **e** Cross section in the Green Façade showing the different wall layers and construction system. **f** The hylofilter is a natural wastewater treatment pond using biological and bacteriological purification techniques

solutions should meet 50–60% of the total energy demand and the rest of consumption is compensated with green energy produced offsite (see Fig. 6.3d–f).

The construction life-cycle stage included the full construction of the building. LCA data from ecoinvent database was extracted for the construction of similar commercial structural systems (cast in place concrete), as well as layers of various envelope materials and interior patterns. During the construction C2C concrete was not found therefore, nearby produced concrete with recycled content and toxic free substances was used. The North Façade is made of a green wall of Modulogreen modules and the south façade is made of aluminium. The internal walls and ceilings of the city hall are cladded with accoya wood. Accoya® wood is timber (Radiata Pine & Alder) from sustainable managed forests, modified by acetylation which introduces no chemicals not already found in the wood. Accoya® is high performance wood with properties designed to match tropical hardwoods and treated woods with a life expectancy of 50 years. All used glass for windows is C2C certified and windows frames are wooden. Thoma Holz 100 is used mainly in the green house and internal furniture as a prefab massive wooden building system for easy assembly and disassembly (C2C 2017a). Holz100 consists of vertical and horizontal wood elements which are densely layered, without gaps, to become solid and compact construction elements. Dry wooden dowels penetrate these layers and, once in position, the dowels soak up any residual moisture and swell into the surrounding wood. The use of dowels as connectors allows a large, solid whole to be created out of individual parts. This product is designed to be an integrated and durable element created without the use of glues and metals. Four our assessment we classified the building materials into two groups namely under the biosphere and technosphere groups.

Annual energy use was based on monitored data with estimation for the average annual consumption. Most, materials in the building are expected to be recycled and the material passport identifies the material components for the end life phase of the building. For Venlo City Hall, most timber used in the project is expected to be reused until incinerated. Flax insulation is expected to be composted. Aluminium, steel and glass are expected to be recycled. The Modulogreen units of the green wall are expected to be down cycled and shredded. Concrete is expected to be crushed and reused with aggregates for new concrete. Generic industry associations' data and publications in the Netherlands and Belgium were used to model the end-of-life stage scenarios. A literature review was conducted and interviews helped estimating the possible scenarios for demolition and waste management practices in the projects' region. End-of-life scenarios are being forecast up to 100 years.

6.5 Case Study 4: Regenerative Paradigm (Residential Building)

The Iewan project is a common living project offering a variety of households with a focus on social sustainability. The project is a social housing project that empowers tenant to reach affordable and healthy housing. The project was initiated by a group of people with interest in sustainable living and lifestyle. Approached by the Organic Living—Iewan Initiative Group, the regional housing cooperation of Gelderland Province (WBGV), Nijmegen Municipality and Province selected architect Michel Post form the ORIO Architects office to deliver the design of the project. The project is located in a new urban neighbourhood in Lent, Nijmegen and was designed and built between 2010 and 2015. The building is located in latitude N 51.86 and E longitude 5.87 and is 29 m above sea level. The site receives in average 820 mm of rain per year and the average temperature in July is around 18° and January low is 4 while humidity during the hot months, is 78 out of 100. The new residential building cluster is designed from bio-based materials. The straw that forms the largest building material volume comes from close by farmland next to the river Waal. The building accommodates 24 units and common facilities for around 50 persons with a total built up area of 2200 m^2. More than 200 volunteer together with the future tenants worked in team to realize the insulation of 36 cm of straw bale and 4 cm of internal clay plaster. The building comprises three floors of a wood construction made of straw and loam. The building did not comply with the Passive House Standard; however, it is built to become a nearly zero energy building. The design follows bio-based design principles and is inspired by nature and biomimicry looking to:

1. avoid needs for fossil energy by focusing on energy saving concepts and passive heating while and achieving self-sufficiency through onsite renewables;
2. use ecological products and finishing materials with low embodied carbon emissions;
3. sharing common services including laundry room, kitchen, food shop and a permaculture garden

The project vision articulated the will of Iewan future residents to live in simply sustainable way. For example, future tenants were willing to reduce the private space of their dwellings and increase common spaces and live more compactly. There was a conviction that the path towards sustainability starts by densification and by creating a compact housing block that is environmentally friendly regarding materials use and heating energy use. Heating needs were used by properly orienting the most important living spaces to the South and increase the window-to-wall-ratio to increase the passive solar gains. In the same time, the glazing surfaces were protected by adequate solar protection in the form of balconies and circulation corridors. Walls with low conductivity were used and made from straw bale with a u-value of 0.13 W/m^2K. The roof was insulated with straw bales reaching 0.14 W/m^2K and windows are triple glazed with u-value of 0.7 W/m^2K. The window-to-wall-ration is 40% in the North facing facades. The low heating needs are met through a pellet (biomass) boiler and a hot water storage tank coupled to underground floor heating. The pellet fuel is sourced form FSC wood. An ultra-efficient heat recovery system is used to preheat domestic hot water (DHW) and ventilation air. A large part of the electric energy needs are generated by 120 m^2 PV panels and the cooking activities are electric. Ultra-efficient appliances and LED lamps are used with a monitoring system that allows tenants to track the consumed and produced energy daily, monthly and annually. An appliances and equipment sharing systems allows tenants to share the washing machines, vacuum cleaners, cars and tools (see Fig. 6.4a–c).

(a) (b) (c) (d) (e) (f)

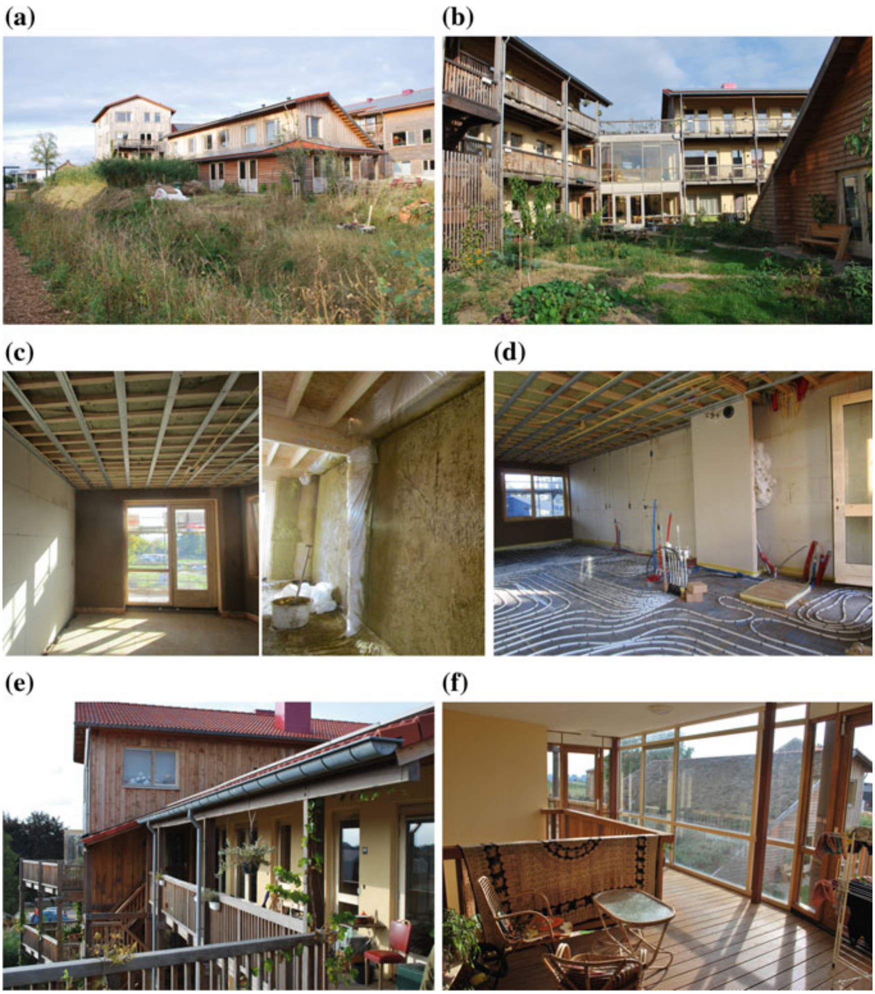

Fig. 6.4 **a** Overview of Iewan Social Housing Project, Lent, The Netherlands. **b** Internal garden used for permaculture and underground water storage. **c** Straw and loam construction and lime sandstone. **d** Under floor heating is coupled to a biomass heating system. **e** Southern façade terraces provide solar protection during summer and view and circulation for tenants. **f** Winter terrace space for tenants

The construction life-cycle stage included the full construction of the building. For the LCA data, ecoinvent and OPEN LCA program were used for the construction of similar bio-based construction systems (timber and straw bale constructions), as well as layers from various envelope materials, interior partitions and finishing. The straw walls of 36 cm were sourced from local farmers within 15 km from the project site. Clay was sourced from Germany. Wood structures and elements where mainly from Accoya wood and FSC certified pine. Accoya® wood is timber (Radiata Pine & Alder) from sustainable managed forests, modified by acetylation which introduces no chemicals not already found in the wood. Accoya® is high performance wood with properties designed to match tropical hardwoods and treated woods. The distances where calculated based on an inventory of major building material volumes. Annual energy use was calculated based on the monitored data. Most materials are expected to by compost at the end of the life of the building. Concrete which was used minimally for foundation was expected to be crushed and recycled after use as gravel under roads or under construction. A literature review was conducted to trace the common practice of recycling for window glazing and other demolition waste. End-of-life scenarios are being forecast up to 100 years. The life cycle analysis was based on the aPROPaille project results published in Belgium (aPROpaille 2016a, b (see Fig. 6.4d–f).

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Chapter 7
Performance Comparison and Quantification

Abstract The results of the life cycle analysis (LCA) applied to four high performance buildings in the US, Switzerland and The Netherlands are highlighted in this chapter. When assessing the sustainability and environmental performance of high performance buildings it is very important to use universal indicators and consider carefully all life cycle phases and subsystems. This chapter summarizes the research findings using evidence based methods. A detailed description of the environmental impact of the four cases studies is presented including the primary energy balance, global warming potential, and embodied energy. Each building is assessed using several quantitative and qualitative environmental indicators such as the embodied energy of window framing and construction materials or the multi-criteria environmental impact of bio-based insulation materials. The presented work is mainly based on the methodology described in Chap. 5 and the detailed project description in Chap. 6. The results are classified and grouped under different topics namely energy, materials, water and construction system. Finally, this chapter presents a valuable and profound comparison reflecting the complexity of the assessment.

7.1 Introduction

Figures 7.1 and 7.2 illustrate the main findings of our assessment. The LCA indicators were summarized in a group of three energy and environmental indicators as follow:

- Primary energy (PE), as an indicator of life cycle energy use
- Non-renewable energy (NRE), as the non-renewable part of PE
- Global warming potential (GWP), as an indicator of greenhouse emissions.

Based on our experience, we learned that assessing the sustainability of a building is a very complex and tedious tasks. The assessment gets more complicated when comparing different buildings in different context. While being heads down on details of single environmental impact attributes, it's equally critical to

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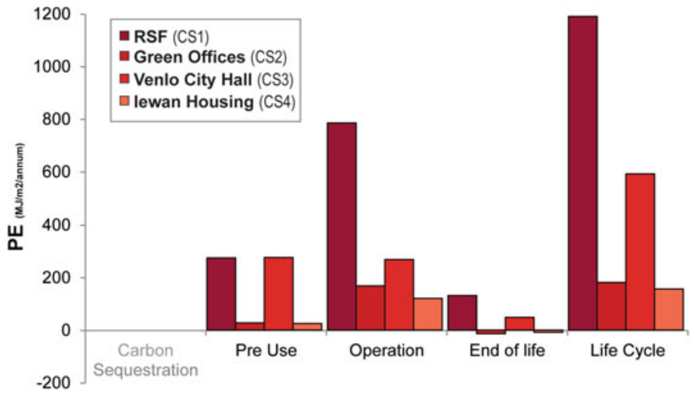

Fig. 7.1 Comparison of the primary energy balance for the four case studies

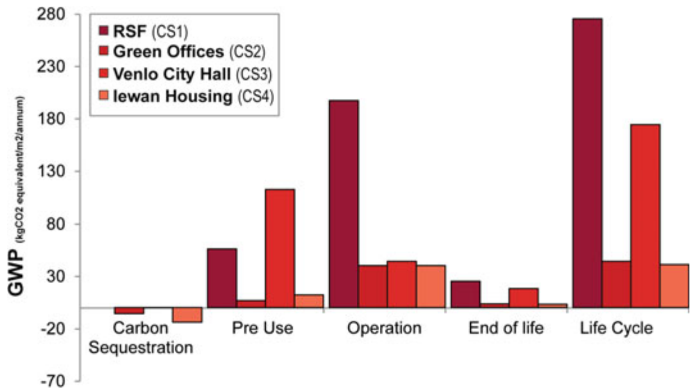

Fig. 7.2 Comparison of the global warming potential for the four case studies

look up: to reflect on how things are going on the high level of sustainability. The assessment of sustainability is complex and difficult therefore, we need to assess sustainability of buildings in a holistic way. The detailed description and interpretation of Figs. 7.1 and 7.2 are presented in the sections below.

7.2 Case Study 1: Efficiency Paradigm

The Research Support Facilities Building (RSF) at the National Renewable Energy Laboratory (NREL) in Golden, Colorado achieved a 67% reduction in energy use (excluding the solar PV offset) at zero extra cost for the efficiency measures, as the design team was contractually obliged to deliver a low-energy building at no extra cost (Torcellini et al. 2010). Torcellini and Pless (Pless and Torcellini 2012) present) present many opportunities for cost savings such that low-energy buildings can often be delivered at no extra cost. Other examples of low-energy buildings (50–60% savings relative to standards at the time) that cost less than conventional buildings are given in McDonell (2003) and IFE (2005). The New Buildings Institute (2012) reports examples of NZEBs that cost no more than conventional buildings. Even when low-energy buildings cost more, the incremental costs are often small enough that they can be paid back in energy cost savings within a few years or less (Harvey 2013). The keys to delivering low-energy buildings at zero or little additional cost are through implementation of the Integrated Design Process (IDP) and the design-bid-build process. Vaidya et al. (2009) discuss how the traditional, linear design process leads to missed opportunities for energy savings and cost reduction, often leading to the rejection of highly attractive energy savings measures.

Energy

The building energy consumption and production has been monitored since its construction. The average annual consumption is 109 kWh/m^2/year including data centre serving 1325 occupant. See Table 7.1 for comparison of monitored performance data.

Materials

Materials used in the RSF contain recycled content, rapidly renewable products, or were regional, meaning they were procured within a 500-mile radius of Golden (DOE 2012). The precast panels that make up the exterior walls of the RSF consist of two inches of rigid insulation (R-14) sandwiched between three inches of architectural precast concrete on the outside and six inches of concrete on the inside. The panels, which were fabricated in Denver using concrete and aggregate from Colorado sources, constitute the finished surface on both the inside and outside of the wall except that the interior is primed and painted. Wood originates from pine trees killed by beetles used for the lobby entry. Recycled runway materials from Denver's closed Stapleton Airport are used for aggregate in foundations and slabs. Reclaimed steel gas piping was used as structural columns. About 75% of construction waste materials have been diverted from landfills (DOE 2012). Table 7.2 summaries the mid-point environmental indicators relevant to the life cycle of the RSF. Pre use and maintenance impacts are higher than those relevant to the use phase.

Water

The water efficiency was achieved by compliance with 4 out of 5 LEED (v2.2) water credits. Water efficient landscaping around the RSF depends on native and adaptive grass and shrub species. Drip irrigation and irrigation zones were designed based on exposure and water frequency. A satellite-based "smart" irrigation controller regulates and manages the daily outdoor irrigation. Bioswales and water canals connect to the campus's *wadi* or *arroyo*. Roof drainage flows into down spouts and then into catch basins. The water running through those troughs waters

Table 7.1 Weight share of material groups in the analysed buildings

Building material category	RSF		Green office[a]		Venlo city hall[a]		Iewan Housing[a]	
	Amount (kg)	Share (%)	Amount (kg)	Share (%)	Amount (kg)	Share (%)	Amount (kg)	Share (%)
Concrete	32,500,000	79	788,650	73.4	65,000,000	96	745,900	54
Brick	–	–	10,890	1	–	–	–	–
Lime sandstone	–	–	–	–	1,200,000	2	230,450	17
Gravel	6,000,000	14.6	50,000	4.6	–	–	250,000	18
Ceramics	84,000	0.2	–	–	120,000	0.2	5150	0.4
Mineral binding materials	82,600	0.2	2000	0.1	220,000	0.3	3000	0.2
Wood and wood based materials	10,000	0.2	144,200	13.5	120,000	0.05	35,668	3
Insulation materials (biobased)	–	–	–	–	30,100	Flax	7500	0.5
Insulation materials (petrochemical)	110,000	0.3	55,000	5.1	45,000	0.1	200	0.01
Insulation materials (biobased)	–	–	–	–	Flax	Flax	Straw	Straw
Metals	1,904,762	4.7	12,600	1	250,000	0.4	3880	0.3
Glass	53,460	0.1	5680	0.05	500,000	0.7	31,080	2.2
Paints and preservatives	48,240	0.1	1340	0.1	22,000	0.01	8900	0.6
Cement plaster and gypsum board	229,680	0.5	2000	0.1	20,000	0.01	–	–
Clay plaster	–	–	–	–	–	–	61,000	4.4

*Annex 1.1 Lehmann 2011

Table 7.2 Durability of elements subject to replacement and repairs in 100 years

Building	RSF		Green office		Venlo city hall		Iewan housing	
Inventory element	Durability (years)	Number of replacements	Durability (years)	Number of replacements	Durability (years)	Number of replacements	Durability (years)	Number of replacements
Construction elements	100	0	100	0	100	0	100	0
Windows	25	3	25	3	25	3	25	3
Internal doors	30	3	30	3	30	3	30	3
External doors	30	3	30	3	30	3	30	3
Wood flooring/cladding	–	–	50	1	70	1	30	2
Heating Installations	30	3	30	3	30	3	30	3
Ceramic tiles	20	4	20	4	–	–	20	4
Electric installations	50	1	50	1	50	1	50	1
Ventilation system	25	3	25	3	25	3	25	3
Roofing	50	1	50	1	50	1	50	1
Roof insulation	50	1	50	1	50	1	50	1
Walls insulation	60	1	30	2	60	1	30	2
Building facade	60	1	60	1	60	1	30	2
Painting internal walls	5	19	5	19	5	19	5	19
Painting external walls	25	3	25	3	25	3	25	3
Varnishing of floors	25	3	25	3	25	3	25	3
PV panels	30	2	30	2	30	2	30	2

the trees and plants as it goes, providing much-needed supplemental water to the RSF vegetation and is finally collected in rain gardens (DOE 2012). The total annual design water for the site is 3,000,000 L, including all building and irrigation uses. This is less than the quantity of rain that falls on the roof area of the building in a typical year, which could make the building water neutral building. However, Colorado State water regulations and laws do not allow harvesting rain water or employing water reuse strategies for water use inside the building. Therefore, the building relied on the public potable water grid and reduced the interior water consumption by installing waterless urinals, low-flow lavatories, and low-flow showers. The use of bottled water was eliminated by adding filtered water to each sink.

Construction System

The RSF construction system is hardly reversible because it is based on a cast concrete structure. The foundations and basement are from cast concrete and the building is carried by reclaimed steel columns. The envelope was assembled form prefabricated concrete sandwich panels. Concrete is dominating the total building weight reaching almost 80% of the weight share and metals represent 4%. Despite the use of recycled, salvaged and local materials the building did not include certified building materials that indicate the regenerative nature of the used products or materials. The construction system of the RSF is not designed for an easy disassembly; however, the structure is robust to last 100 years. On the long term, this will depend on the durability of petrochemical insulation and maintenance of the envelope components.

7.3 Case Study 2: Regenerative Paradigm

Green Offices project complies with the MINERGIE-ECO® certificate which is a complementary standard to that of MINERGIE® and MINERGIE-P seeking to ensure, in addition to a building satisfying the energy efficiency requirements, an sound environmentally friendly construction.

Energy

The building energy consumption and production has been monitored since its construction. The average annual consumption is 8 for heating plus 28 kWh/m^2/year for electricity. A building of the same size would have the right to consume 25 kWh/m^2/year for heating according to MINERGIE-P® standard. The total impact of the building would be relatively low when compared with other buildings same functional unit. Building materials and renewable source of heating decrease mainly the impact on resources and climate change.

Materials

The requirements for human health and the immaterial impact on the environment are obligatory. Therefore the architect used wood as raw materials that is widely available and with the least possible impact on the environment. 450 m^3 of wood were transported from a 20 km close wood forest. The forest wood is sustainably managed and each tree was selected explicitly with the lower possible moisture content to reduce the energy of the wood kiln. As shown in Fig. 3.2, the use of wood resulted in a carbon negative footprint. By carbon negative we mean a negative outcome of the carbon footprint of wood, i.e. when carbon credits through carbon sequestration and energy production at the end of life phase are higher than the emissions caused by production and transport. The architect design prefabricated wooden panels filled with wood fibre insulation. The structural elements were mainly glued laminated timber trusses and beams. The whole construction was designed to be easily dismantled easily and in addition to materials that could be for the most part, reused or recycled. This includes the wooden door and window frames, which were selected based on a careful comparison with other framing materials (see Fig. 7.3). The compactness of the building space was not only strategically achieved heat loss reduction but also to reduce the material total quantity and reduce the embodied energy of building materials. MINERGIE-ECO® required the use of an exclusion list that prevents materials that end up in the landfill and are not compatible with a healthy indoor environment. Concrete was used in the foundation from a cement factory 100 km away and other materials were transported from maximum 1000 km distance. All materials from a distance less than 500 km were transported with 3.5–20 t trucks materials transported from further

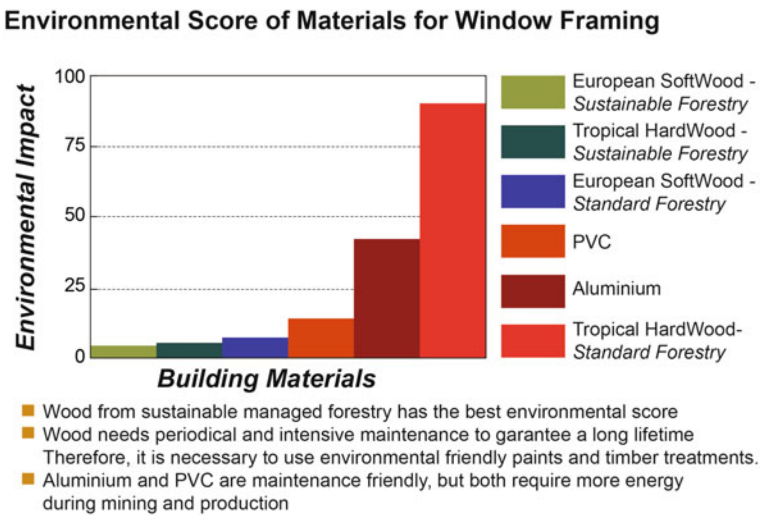

Fig. 7.3 Generic environmental impact assessment of window framing materials

away came on 32 t trucks. A more comprehensive description of the production processes and tables for the other varieties can be found in Lehmann (2011) and Attia (2016a, b).

Water

In order to reduce to a strict minimum the consumption of the potable water from the public water grid, rainwater is recovered to supply water faucets, the kitchen sink and outdoor plant irrigation. A rainwater collection tank is used to store water. 100% biodegradable dry toilets have been installed (see Fig. 6.2e). This technique of waterless dry toilets, which has been proven for decades in the Scandinavian countries, reduces water consumption in toilets to zero. Dry toilets, combined with a digester in the basement, generate compost that is used without overloading wastewater treatment plants and lakes. The annual saving of drinking water is over 400,000 L for the Green Offices building, which hosts about 50 employees (Lutz 2017). Hot water is prepared with 6 m^2 of solar thermal panels. Potable water is therefore only used for drinking and for dishes washing (Lehmann 2011).

Construction System

The Green Offices is a 4 floors plus basement building that was designed for disassembly and framed by a primary steel structure and secondary timber columns. The envelope was assembled from prefabricated wood panels and insulated with cellulose. The dominating materials are concrete and wood. Concrete has almost the highest weight share constituting mainly foundations. Wood is the second most common material reaching almost 14%. Despite not using certified building materials the LCA analysis approach together with the flexible and reversible construction system allows the building to be regenerative. Green Offices is designed for an easy disassembly; however, during the 100 years operation there is a high chance that the building envelope will require deep renovation or replacement(s). On the long term, this will depend on the durability of the cellulose insulation and maintenance of the envelope components.

7.4 Case Study 3: Regenerative Paradigm

Venlo City Hall is a C2C inspired project design that powers most of its operational energy from renewable energy offsite. The total project estimated cost was €46 million. The energy demand was requested to 50% below the national requirements. The project includes a material passport and has server C2C certified products.

Energy

Based on monitored data the building did not achieve the neutral energy balance. The estimation of energy consumption based on monitoring results since end 2016 indicates that the building consumes 80 kWh/m^2 per year. This is mainly due to the ground source heat pumps that exchange heat underground through several pillars.

Also the solar panels are estimated to generate 15,000 kWh/m^2 annually. Unfortunately, the building did not follow a performance based design approach and no certification regarding energy efficiency was achieved. However, the building did comply with the national building energy efficiency code of the year 2014.

Materials

Unfortunately, the dominant construction material construction of Venlo City Hall is reinforced concrete. The used concrete is not a C2C certified concrete, however, the used concrete had a 50% recycled aggregates. According to Figs. 7.1, 7.2 and 7.4 concrete is associated with the highest embodied energy and carbon emissions of this building. 11,200 m^3 of concrete are casted underground in the foundation pillars and underground parking walls and floors. 15.500 m^3 are casted and stand in the building structure and fabric making concrete the most used material. The concrete came from nearby *Mebin Beton* supplier using a convoy of trucks. When the architect was questioned why concrete was selected, he mentioned the risk of cost and the structural challenges that a timber construction would impose for an open space office building. In the same time, the design team used Hycrete as much as possible, a C2C certified admixture, for concrete that is designed to shut down capillary transport of water and chlorides through concrete and protect steel rebar from corrosion. Hycrete admixtures are designed to enhance structural durability and extend a building's useful life and can be re-used in post-structure recycle concrete. Also the design team reduced and optimized the used concrete quantities for the whole building.

Other than concrete, the project had the largest number of C2C products and materials including Accoya wood and window glazing. 175 m^3 Accoya wood was used for internal walls cladding and has minimum lifespan expectance of between 77 and 90 years. 168 m^3 of AGC Stopray vision-60 and Thermobel Top N + were used for the building facades. The south façade was insulated using 838 m^3 XPS and the North façade was insulated using 463 m^3 flax insulation. 68 m^3 of aluminum were used for the building façade.

A material passport was used in this project to list and quantify all used products and materials. The material passport is also the carrying framework for material and products leasing in Venlo City Hall. The material passport was based on a database and platform that allows suppliers and manufacturer to fill in necessary information related to their delivered products and their specifications. Many suppliers found the material passport a challenging idea in the beginning; however, the owners are now ready for future used of the building materials. For example, the technical installations are actually leased and suppliers are ready to take them back after the period of use is determined.

Water

The water management strategy divides water into five streams: (1) rainwater, (2) drinking water, (3) grey water, (4) black water and (5) yellow water. Roofs collect water to irrigate the green wall and flush toilets. Grey water collected in the

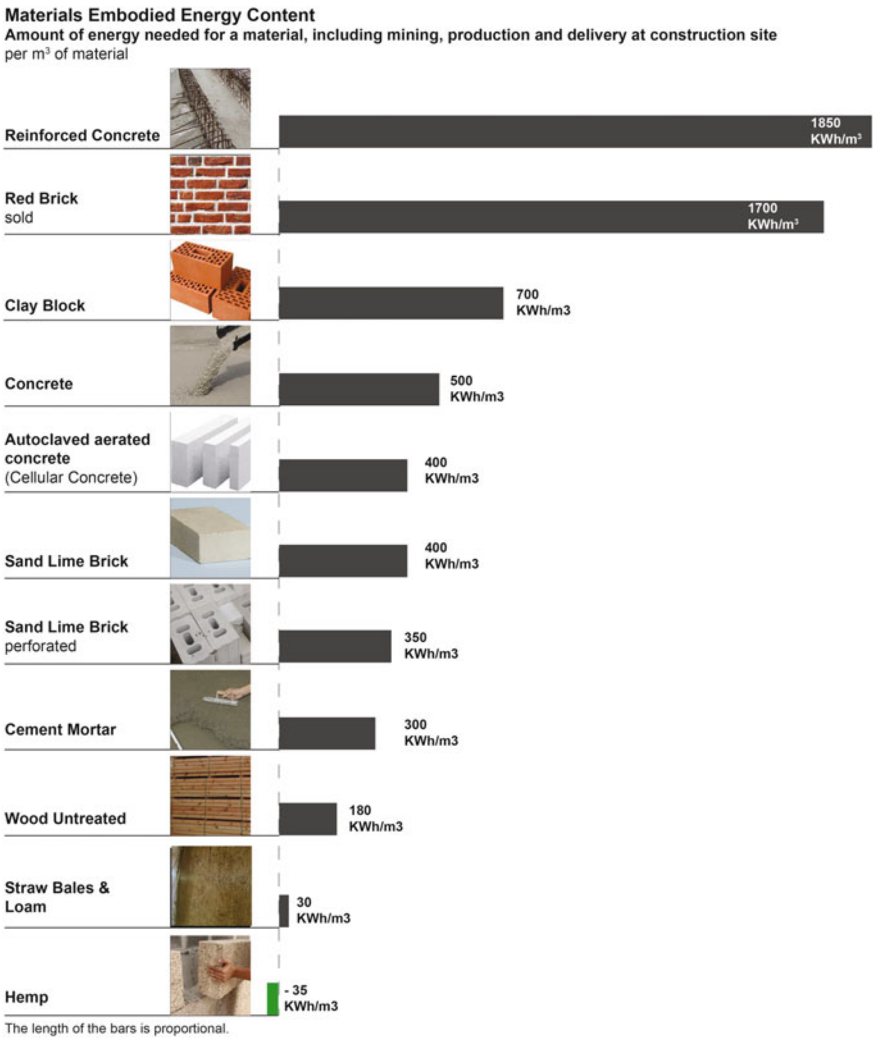

Fig. 7.4 Embodied energy in commonly used construction materials

waste water treatment ponds or hylofilter system gets purified naturally as shown in Fig. 6.3f. The filtered grey water can be used for toilets flushing ending up in the black water stream. Out of 120 L needed per person per day, only 4.5 L are coming from the potable water line. The other 115.5 L are covered by rainwater harvesting and water filtering using the hylofilter. In 2017, approximately 12000 litre of rainwater were collected.

Construction System

The construction system of Venlo City Hall is made of a concrete skeleton and deep foundation. The building stands on 180 concrete pillars ranging between 12 and 18 m deep. A concrete wall-frame is surrounds the underground parking 3 floors deep. Post and columns concrete structure carries the 12 project floors. The North façade is made of concrete walls cladded from outside the green wall. The south façade is made from aluminium cladded panels. Four concrete batteries or cores are centralized in the building layout. The batteries include the lifts, staircases, toilets and technical installation shafts.

Reinforced concrete has the high share of the building and the green house located on top of the building, made from wood, is the only flexible structure that is ready for disassembly. Except for the green house, the building structure is rigid but robust in the same time. This can allow for a long period of use with several deep renovations over the buildings' period of use.

7.5 Case Study 4: Regenerative Paradigm

Iewan housing project was selected as an eco-village that represents social and sustainable housing. The project won the European Green Capital Award 2018. It represents a new sustainable living style that is based on sharing services and common spaces. As example for affordable housing, the project is not owned by the tenants who initiated the idea. The project serves as a showcase for positive impact architecture and participatory development. The success factor of this project, beside its positive-impact environmental performance, was the grass root based approach. 200 volunteer helped placing the straw and plastering clay, following a participatory self-construction approach. The solid tenants group that came together before the project guided the process and articulate clear performance requirements.

Energy

The building energy consumption and production has been monitored since its construction. The average annual consumption is 20 kWh/m^2/year for heating plus 15 kWh/m^2/year for electricity. The building has a positive electric energy balance and the used wood pellets, for central heating boiler, are FSC certified and carbon neutral.

Materials

Iewan tenants wanted to use renewable and environmental friendly materials. The architect used mainly timber, straw and loam as the main building materials. The construction system comprises a single-side open structure that allows placing straw (36 cm thickness) from inside followed by a loam finishing layer to finish the inside layer. The 4 cm loam layer plays the role of fire protection in case of fire. The outside layer is made of oriented strand board (OSB) that is fixed on vertical load-bearing timber. The outside cladding is made from horizontal wood cladding. All wood structural elements such as frames, beams and columns are made from C2C certified Accoya wood. As a result of the wall thickness, the architect used metal-studs as separation walls in most of the building floors. Another advantage of the metal studs is their light weight, which reduced the overall foundation and skeleton sizing and weight. The effect was achieved with autoclaved aerated concrete that was used to separate apartments.

The straw was recovered from surrounding agricultural fields (20 km distance) and compacted into standardize bales. Loam was imported from Germany in cubic meter large bags from Conluto earth supplier in East Westphalia. Fine clay was bought in the East of the Netherland, from Tierrafino Company, as finishing clay plaster for the interior walls. Clay represents almost 5% of the total building material weight. All floor slabs were from prefabricated reinforced concrete to improve the resistance to horizontal shear and provide thermal mass for the floor heating. The prefabricated floor panels were delivered by a 50 km nearby company. The foundations are shallow and were casted from low emission concrete on-site. The LCA results indicate that straw has a negative environmental impact compared to cellulose or hemp (see Fig. 7.5). Despite the relatively low carbon associated emissions the main negative impact of straw is significantly associated to acidification, eutrophication, and ecotoxicity of water and soil.

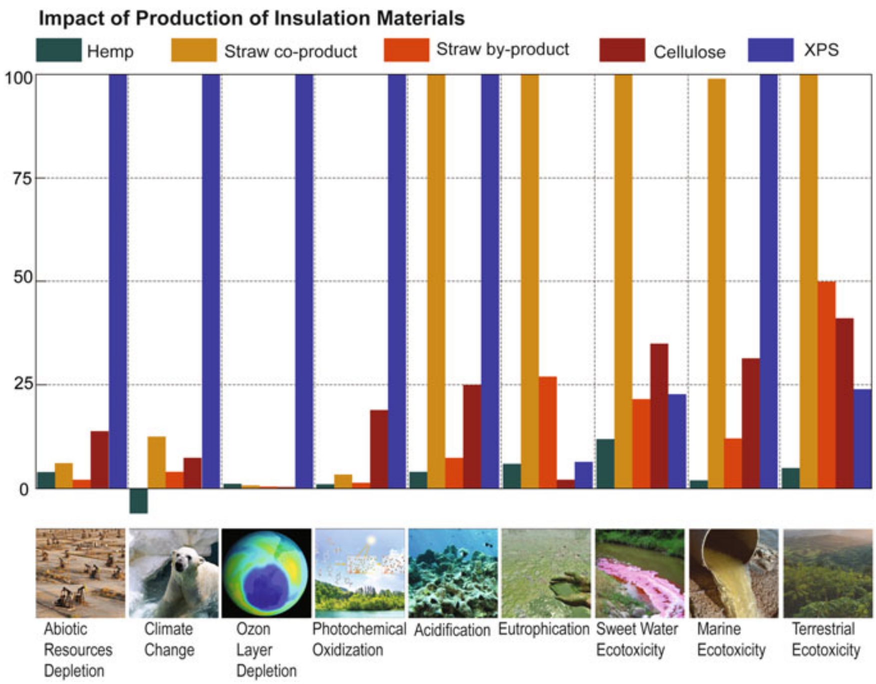

Fig. 7.5 Detailed environmental impact assessment of different insulation materials (aPROpaille 2016a, b)

Water

Water is treated and harvested as efficient as possible. A dual water collection system is installed to collect water individually for each apartment and collectively for the common services including washing machines and maintaining the phytofilter system. The water collected from the green roof above the community building roof serves too as a water feeder for the phytofilter. Black water and graywater are collected in a septic tank followed by a graywater tank. Both tanks are connected and are drained in the case of overflow in the phytofilter. The phytofilter is mainly irrigated using the toilet flushing water. The phytofilter is a 20 m extended *wadi* or a large bioswale (see Fig. 6.4a) with reed plants and bacteria to digest the pollutants. This makes Iewan housing project not connected to sewage grid. According to the project tenants the water consumption is neutralized by filtered rainwater.

Construction System

Iewan building was designed as an ecological building using natural or ecological materials. The project tenants from the beginning selected a waste product that is a by-product of the agricultural chain. The structural system is made of simple timber skeleton. The envelope was assembled from an open structure envelope allowing volunteers and tenants to fill it by them with straw. Iewan was not design explicitly for disassembly; however, during the 100 years operation there is a high chance that the building envelope will require deep renovation or replacement of straw. On the long term, this will depend on the durability of the straw insulation and maintenance of the envelope components.

7.6 Case Studies Comparison

Finally, we reached the final part of our assessment. The results in the most general view are presented in Figs. 7.1 and 7.2 and Tables 7.3 and 7.4. The impact shown here relates to the functional unit, therefore the production and transport of the amount of materials necessary construct both buildings and use them, including

Table 7.3 Comparison of monitored performance of the four case studies

	RSF	Green office	Venlo city hall	Iewan housing
Estimated annual energy consumption	100 kWh/m^2/year incl. data centre	25 kWh/m^2/year	85 kWh/m^2/year	25 kWh/m^2/year
Annual energy consumption monitored	109 kWh/m^2/year incl. data centre	36 kWh/m^2/year	80 kWh/m^2/year	30 kWh/m^2/year
Occupants/surface	1325/20,400 m^2	50/1299 m^2	850/13,500 m^2	50/2200 m^2

Table 7.4 Mid-point environmental indicators relevant to the life cycle of four case studies

Case study 1	Carbon sequestration	Pre-use	Operation	End of life	Life cycle
PE $MJ/m^2/a$	/	274 (23%)	785 (66%)	131 (11%)	1190
NRE $MJ/m^2/a$	/	274	785	131	880
GWP $kgCO_2$ equiv./ m^2/a	/	56 (20%)	197 (71%)	25 (9%)	275
Case study 2					
PE $MJ/m^2/a$	/	27 (10%)	168 (86%)	−14 (4%)	181
NRE $MJ/m^2/a$	/	27	56	5	88
GWP $kgCO_2$ equiv./ m^2/a	−5.9 (−13%)	6.5 (14%)	40 (90%)	3.4 (7%)	44
Case study 3					
PE $MJ/m^2/a$	/	276 (46%)	268 (45%)	48 (9%)	591
NRE $MJ/m^2/a$	/	276	27	48	351
GWP $kgCO_2$ equiv./ m^2/a	−0.1 (0%)	112 (64%)	44 (25%)	18 (11%)	174
Case study 4					
PE $MJ/m^2/a$	/	25	120	−10	135
NRE $MJ/m^2/a$	/	(18%) 15	(89%) 45	(7%) 4	64
GWP $kgCO_2$ equiv./ m^2/a	−14 (−34%)	12 (22%)	40 (72%)	3 (6%)	41

replacements repairs, demolition, as well as transport and disposal of the demolition waster after 100 years. According to Table 7.4, two different analyses were performed in order to validate the final results. The operational energy outcomes, reported in Table 7.3, were based on the monitored data tracking and the calculation of the energy mix in both states/cantons. Since all buildings were on-grid we had to take into account the primary energy of the imported energy. The second analysis was the LCA results which can found in Figs. 7.1, 7.2, 7.3, 7.4 and 7.5, where the weighted results of impact category indicators have been presented. The primary energy and carbon emissions calculations represented in figures provide a new perspective for the overall life cycle assessment of the four buildings. For example, the carbon emissions associated with the generation and importing of energy was traced. This means that at this degree of results aggregation, even if a benefit exists, it is neutralized by the dominating negative impacts. As mentioned before, the main reason is due to carbon emissions associated with the energy imported from the grid. Briefly, we could not find any of the buildings 100% regenerative or having a 100% positive impact.

In Table 7.4, the derived breakdown of embodied energy, operational energy and carbon emission values during the different life cycles are compared for both building components considered in the analysis. These indicators are listed in terms of energy per square area (MJ/m^2) of the given material, as well as unit mass per square area ($kgCO_2/m^2$) to account for varying associated material emissions. Table 7.4 presents the embodied energy (pre-use phase) in materials of the entire building based on the as built drawings. In the following paragraphs we will discuss each case study individually in a descending order of each case's impact. At the end of this chapter, we will discuss the overall implications of our analysis and compare the different cases studies.

Case Study 3: Venlo City Hall—Regenerative Paradigm

- Indoor air quality and occupants well-being at Venlo City Hall are a significant quality of the project.
- Venlo City Hall has the highest number of C2C certified products and materials and developed a material passport documenting and tracing all the building components for future reuse or replacement. However, this does not compensate that 95% of the building materials are made of concrete. The weight of used C2C materials is negligible.
- The embodied energy share is extremely high (46%) over the three main building life stages (Table 7.4). This is mainly due to concrete that form 96% of the building weight (Table 7.1). The use of reinforced concrete and steel resulted in a very high environmental impact on carbon emissions. Surprisingly, this is the first project that the embodied energy exceeds the operational energy over 100% years.
- Also, the carbon emissions embodied in the building materials are very high, reaching 112 $kgCO_2$ equivalent/m^2/year. The amount of used concrete in this project was massive.
- The carbon emissions associated with the operation of the building are relatively low reaching 44 $kgCO_2$ equivalent/m^2/year. However, the building is generating less than 30% of its energy needs. This is mainly due to small area of renewable energy systems. The good aspect about the project is that it import green energy produced off-site and that it relies on ground source heating.
- The project delivery did not follow a Design & Build approach, which complicated the process and decision making, delayed the project and increased its budget.
- The project main concern was to be C2C inspired regardless to performance targets or carbon emissions associated with the construction material choice. Pouring 4700 m^3 of reinforced concrete underground and 15,500 m^3 of reinforced concrete in the 12 building floors outnumbered any other environmental friendly or regenerative material. Table 7.1 is based on a simple calculation that should have been made before the building material selection. Unfortunately, there is no available C2C certified concrete or low carbon emission concrete.

- The construction system is rigid and cannot be disassembled if includes less toxics. The building was designed as City Hall office building and does not anticipate future changes in function use.

Case Study 1: RSF—Energy Efficiency Paradigm

- The RSF project followed an outstanding project delivery process and Design & Build contract.
- The RSF project respected the budget using prefabricated modular construction and succeeded to embrace an integrative design process.
- The RSF has the lowest primary energy (66%) among the four projects due to operational energy that depends on natural gas for heating and electricity to meet other loads.
- The carbon emissions associated with the operation of the building is the highest among the four projects reaching 197 $kgCO_2$ equivalent/m^2/year. The RSF is expected to generate 71% of the carbon emissions during operation. This is mainly due to the dependence on non-renewable energy.
- The embodied energy share is high (23%) over the three main building life stages (Table 7.4). This is mainly due to concrete that form 79% of the building weight (Table 7.1). The use of reinforced concrete and steel resulted in a very high environmental impact on carbon emissions
- Also, the carbon emissions embodied in the building materials are high, reaching 56 $kgCO_2$ equivalent/m^2/year.
- The construction system is rigid and hardly dismountable.
- The insulation levels were not high enough and depend mainly on petrochemical insulation materials.
- The project main concern was to achieve energy neutrality regardless to the carbon emissions and material choices.

Case Study 4: Iewan Social Housing—Regenerative Paradigm

- Iewan Social Housing is an outstanding project that reflects a grass-root collective and social initiative. The project represents the ideas of shared use and collaborative consumption of products by consumers and involved 200 volunteers during construction.
- Iewan project designer used local bio-based materials, mainly straw bales and clay, and succeeded to achieve an ultra-efficient building that is electricity neutral exceeding the energy efficiency code requirements.
- Iewan has a low primary energy (72%) due to operational energy that depends on wood pellet heating system and self-generated electricity to meet other loads.
- Also, the carbon emissions associated with the operation of the building is low, reaching 45 $kgCO_2$ equivalent/m^2/year. Iewan project is expected to generate 72% of the carbon emissions during the 100 year building life cycle. This is mainly due to negative carbon balance.

- The embodied energy share is relatively low (18%) over the three main building life stages (Table 7.4). This is mainly due to the use of straw bales and wood. The largest significant contributors to embodied energy are concrete and lime sandstone reaching all together 71% of the building weight (Table 7.1). The designer was aware to reduce the embodied energy share as much as possible resulting in a significant decrease of carbon emissions. The use of bio-based construction materials including wood and straw bales (−14%) resulted in creating a carbon negative outcome. The biogenic CO_2 captured in wood and straw bales, which were considered as a by-product in the LCA, resulted into a negative balance of carbon (see Fig. 7.5).
- Carbon emissions embodied in the building materials are low, reaching 12 $kgCO_2$ equivalent/m^2/year.
- The construction system is flexible, modular and can be easily disassembled, however, over the buildings life cycle several replacement of the envelope will be required. The straw insulation will require at least 2 times replacement (Table 7.1).
- The insulation levels were high enough and depend mainly on locally harvested straw insulation materials. However, the LCA analysis presented in Fig. 7.5 indicate the serious environmental effects of straw. The use of bio-based insulation materials should be LCA-based to avoid conflicting materials.

Case Study 2: Green Offices—Regenerative Paradigm

- The Green Offices project had a serious regenerative design approach involving operation and embodied energy and emissions from Day 1.
- The design team succeeded in reducing the operational energy significantly while respecting the stringent requirement of MINERGIE-ECO.
- The construction system is outstanding providing a flexible, modular and easily dismountable construction components and elements.
- The Green Offices primary energy is 86% the highest in percentage among the 4 projects, due to operational energy that depends on a central pellet furnace and electricity (Table 7.4). The designers succeeded to focus on embodied energy reduction and primary energy reduction.
- The carbon emissions associated with the operation of the building is the lowest among the four projects reaching 40 $kgCO_2$ equivalent/m^2/year. Green Offices is expected to generate 90% of the carbon emissions during the 100 year building life cycle. This is mainly due to negative carbon balance.
- The embodied energy share is low (10%) over the three main building life stages (Table 7.4). This is mainly due to wood and wood based materials that form 13.5% the building weight (Table 7.1). However, the impact of foundations and concrete walls (average 1400 kg/m^2) has been the highest (73%). The use of timber and cellulose insulation resulted in a very low environmental impact on carbon emissions. The use of cellulose insulation will require 2 times replacement, which increased the operational energy. Even the use of bio-based

construction materials like wood or wood fibres was not enough (−13%) to create a carbon negative outcome. However, if we take into account the biogenic CO_2 captured in wood and wood fibres and make sure to have a zero carbon operational energy we mighty reach a total negative balance of carbon (see Figs. 7.1 and 7.2). This shows the importance and dominance of operational energy (use stage) on the overall carbon emissions impact.

- The carbon emissions embodied in the building materials are very low reaching 6.5 $kgCO_2$ equivalent/m^2/year.
- The construction system is flexible, modular and can be easily disassembled, however, over the buildings life cycle several replacement of the envelope will be required. The cellulose insulation will require at least 2 times replacement (Table 7.1).

Comparison

The overall implications of our analysis are significant and the comparison of the four cases studies helped us develop the following findings summary:

- The role of reaching a negative CO_2 balance over the whole building life cycle should become increasingly prominent for regenerative buildings.
- The use of bio-based materials can significantly lower the embodied energy and embodied carbon of a building. For example, Green Offices almost succeeded neutralizing its embodied carbon. The use of local wood for building construction and cellulose for insulation resulted into a negative balance of carbon, if we take into account the biogenic CO_2 captured in wood. Based on Figs. 7.4 and 7.5 and previous studies conducted by Gauvreau-Lemelin and Attia (2017) and Delvenne (2016), we recommend hemp as a viable alternative for bio-based materials for future construction.
- Operational energy was found to be more influential regarding its environmental impact compared to the embodied energy over the life cycle of the four investigated projects. As a consequence, the carbon emissions of the four buildings will be mainly emitted during their operation.
- Lowering the operational energy and the associated carbon emissions should be the priority for any building designer. Unfortunately, we found a great disparity of operation energy among the four projects. Table 7.4 reveals surprising findings regarding operational energy. For example, the operational energy of the RSF exceeds Green Offices by over 7 times if we include the end use energy and by over 40 times if we include the primary energy. This purpose of this comparison is not to point fingers, but to make designers aware about the importance of lower the EUI and operational energy as much as possible. Already Green Offices is complying with a stringent energy efficiency standard (MINERGIE–ECO) that could be compared to the Passive House Standard. The reduction of heat transmission through a highly insulated and airtight envelope together with a heat recovery mechanical ventilation and pellet heating system

resulted in a low EUI. Therefore, reducing the operational energy and the compliance with an ultra-efficiency performance based standard should be always the first concern for any design team.

- Compensating the electric energy consumption for on-grid nZEBs or NZEBs or even Plus Energy buildings should be achieved by importing green energy produced from renewable energy sources. The building should first seek self-sufficiency through onsite renewable energy production. As a consequence, lowering the operational energy and relying on renewables on-site and off-site can lead to neutralizing if not pushing carbon emissions to a negative balance.
- The selection of a construction system and building materials is crucial. Design for disassembly and future anticipate should be present in any regenerative building design. For regenerative architecture, there is no problem in particular with concrete, steel or aluminium. On the opposite if those materials are used to enforce the design for disassembly, modularity and flexible reuse, they can contribute to the development of a regenerative built environment. However, cast concrete and glued or welded connections are not promoting circularity. Pre-fabrication and tracing of materials and products using a material passport is highlight recommended.

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Chapter 8
Regenerative and Positive Impact Architecture Roadmap

Abstract In this chapter, we summarize the key research findings described earlier in Chap. 7. We found that the regenerative paradigm is closer to reverse the ecological foot print and provide a positive impact building than the reductionist efficiency paradigm. Thanks to the biogenic CO_2 calculation approach for bio-based construction and insulation materials, or rapidly renewables agricultural products that are typically harvested within a 10-year or shorter cycle following a sustainable management process. Also, we reflect on the effectiveness of our novel framework for regenerative building design, presented earlier in Chap. 4. The framework could have been used by architects to prevent the negative impact of some case studies and adopt a regenerative and resource centred thinking. Another key contribution of this chapter is the presentation of ten key learned lessons for regenerative and positive impact architecture. The learned lessons are presented and illustrated in an informative way proving relevant content and corresponding illustrations forming a roadmap for future regenerative architecture. In fact, the regenerative paradigm increased knowledge about the materials and embodied energy, generated a more conscious attitude to materials and energy resources selection and almost eliminated the reductionist paradigm in design. Finally, we discuss the limitations and implications of our research on the architectural design practice.

8.1 Introduction

The building sector is a key target for circular economy and regenerative economic systems in which resource and energy consumption become beneficial. Inspired by the regenerative approach to design, we must rethink the design and construction of green and healthy buildings, increase the flexibility and lifetime of buildings, improve the quality of life in the built environment and increase the planets carrying capacity. In this last book chapter, we discuss the main research findings and the framework for regenerative design as a key research achievement. Also, we present

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lessons learned from comparing four state-of-the-art high performance buildings and discuss further the implications of our findings and the expected future research.

8.2 Research Findings

Based on our analysis of four case studies, we could not find a 100% regenerative building with an overall positive impact on environment and health. Instead, we found that the regenerative paradigm is closer to reverse the ecological foot print and provide a positive impact building than the reductionist efficiency paradigm. Thanks to the biogenic CO_2 calculation approach, the life cycle stages responsible for creating the positive and the negative environmental impact related to global warming are presented, even though there is no consensus in literature or practice to used carbon sequestration for bio-based materials. In fact, the regenerative paradigm increased knowledge about the materials and embodied energy, generated a more conscious attitude to materials and energy resources selection and almost eliminated the reductionist paradigm in design. The design team who used LCA and who demonstrated a high level of knowledge on materials and resources' environmental impacts, succeeded to create an almost regenerative building with a positive impact beyond certification and standards requirements. In order to create a positive impact building the building had to produce more than its requirements to compensate the emissions released during operation for space and water heating. Moreover, the building had to be built with the maximum possible amount of plant based or bio-based construction materials while allowing disassembly of components. The use of plant based or bio-based construction materials can help to offset the environmental effects of climate change, provided the wood is harvested from a sustainable managed forest or a plantation created to improve degraded lands and is managed using renewable energy (during the pre-use phase). After succession of multiple reuses and down cycling cascades the main insulation and construction material will be composted or in the worst case incinerated.

On the other side, the zero energy objectives achieved the environmental neutrality only for operational energy and could not guide the design team to focus on the overall environmental impact of the building. After one year of full monitoring of the RSF the bet zero energy balance was not achieved and a new parking lot was constructed to host new arrays of 668 kW. The roof was covered with PV panels that are more than 17% efficient. The rooftop array alone could not offset the RSF's energy needs, so several adjacent parking structures were covered with additional PV. Moreover, the rebound effect associated with the increase of plug loads and panels' efficiency degradation factor of 0.7% per year eradicated the efficiency and impact neutrality paradigms. The results are in accordance with previous studies (Jordan and Kurtz 2013; Phinikarides et al. 2014). The energy and resource efficiency claims have potential consequences of unsustainable approaches to building and planning. This claim of annual building operation carbon footprint neutrality of zero carbon emissions/year is misleading. The four case studies could not overcome the limitation given by a non 100% carbon neutral grid infrastructure or energy supply. Therefore, maintaining such objective on the short and long term cannot increase the carrying capacity of nature and reverse our foot print.

By tracing the environmental impact of operational energy and embodied energy over 100 years for four case studies we could proof that the choice of building materials comes in the second place of importance and relevance after the operation energy. Despite the slightly different climatic conditions between Golden (Colorado, US), Givisize (Fribourg, CH), Venlo (Limburg, NL) and Lent (Gelderland, NL) and the different needs for heating, cooling and DHW, it is worthwhile to consider operational energy and the sustainability of grid energy supply followed by building materials when building high performance buil-dings. With the mandatory performance requirements of nearly zero energy buildings by 2020 in the EU we cannot remain operating under the current efficiency or energy neutrality paradigm (Sartori et al. 2012; Attia et al. 2011). Therefore, in this book we have demonstrated that setting the right performance goals (MINERGIE-ECO or Passive House as examples) can play a role in mitigating the effects of climate change and helping architects to create a positive impact of the built environment. By highlighting the potential of regenerative design paradigm it can contribute to sustainable building practices, we also hope to increase the awareness about its impact of operational energy and embodied energy of foundation and concrete construction design principles. Regenerative design can lead to beneficial footprint and positive impact buildings and can inform architects and building designers in accordance with the United Nations Framework Convention on Climate Change. However, in order to maximise its impact, and benefit the greatest number of communicates, its use needs to be promoted amongst the public and buildings professionals. The regenerative approach should be based on maximum efficiency coupled with renewable dominated energy mix. Creating a circular economy means shaping the building regulatory and market frameworks to strengthen regenerative finance and delivery, and to support architects and building engineers with requires simple environmental indicators, calculation methodologies and national implementation standards and strategies.

8.3 A Novel Framework for Regenerative Building Design

Regenerative design holds great promise for a new era of sustainable and positive impact architecture, sparking considerable interest among architects, building professionals and their clients. Accelerating the embracement or uptake of sustainability principles in the architectural design practice is essential. Bringing sustainability to the ideation or concept development phase; supports the inherent integration of sustainability principles in the architect's design practice. Therefore, we developed a carrying framework for regenerative design. This framework for regenerative building design, presented in Chap. 4 and illustrated in Fig. 8.1, can

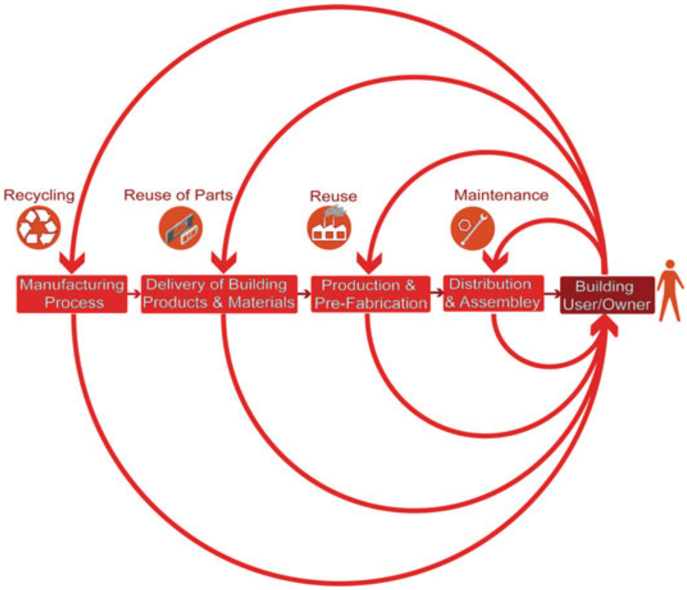

Fig. 8.1 A conceptual framework for regenerative design

inform and guide architects during the design process for regenerative design outcomes, starting from early design.

The framework for regenerative building design sets a priority of for designing flexible and reversible positive impact architecture. Based on our proposed regenerative design framework a reversible construction system maximises the potential of renovation, reuse, re-manufacturing and recycling of the buildings and their components. The next step is to integrate design elements with multi-performance criteria that that can achieve the occupants needs comfort and well-being and, in the same time, neutralize the building negative impacts, if not improve the building beneficial footprint. The selection of regenerative materials and products should be done following a holistic approach that depends essentially on the residual value of its components and its ability to be reused.

8.4 Lessons Learned

This research builds on earlier studies that have considered the mitigation of global and local resource deple-tion and environmental degradation (McHarg and Mumford 1969; Lyle 1996; Attia 2011 and Cole 2012). Regenerative design and architecture, as previously noted in the regenerative-based design case studies, has consistently been shown to deliver innovative buildings with beneficial qualities. With respect to Cole who stated the scarcity to find similar built projects can show the capability of expanding our environmental performance targets (Cole 2012; Waldron et al. 2013; Wolpensinger 2016). This study is in line with environmental assessments made for plant-based construction materials (Van der Lugt 2008; Prétot et al. 2014; Ip and Miller 2012; Wolpensinger 2016; Waugh et al. 2010). Despite the small sample of case studies, the author tried to go into buildings with a well-defined focus and to collect specific building performance data systematically and estimate the environmental impact for 100 years. Based on the four case studies ten learned lessons are highlighted in Fig. 8.2 and in the text below. Those ten learned lessons can be used as a roadmap, covering key areas for green buildings performance and providing a vision for architects and building professionals. The following paragraphs provide a summary and shed the light on the key take-away message for those four projects.

1. **Design for Reversibility and Modularity**

Sustaining the reversibility and modularity of buildings is the key to circular material use and sustainability. Design for reversibility enable assembly and disassembly and consequently expand the life span of building components and materials. Case studies showed how regenerative design principles and strategies are successful in translating regenerative architecture theory into practice. Preparing new construction for demolition, disassembly and reuse of complete building elements form the following stage in the transition to a regenerative architecture and a circular economy. Future changes of functional uses must be anticipated in any regenerative building. Buildings should be able to be upgraded according to new needs over time, like new ways of working and living. Technical installations must be easily accessible and documented using smart information management systems

Fig. 8.2 Learned lessons of 4 cases studies

like BIM. We learned from cases studies that a modular and flexible building construction makes it easy to assemble and disassemble building components including building systems, envelope, facades and finishing products.

Designers should select right construction technology. In the building sector, modular design is not a new trend. Modular buildings can be disassembled and the modules relocated or refurbished for reuse, reducing the demand for raw materials and minimising the amount of energy expended in creating a building to meet the new need. The potential reusability of detachable components raises the resale value of building parts that can be replaced, recycled or moved according to need. We learned from the four case studies that the building that has a modular construction system or modular multifunctional façade system can extend resources usages to a rate that improves the carrying capacity of the planet. Special attention should be made for construction details and façade design while avoiding glue, casting and welding in building connections and joints. Modularity could increase the lifetime of the product's basic structure. The impact of modular design on product circularity depends on the role of modularity in the business model (EEA 2017).

2. **Design for Circularity**

Regenerative architecture promotes circular use of resources. Buildings must be designed as banks of valuable materials. High-grade reuse of materials and building elements is not more future dream. We learned from our case studies that closing the cycles of water, carbon, materials and energy is possible. A priority is placed on cascading materials as long as possible as products rather than components, and as components rather than materials. Restoring the original stock of mineral and metal resources should be achieved. If not, then sustainably managed bio-based materials should be used. Material cycles are designed to be as geographically short as possible. Materials should not be mixed in ways that they can no longer be separated and purely recovered, unless they can continue to cycle infinitely at high value in their mixed form.

3. **Apply Green Building Certification and Use Multi-attribute Products**

Regenerative buildings must meet a series of strict performance requirements on the building level and on the product level. Regenerative and positive impact architecture is performance based which makes them complex. Integrating all performance multi-criteria performance requirements into a robust operational building is critical. Therefore, this integration can only happen through holistic and internationally third-party recognized green building certification systems. Third-party certification systems, such as LEED, BREEAM, DGNB or the Living Building Challenge generally have a transparent, open and clear system that standardizes how building components and services are combined to achieve highly optimized positive impact buildings addressing mobility, site, air, water, energy, carbon, material and IEQ. They make sure that the performance is monitored and apply the best practice of measurement of verification. During the compliance process with rating systems and certification schemes it is accepted to comply with strict single or double criteria standards such as the Passive House Standard, Active House, MINERGIE, ASHRAE and EN standards. However, designer should not forget that those standards mainly focus on energy and carbon efficiency and lack the holistic approach of third–party certification systems.

In parallel, regenerative buildings must rely on certified single and multi-attributes products. Single attribute product certifications such as Energy Star, FSC or Water sense are important as well as multi-attribute product certifications including EPD, C2C, Green Seal or the Health Product Declaration (HPD) certified products. They inform architects and builders about products' footprint or environmental impact or efficiency, the degree of chemical composition. Certified products can inform designers the extent to which components can be separated from each other or recycled or composted. We learned from the four case studies that combining building and product performance requirements is the only way to achieve significant beneficial impacts. Sustainable design is not merely the use of energy-efficient materials. It also involves the creation of products and systems with a positive footprint on the environment over the full life-cycle. The duality of third party certification of buildings and products is the only way to eliminate the energy and carbon gap and increase transparency, performance assurance and occupants' health and well-being.

4. **Use Renewable Energy Sources**

All energy used in buildings should be based on renewable sources. The materials required for energy generation and storage technologies should be designed for recovery into the system. Energy should be intelligently preserved, and cascaded for use. Density of energy consumption should ideally be matched to density of local energy availability to avoid energy losses in transport. Conversion between energy types should be avoided. The system should be designed for maximum energy efficiency without compromising performance and service output of the system. Lessons from the case studies indicate the feasibility of creating plus energy buildings. Renewable energy source should be design to generate more energy than the building uses on annual bases and should compensate for the construction embodied energy and carbon emission. Photovoltaic, solar thermal collectors and heat pumps are the most promising building integrated technologies. On the long term, energy companies should turn the national energy mix into renewable energy dominated energy mix.

5. **Apply Performance-Based Contracting**

Regenerative architecture employs high efficiency measures to decrease resources demand as much as possible and they cover the rest of resources mandate and more, using renewable sources and advanced resource management systems. Lessons learned from case studies indicate that a performance-based design and contracting approach is crucial to achieve the multi-criteria performance goals. The performance-based approach is the only approach that can address the complexity of regenerative and positive impact architecture. It forces the design team members to collaborate during the various design and construction phases of the building delivery process to ensure predicting and achieving high performance building requirements. It can get the right mindset for the Design & Build team including the architect and contractor. Using multi-criteria key performance indicators (KPIs), for energy, water, air, materials and IEQ, is a fundamental step in the performance-based design approach. With the help of powerful building performance simulation (BPS) tools as well as evaluation tools design teams can assure achieving the pre-defined performance indicators. Tools and methods are used to permit measurement and testing of the requirements, and the relating measurement of the capability of buildings to perform. The key performance goals allow streamlining the building quality and allow the owner, design team and builder to commit to the high performance targets and specifications as early as possible in the design process.

6. **Engage Integrative Design Process**

The project acquisition and delivering of the four case studies was based on Design & Build project contracting. The Design & Build contract included the owner project requirements (OPRs), which included the program and key performance and prescriptive requirements. The performance-based contracting guided the architects, engineers and builders and assured a clear understanding of performance requirements. This allowed several market consultation and pre-design brainstorming with suppliers and manufactures to think deeply about the building materials and products footprint and quality. This was not a coincidence. Regenerative architecture is by default is a high performance architecture that requires empowering and enabling the whole team creativity as early as possible. The Design & Build contract allowed creating a unified Design & Build team that embraced the performance criteria and followed an integrative design process. We learned that IDP helps to create solid design team that can optimize design and come up with simple, ultra-efficient and cost effective solution sets for regenerative and positive impact architecture (Fig. 8.3).

7. **Design for Occupants Comfort and Well-Being**

Regenerative architecture is occupant and user centred seeking the health and well-being, and in the same time, achieving positive impact architecture. The creation of occupant centred buildings that allow concentration and contemplation or collaboration and communication will remain as the root cause of architecture. Occupant's interaction with their surrounding environment using various adaptive opportunities, such as opening a window, or controlling temperature or air speed, together with the environmental factors such as visual comfort, acoustic comfort or indoor air quality, can lead to user satisfaction and consequently energy savings. One of the learned lessons from our case studies analysis is that personalization and interaction increase productivity, enhance occupant happiness and well-being and as a consequence improve sustainability, and optimize service delivery and

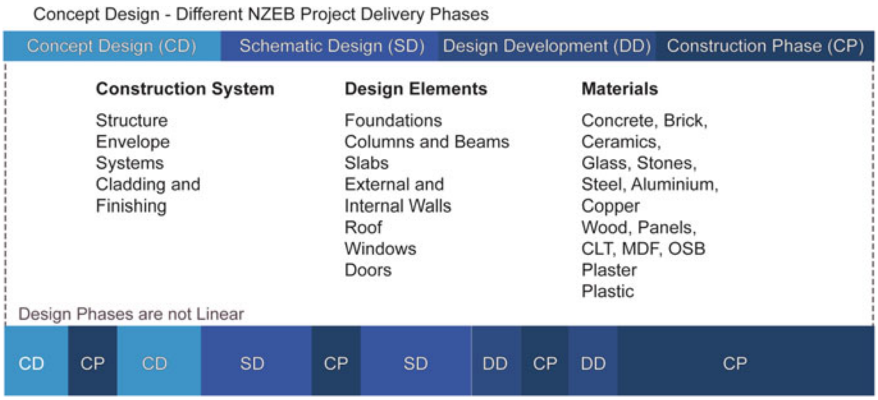

Fig. 8.3 Comparison of the primary energy balance and global warming potential for the four case studies

operations. The empowerment of building occupants beside the availability of personal control makes occupants feel thermally comfortable across a wider range of conditions and make them responsible to maintain the building performance and achieve the expected performance targets.

8. **Create a Database and Materials Passport**

Consequently, this requires an accurate identification of building products and materials in regenerative buildings. A material passport emerges here as a necessity to trace building materials. Extending producer responsibility and selling product functionality instead of owning them encourages the design of regenerative buildings as material banks (EU 2017). This can prevent the construction and demolition waste, reduce the consumption of raw materials and can lead to new circular manufacturing techniques that consider buildings as part of the planets materials mines. Building Information Modelling (BIM) appears as an important vehicle to achieve the identification and training of building products and materials. Use BIM to create 3D models and a database that centralizes the information about building components and products connecting suppliers, manufactures and facility management.

9. **Enable Collaborative Consumption and Leasing Services**

Regenerative architecture enables collaborative consumption and manufactures to deliver and operate building product services. Instead of owning building materials and products regenerative buildings rely on leasing services. Collaborative consumption, or the shared use of products by consumers, either peer to peer or mediated through a platform, was one of key lessons learned from Iwean project. Time, space, sustainability and effort saving are reasons for joining collaborative business models. Shared use of assets leads to an increasing utilisation of existing products and consequently to a lower demand for new products.

Another key learned lessons, from case studies is that positive impact buildings rely on leasing and services business models. Regenerative architecture enables lending for sustainability based on circular business models that create business incentives for circular manufacturing. Leasing contracts for carpets, furniture, lighting and lifts, shift the ownership from building owners to building material manufactures. By extending producer responsibly the future ends value of a products or material increases. The residual value of products, in terms of absolute value in monetary terms, increases because products and material remains as an asset which make building materials efficiently used. Shifting the focus to product and material servicing will improve eco-efficiency as well achieve eco-effectiveness (Rau and Oberhuber 2017). Product ownership is not transferred to the customers but remains with the manufacturing firms including maintenance.

10. **Apply Sustainable Sourcing and LCA**

Responsible sourcing raises awareness for a sustainable and efficient use of building materials and naturals. By creating transparency on the social and environmental performance, material sourcing can trigger improvement and comparison of construction product, but also positively influence the entire supply chain, creating a beneficial multiplier effect. Next, Life-Cycle Assessment (LCA) is one of the most important drivers in the regenerative building design and stakeholders' decisions. It is a valid method to improving the operating performance while minimizing embodied energy and negative environmental impact. LCA can provide an insight of a particular point in time on the basis of our current knowledge of material impacts. The measurability of data depends on the ability to forecast future outputs accurately for most building components. LCA is an essential tool for regenerative design and can help to identify whether environmental burdens are shifting or eliminated.

Lessons learned from case studies indicate that we should integrate multi-criteria life cycle assessment and including as much as possible environmental indicators during analysis over the long possible calculation period. So far it was difficult to measure the recyclability of a product and calculate the benefits of recycling that relate to a single product in the materials cascade. However, we expect that this will improve in the near future. New developments in LCA—such as assessing social impacts and assessing the impact of materials on indoor air quality can bring measuring regenerative design a step closer.

8.5 Implications for Research and Architectural Design Practice

The controversy surrounding efficiency paradigm has recently been reignited by several studies, published simultaneously (Ankrah et al. 2013). The large contribution of building to resource consumption is highly relevant, not least because optimisation potential is equally great in the same sector. Whatever the outcome of the technocratic reductionist efficiency debate, the fact remains that the resources efficiency and the reductions approach have significant limitations. Those architects, building designers and owners seeking sustainable architecture in their practice require valuable information in order to make informed decisions. However, effort spent to predict or reduce buildings environmental impact should be replaced by high quality regenerative design support metrics, indicators, tools, strategies and frameworks for net positive development (Meex and Verbeeck 2015).

In the last ten years, there has been a progress made in measuring the environmental impacts of the building sector. Consider, for example, the growing importance of the EPDs documents or progressive development and application of LEED, BREEAM and DGNB rating systems, Passive House Standard, Active House Standard or C2C Standard, which provide product information on the environmental and social impact of building materials based on thorough life cycle analyses. Figure 8.4 illustrates the accelerating evolution of sustainable building rating systems, building standards and building product/materials labels. Design teams need information on how to replace fossil fuel based system and components with passive or natural/renewable sources on the building and grid level. They need to benefit from services and functions that are based on sustainable leasing and management of building materials and products. This information will need to be easily accessible, based on well establish predicts and materials life cycle analysis.

In this research, we used life-cycle assessment (LCA) and carbon footprint calculations to analyse the environmental impact of four state-of-the-art buildings. The main limitation of LCA remains in its cradle to grave approach that mainly

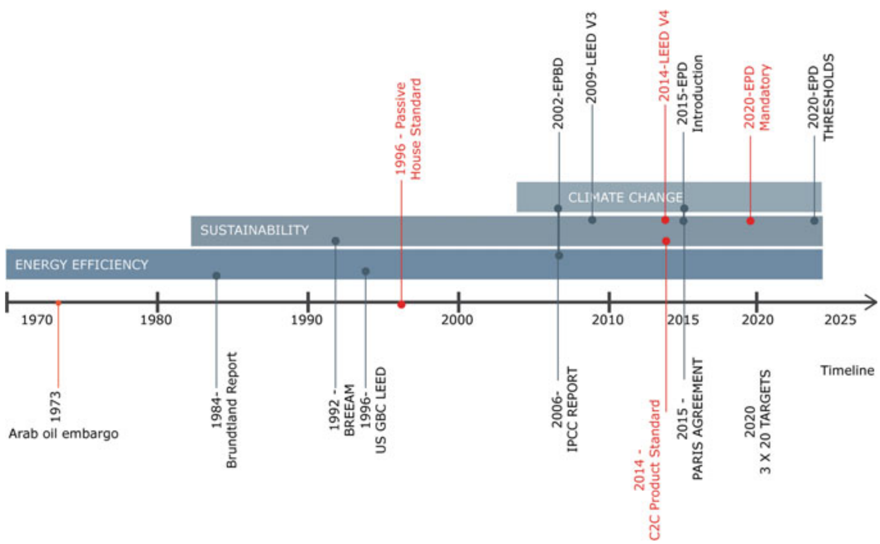

Fig. 8.4 Evolution of key influential building rating systems, building standards and building product/material labels

measures the environmentally damaging footprint. For example, the Green Offices project and Iewan Social Housing Project were designed for disassembly and adaptation to change of function. The structure had modular dimension systems, the skin is made of demountable facades and the internal spaces allow movable separation walls. Issues such as adjustability, versatility, movability and scalability are of great added value allowing anticipation go future changes including high quality future reuse. However, the LCA approach could not quantify those beneficial design qualities.

- We believe that the assessment of sustainable and regenerative architecture is complex and difficult and requires a holistic approach. Beside environmental assessment criteria we should include technical, social and economic criteria. For example, we should include functional attributes such as cost effectiveness, durability, fire resistance, moisture resistance, recyclability and ease of installation and fixation. We should think of regenerating the worlds damaged ecosystems and human communities from a wider perspective. Regenerative development should be interdisciplinary.
- We should not focus only on single environmental attributes of materials and resources. The *claim effects* about the outstanding performance of certain insulation materials, is a marketing tool that is used by many manufacturers. Instead architects need to understand that any insulation material or other construction material will have a multi-attribute environmental impact as shown in Fig. 7.5.

Therefore, new tools and indicators are needed in the future to assess building's functionally and which environmental, social, and health benefits that can be achieved in particular at the end-of-use phase (reuse, recycling, incineration, landfill) (Bor et al. 2011; Geldermans and Rosen-Jacobsen 2015). A harmonisation of building assessment systems is needed in order to make the evaluation of regenerative buildings' environmental impact comparable and enable building professional to better select regenerative construction systems, create regenerative architecture, and select regenerative building materials.

Needless to say, the research was limited to only three energy and environmental indicators and did not include cost. We focused mainly on how those four case studies bring quality and achieve a positive impact from a technical and performance point of view. A future research can use the same four case studies to discuss the budget, cost and financial aspects. We would like to add that all four projects respected their budget limits and even were managed and delivered under budget cuts as a consequence of the he 2008 financial crisis.

From the results, it can be concluded that bio-based buildings can generate energy and are CO_2 negative. However, without studying the other indicators such as eutrophication, acidification, air/soil/water toxicity and the associated embodied water consumption the results of the wood construction cannot be generalized. On the other side, the aim of the research was not conduct a full LCA but to use the LCA for comparison and highlight the importance of including materials environmental impact in any future green or sustainable building rating. Using LCA we proofed by evidence that the zero energy objective cannot be the answer to our ecological and economic crises.

Finally, we would like to remind the reader that in the last three decades architecture was influenced by the sustainability discourse and many innovations were tied to progress in technology. The influence of technological advances was profound, driven by new construction technologies such as insulation materials, renewable systems and efficient heating and cooling technologies. It is time to think not just sustaining the planet that is seriously damaged, but about regenerating it instead. From this research, there is a proof that there is change of current practice and that there is a shift in the design and construction of sustainable architecture. This implies that new theories, frameworks, strategies and performance indicators and metrics will appear in the near future. There is a need to develop comprehensive rules for an environmentally enhancing. This includes circular business models and incentives that sell functionality, comfort and well-being as services instead of owning decaying buildings and product. We presented in this research a solid framework for regenerative building design. This framework represents a roadmap for new vision and performance driven architecture and can results in new production and performance calculation indices and methods. Creating a circular rather than a linear architecture can revive human communities. A policy context can help creating optimal legal and fiscal support to regenerative and positive impact built environment. Today, the regenerative design paradigm can provide a new vision of a new built environment. Regenerative design will become a necessity to support a healthy and positive ecological footprint of buildings and the built environment.

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