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PATHWAYS TO DECARBONIZING THE BUILT ENVIRONMENT

Towards a Circular Building Industry in Berlin – Emerging Concepts from the Circular Economy

Kopernikus Projects Enavi

Working Package 4 | Task 7 “Technical-systemic analysis with a focus on energy efficiency in buildings”

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KOPERNIKUS PROJEKTE
Die Zukunft unserer Energie

GEFÖRDERT VOM
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The Federal Ministry of Education and Research (BMBF) has allocated a total of EUR 400 million to fund the Kopernikus program until 2025. The objective of the program is to develop innovative technological and economic solutions that can facilitate the transition to a more sustainable energy system. Over a period of 10 years, more than 230 partners from science, business and civil society will conduct research in four subject areas: "New Network Structures", "Storage of Renewable Energies", "Reorientation of Industrial Processes" and "System Integration". Researchers are adopting a holistic approach to these four subprojects in order to examine specific issues relevant to the individuals and institutions that play key roles in energy generation, transmission, supply, and distribution. The program's 10-year lifespan ensures that the initiative will include a long-term interchange between theory and practice.

System integration: ENavi

As a participant in the "ENavi" subproject, IKEM is partnering with roughly 90 institutions from the fields of science, business, and law to develop a navigation system that promotes the transition to sustainable energy. Because system integration is vital to the success of comprehensive energy reforms, the program partners' integrative approach includes research on heat, gas, and fuel use. IKEM plays a key role in ensuring that the findings from theoretical analyses can be applied in practice. From the outset, field tests are conducted to assess the concrete technical, economic, and legal implications of the energy transition. Test results can then be applied to other regions. Program partners intend to expand the initiative to include research on 50 municipally owned power generation and electricity distribution companies, or Stadtwerke.

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Table of Contents

List of figures

List of tables

Introduction

Scope

Within the framework of the Kopernikus E-Navi Project, the research seeks to contribute to the German energy transition process by finding alternative pathways towards the decarbonisation of the built environment. The overall research aim is to provide research-based findings that could support the design of innovative policies targeted at CO_2 emission reductions of the built environment.

The research discusses the implementation of emerging concepts, methodologies, and business models in the field of circular economy in the construction industry that could enable a transition from the traditional practice of construction towards a circular construction. Facing an innovation process is not an easy task; therefore, the research seeks to illuminate the problem from various perspectives, both methodological and empirical. Thus, this report is the first in a series of publications that seek, based on an active interaction between scientific research and professional practice, to discuss the implications of a paradigm shift in the construction industry towards circularity.

The scientific work deals with several tasks, such as literature review, data collection, and the analysis of empirical data through different qualitative and quantitative methods. Given that the research seeks to initiate the discussion about a potential implementation of concepts, business models and methodologies of the circular economy in the construction industry, the research methodology follows a sequence of three main steps that are detailed below.

- The first step considers a systematic in-depth review of secondary sources of information by analysing current literature in the field of circular economy in the built environment. The literature review analyses concepts, methods, and relevant business models discussed in different sources published in the field of circular economy for the built environment; namely: scientific, institutional, and grey literature. This report discusses the most relevant findings in the literature review.
- The second step deals with primary data, by collecting and analysing expert's opinion regarding the research findings presented in this report. By applying qualitative research techniques, both in data collection and analysis, it is intended to capture expert`s and decision makers' opinions in their roles as key-players within the construction industry. Specifically, it is sought to explore and discuss the implications, barriers, and relevant drivers for a potential transition towards the circularity in the industry. The basis for the discussion is the information collected in the previous step, presented in this report in sections III trough VI.

- The third step seeks, following a quantitative approach, to analyse the embodied energy of building materials used in Berlin`s housing stock. The relevant literature shows that, from a circular perspective, it is necessary to analyse the energy performance of buildings throughout their whole life-cycle. Thanks to the active involvement with the Kopernikus E-Navi project partners, valuable information is available for the life-cycle assessment of buildings' energy performance in the different stages of the life-cycle, such as: design, construction, operation or use, and the end of the life. Therefore, it is important to analyse not only the energy used during the operation phase, but also to consider the energy consumption in the production of building materials before the construction or use stage of the building begins, the so-called embodied energy. The overall aim is to explore whether alternative materials could reduce the sector's emissions already from the design and construction stage of the buildings. Likewise, it seeks to analyse building's whole life-cycle and to find alternatives for disposal and/or recycling of building materials that minimize waste production in the sector. This step is currently ongoing on a pilot basis thanks to the information provided by GESOBAU. The dissemination of the preliminary results is expected within this year, following a discussion of the findings with the key stakeholders and involved research partners.

The professional experience, on the other hand, plays a fundamental role in the research since it is sought to generate scientific-based policy recommendations. Thus, the Kopernikus E-navi project provides ideal conditions for scientific inquire based on empirical information emanating from professional practice and the experience of relevant key stakeholders, that might enable the discussion with decision makers in the construction industry. In the specific case of research on alternatives for the decarbonization of the built environment for the case of the residential sector in Berlin, the main partners are HOWOGE and GESOBAU.

The project as a whole, and this report in specific, are based on the findings of an ongoing research that initially focuses on the residential construction industry in Berlin. However, the results are relevant for other sectors of the construction industry in other federal states within Germany. Moreover, since the research is nourished significantly from the international experience and discussion, the results also seek to contribute to the international discussion regarding circularity of the built environment.

Audience

Given that the report seeks to initiate the discussion regarding alternatives for the decarbonization of the built environment towards the circularity of the construction sector, this report is aimed at a wide audience. Amongst other key stakeholders and decision-makers, all firms active along the construction value chain, including suppliers of building materials, chemicals and construction equipment;

contractors; and engineering, architecture and planning firms, as well as project owners and developers are targeted. Moreover, local and federal governments are also considered as target audience, as they not only have an impact on the industry via regulation but also act as the main procurer of most infrastructure projects in the built environment. Finally, this report is also aimed at the scientific community working on the field and members of the civil society, in view of the socio-economic relevance of the construction industry and the circular economy potentials.

Report structure

This report is divided into seven sections.

The first section and subsections present the research design. An in-depth literature review of secondary sources of information was conducted in order to build a robust theoretical framework about the circular economy. Available publications on the topic were detailed review.

The second section and subsections discuss the current linear model of resource consumption and the growing need to decouple economic growth from resource consumption. Current trends on resource consumption that are exhausting the Earth's natural resources are set at the centre of the discussion. A need for a paradigm shift in the current model is stressed.

From the third trough the fifth sections and subsections, the circular economy, key related concepts, principles, and business models are reviewed in detail. The implications of the concept in the built environment research are on the focus of the inquiry.

The last section and subsections provide a short discussion bases on a summary of main findings and provide an outline of further research and key implications within the Kopernikus ENavi project.

I. Research Design

Each research project is unique in nature, since it responds to a precise set of motivations and attempts to answer a precise set of research questions. The sections below present and substantiate each one of the methodological steps taken throughout the research for achieving the research goals, to make the research process transparent and traceable.

1. Aims

The main research goal is to initiate the discussion about the potential implementation of a paradigm shift in the building construction industry that contributes to the decarbonization of the built environment. Thus, an initial task – prior to the interaction with key actors, as described in the *Further work* section – is to find some common ground in terms of understanding an emerging concept: the circular economy (CE) in the built environment research.

Therefore, the literature review explores the CE concept in recent publications, mainly from the scientific and institutional perspectives. Secondary sources of information are thoroughly reviewed in the relevant literature that discusses the implementation of the concept in the built environment research. Without seeking a deep theoretical discussion, the review focuses rather on discussion regarding the potential practical implementation of the CE concept. Hence, the guiding research question addressed in the literature review was: What are the current understandings of the CE concept among scholars and practitioners?

The main aim of the literature review is, therefore, to conduct an in-depth critical review of the current literature on the CE concept, focused on the implementation of the concept towards the decarbonization of the built environment with a focus on the housing construction sector in Berlin. The specific aims are:

- To provide a panorama of how this approach has been developed and implemented;
- To review the concept, current practices, and assessment of the CE;
- To identify the fundamental dimensions of the CE approach regarding the built environment research;
- To explore the potential applications of the CE approach for investigating opportunities for decarbonizing the built environment and the housing sector.

2. Methods

As mentioned in the introduction, a systematic in-depth review of secondary sources of information was conducted for analysing current literature in the field of circular economy in the built environment research. To fulfil this task, a systematic literature review was conducted, that is further detailed in this section.

According to Kirchherr and others (2017) there are at least two methods to investigate the understanding of a concept. The difference between them is, basically, about the interaction between researcher and sources of information for building new knowledge. The first one, deals firstly with primary data, that means interviews for asking for the understanding of a concept should be conducted with relevant stakeholders. In this case, it is assumed that It is assumed that the informants have some knowledge of the research topic. The second one, starts dealing with secondary data – in this case written definitions of a concept – for the analysis; following this approach, written definitions of a concept can be gathered and then analysed. It is estimated that, for providing a more valid view on the current understanding of a concept in the discourse this method is more suitable since, usually, written definitions[1] are more thoughtful than ad hoc ones provided in interviews (Kirchherr et al. 2017:222). This second method was, therefore, chosen for the purposes of this research.

Since the research in general, and in particular this report, aims at investigating key stakeholders' understanding of circular economy (CE) as an emerging concept in the built environment research, seeking to explore different pathways for decarbonizing the sector, the secondary data collected during this phase will be later contrasted with primary data collected in the field.

Previous analysis of worldwide literature the CE concept reflected that the concept was rooted in very diverse theoretical backgrounds, namely: ecological economics, environmental economics, industrial ecology. Therefore, articles, reports, and other publications were identified through multiple formal search methods including hand searching of key journals and electronic searching of main scientific databases. The most relevant periodicals consulted during the review include, but were not limited to:

[1] According to Kirchherr and others (2017) there are some considerations to keep in mind when analysing written definitions. The authors acknowledged that definitions can be rather "narrow operationalisations of the understanding of a concept – particularly those published in peer-reviewed journals" (p.222). Such 'narrowness' could be related to space restrictions in most of journals; authors might thus choose to only present an abridged definition of a complex concept that focuses solely on the aspects of the concept investigated in their paper. The latter will imply having a rather narrow focus.

Building and Environment, Energy and Buildings, Ecological Economics, Energy Procedia, International Journal of Production Economics, Journal of Cleaner Production, Renewable and Sustainable Energy Reviews, Resources, Conservation and Recycling, Sustainable Cities and Society, and Waste Management. Moreover, some studies and reports were identified when reviewing the references cited in key documents in order to ensure having a comprehensive corpus for the analysis.

Finally, since the research, in the long run, seeks to enable a potential transition within the practice of construction towards a circular industry, the literature review also considers business models implemented in the field in the international experience. Following the same approach as with the CE concept, the aim is to confront key experts and decision makers with current CE business models found in international experience. The aim is twofold; 1) it is sought to provide examples that operationalize the CE concept within the practical experience; and 2) to increase the adoption rate in the industry through reducing the uncertainty regarding the potential of implementing the concept.

II. The Role of the Built Environment

According to ARUP (2016) the built environment[2] is a major consumer of natural resources. The sector involves several stakeholders, where the construction industry is a key player, and several processes, components, and systems that relate and interconnect with each other in a very dynamic way. When considering the energy demands for sustaining the sector and processing the natural resources into the built environment, the need for obviating waste and increasing efficiency is paramount. When seeking to achieving these goals, there is a breadth of opportunity that this will create across the entire supply chain in the construction industry (see ARUP 2016, 2018).

This section and subsections analyze the impacts of the current model of consumption of resources for the construction of the built environment. The growing need to decouple economic growth from resource consumption, mainly due to finiteness of resources, and the threats represented by the current linear model are also discussed.

1. The limits of Resource Consumption

Natural resources are currently being consumed at twice the rate they are produced; by 2050, this could be three times the rate (ARUP 2016). Thus, the concern about worldwide resource scarcity and the consumption of virgin materials, mainly by the construction industry, is gaining increasing attention in public policy, the private sector, and academia. Figure 1 shows finite resources necessary for the elaboration of diverse products of daily use. Similarly, the image shows the number of years that these resources will be available on our planet if our consumption rate continues at the same pace.

According to ARUP (2016) and Sauvé et al. (2016) major anthropogenic-driven changes, like global demographic and lifestyle changes, are increasing the demand for natural resources, many of which are becoming scarcer and harder to extract. In particular, world's population growth is putting unprecedented pressure on natural resources needed for satisfying the existing demand for homes and services. The aforementioned drivers have repercussions that are reflected in several areas of the local and global economy. Competition for resources and disruptions to supply are already contributing to

[2] According to Roof & Oleru (2008) in the social sciences, the term "built environment" refers to the human-made surroundings that provide the setting for human activity, ranging in scale from buildings to parks. The authors de define it as "the human-made space in which people live, work, and recreate on a day-to-day basis".

volatile materials prices, creating uncertainty in the short term and increasing costs overall, to name a few.

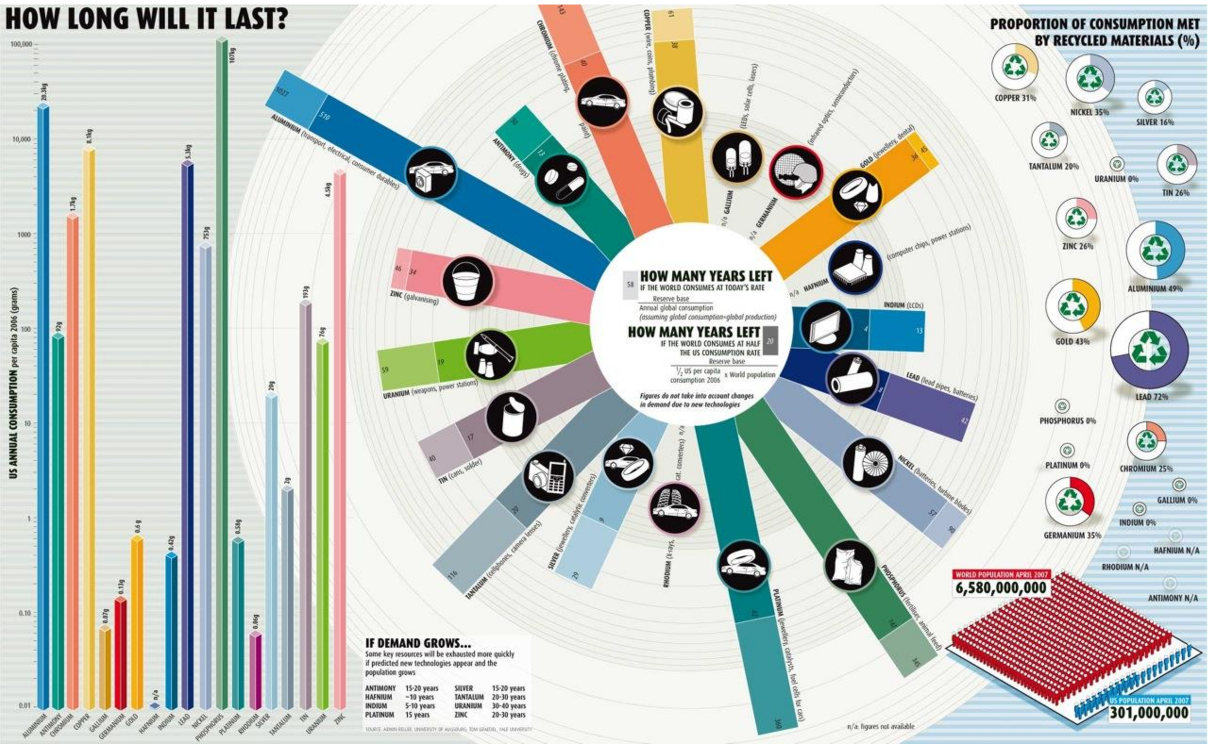

Figure 1: Current Resource Consumption

Source: www.ellenmacarthurfoundation.org.

In the German Context, the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety[3] (BMUB), argued that the main drivers for the increasing input of raw materials are the growth in the world's population from around 4.3 billion in 1980 to over 7 billion in 2012 and an estimated 9.3 billion in 2050; accordingly, an increase in raw materials input per capita in newly industrialising countries such as China, Brazil or India is expected (BMUB 2012).

In order to cope with the abovementioned population changes, the construction industry and the built environment have become the world's largest consumer of raw materials. According to ARUP (2016) the construction industry accounts for 50% of global steel production and consumes more than 3bn tonnes of raw materials. The building sector is responsible for a good share of material and energy consumption. Moreover, according to Rees (1999 in Pomponi & Moncaster 2017) buildings were in the 90s responsible for 40% of the material and a third of the energy consumed globally. Almost three

[3] Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit (BMU).

decades later, the construction sector is still the world's largest consumer of raw materials, and accounts for 25-40% of global carbon dioxide emissions (WEF 2016).

According to Ecofys (2016) an important share of emissions is caused by: industry (29%), agriculture & forestry (20%), buildings (18%) and transport (15%). Within emissions in the industry and agriculture & forestry sectors can be related to materials, such as non-metallic minerals (6% of world emissions), iron and steel (5%), chemical & petrochemical (4%), livestock and manure (7%). The later implies that half of the worldwide emissions are related to the raw material exploitation for the materials manufacturing. Moreover, recent studies in the field of climate protection (see ECOFYS 2016, EMF 2015) have estimated that, in order of magnitude, the potential of a more circular world economy can play a key role in bridging the emissions gap to a 1.5 °C pathway. Ecofys' report (2016) states that the benefits of implementing the circular economy go beyond climate protection. Making economies more resource efficient will reduce greenhouse gas emission all the way up the value chain, from logistics to manufacturing to the mines and extraction pits from which raw materials are sourced.

2. Decoupling Economic Growth

The concern for finite resources is not a novelty. In 1972, Meadows' and the Club of Rome's report sent out a warning about the finiteness of resources (Meadows 1974). Since then, not much has changed other than a significant increase in the global consumption of natural resources, as discussed in the previous sections, and resource scarcity remains a pressing topic. Resource scarcity has also substantial economic impacts in the worldwide economy. In this regard, the limited amount of resources has led to a significant increase in the prices of basic products. The Ellen MacArthur Foundation's report (EMF 2013a:18) conducted an in-depth analysis of the McKinsey's Commodity Price Index for 2011 and concluded that since 2000, the prices of natural resources have risen dramatically, erasing a century's worth of real price declines.

Moreover, the Figure 2 shows that, the arithmetic average of prices in four selected commodity subindices (food, non-food agricultural items, metals, and energy) stood at a higher level than at any time in the past century. The above reflects the growing need to change the way in which resources are consumed on the planet, mainly thinking about sustainability and future generations, but also in the prevailing socio-economic conditions.

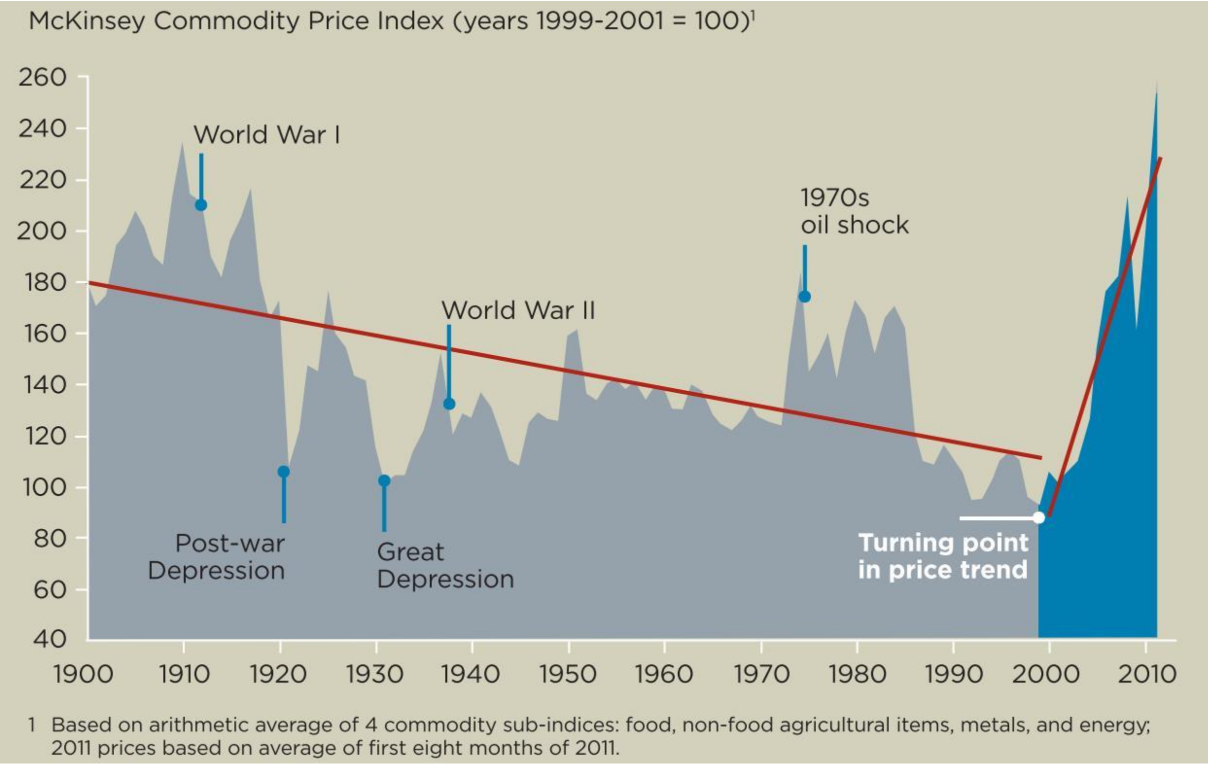

Figure 2: Sharp Price increases in commodities since 2000.
Source: EMF 2013a:18.

Schrödl (2014) argued that the concern for finite resources calls for a careful use of natural resources, as they directly affect the environment, for preserving populations and enabling their economies. The later emphasizes the growing need for strategies that allow decoupling CO_2 emissions form resource consumption. According to Wilts & Palzkill (2015) the overall aim of implementing decoupling strategies is to reduce the use of resources with the help of technological progress and closed material cycles. Thus, strategies for the decoupling of consumption, waste generation, and related environmental burdens predominantly focus on technical efficiency and consistency.

When addressing such goal, the private sector plays an important role in managing activities in a way that enables a sustainable use of resources, thus maintaining the local and national economy in the long term. According to Schrödl (2014) companies and their networks can contribute with their actions to a sustainable use of natural resources. Schrödl´s work highlights the role of supply networks when seeking a sustainable use of resources, that could be relevant for the construction industry. In order to be able to produce goods and offer services, supply networks started by primary product suppliers, whose products come from raw materials – like building materials, are required to apply efficiency measures and engaging all network components, namely: the organizations, processes, and technologies. The role of supply chain management and the focus on green supply chain management are further discussed in the *Circular Recovery* section.

The Club of Rome report (2016 in ECOFYS 2016) concluded that decoupling strategies, which include renewable energy, energy efficiency, and material efficiency, have the potential to cut carbon emissions by two thirds, helping to reduce the emission gap. Material efficiency measures in the report consider overall material efficiency, replacement of virgin materials by secondary materials, and increasing the lifetime of products. Such measures are completely aligned with principles of the circular economy, as it will be detailed described in the later sections and subsections. Nonetheless, among the various benefits found by implementing decoupling strategies, the Club of Rome estimated that material efficiency is likely to cut carbon emissions up to 10% in comparison with the business as usual scenario (ECOFYS 2016).

Aligned with decoupling strategies, a new paradigm, the so-called circular economy (CE), is now gaining momentum, and it promises to overcome the contradiction between economic and environmental prosperity, and decoupling CO_2 emissions form resource consumption. There are many different schools of thought on the CE (see *Debating the Circular Economy* section) nonetheless, the common founding principles lie in the better management of resources. From the resource management perspective Pomponi and Moncaster (2017) highlighted the role of the built environment – due to its high environmental impacts – which offers significant opportunities for reductions in energy use, CO_2 emissions and waste production, as discussed in the sections above.

3. Challenges of the Linear Model

The literature discusses key aspects of the current production model leading to its unsustainability. This section and the following subsections analyse main issues of the current model that are relevant to the built environment and the construction industry's supply chain. Likewise, the need for a transition to a circular model, able to optimize the use of resources, reduce waste, and incorporate the environmental costs of the current model is discussed.

a) Limits to the Linear Model

According to Andrews (2015) practices of making do and mending (reusing and repairing) and salvaging (recycling) were commonplace across society during and immediately after World War II, because resources were rationed. Nonetheless, the author argues, once rationing ended, products were again disposed of at end of life. Hence, a linear model was further substantiated in the 1960s when significant changes in global markets meant that salvaging metals, paper, glass and textiles, for example, became less economically attractive than buying new ones. Such a model it is still in place and is reaching its limits (EMF 2013a, 2014, Sariatli 2017). In fact, this system is running out of resources, causing price volatility, uncertainties, and economic crises (EMF 2013a:17).

The current industrial economy remains since the sixties, despite its evolution and diversification (Sariatli 2017). One of its fundamental characteristics, the so-called 'take, make, dispose' model or 'lineal model', which relies on large quantities of cheap, easily accessible materials and energy, has aroused concerns amongst scientist and practitioners (see EMF 2014, 2015, Andrews 2015, Ghisellini et al. 2016, Sariatli 2017).

Nowadays, companies harvest and extract materials, use them to manufacture a product, and sell the product to a consumer, who then discards it when it no longer serves its purpose. According to the Ellen MacArthur Foundation, the latter is truer now than ever; in terms of volume, the Foundation reported, around 65 billion tonnes of raw materials entered the economic system in 2010, and this figure is expected to grow to around 82 billion tonnes in 2020 (EMF 2014:12). When confronting such model – that has been at the heart of industrial development and has generated an unprecedented level of growth – with current concerns about resource availability, the need for alternative economic models and strategies steps forward in the discussion.

b) Costs of the Linear Model

The current linear model (LM) generates significant environmental and economic costs, the literature shows. According to Sauvé and others (2016) the model is characterized by the importance given to economic objectives, with little regard for ecological and social concerns (and internalization of these costs) as well as little reliance on related public policy interventions, following policy environment that favours the market.

Andrews (2015) argues the LM had benefitted "the creative, manufacturing and retail industries, energy suppliers and raw materials producers (such as the mining and oil industries)" (p.307). Instead, the environment was damaged as vast quantities of waste were sent to landfill sites and/or combusted as waste. Moreover, the LM makes only partial attempts to internalize the cost of environmental damage in productive activities when it comes to collecting and recycling waste (Sauvé et al. 2016). Such attempts, nonetheless, has not been able to reduce environmental damage fast enough for catching-up with the speed at which the environment degrades due to extraction and waste-disposal activities. Both ends of the linear process are, therefore, environmentally harmful.

Based on empirical data and economic modelling, the Ellen MacArthur Foundation (EMF 2013a) quantified some of the costs of the LM. The Foundation quotes the report of the Sustainable Europe Research Institute which states that 21 billion tons of materials used in production do not get incorporated in the final product. Moreover, the Foundation (EMF 2013a) refers to Eurostat data from 2011 indicating that the volume of material input to the European economy tallied with 65 billion tons in 2010, out of which 2.7 billion tons were dumped as waste, merely 40 percent of which was used again in any form (e.g. through recycling, reusing, or composting). According to Sariatli (2017) the unmanaged waste lost not only its original function, but it was also wasted as a source of energy.

c) Linear vs. Circular Models

As discussed before, the linear economy model is based on a simple, linear process, which basically implies: extract, produce, consume and trash, with little or no attention to the pollution generated at each step; the Figure 3 illustrates the extraction a production processes in the linear economy (LE), on the left-side, in contrast to circular economy (CE), on the right-side.

The work of Sauvé and others (2016) states the LE model is characterized by the importance it gives to economic objectives, with little regard for ecological and social concerns (and internalization of these costs) as well as little reliance on related public policy interventions. However, as discussed in the above sections, the planet has finite boundaries, and even in the Le model of production and consumption, the wastes generated through extraction and production activities and the post-consumption products generate pollution and environmental contamination.

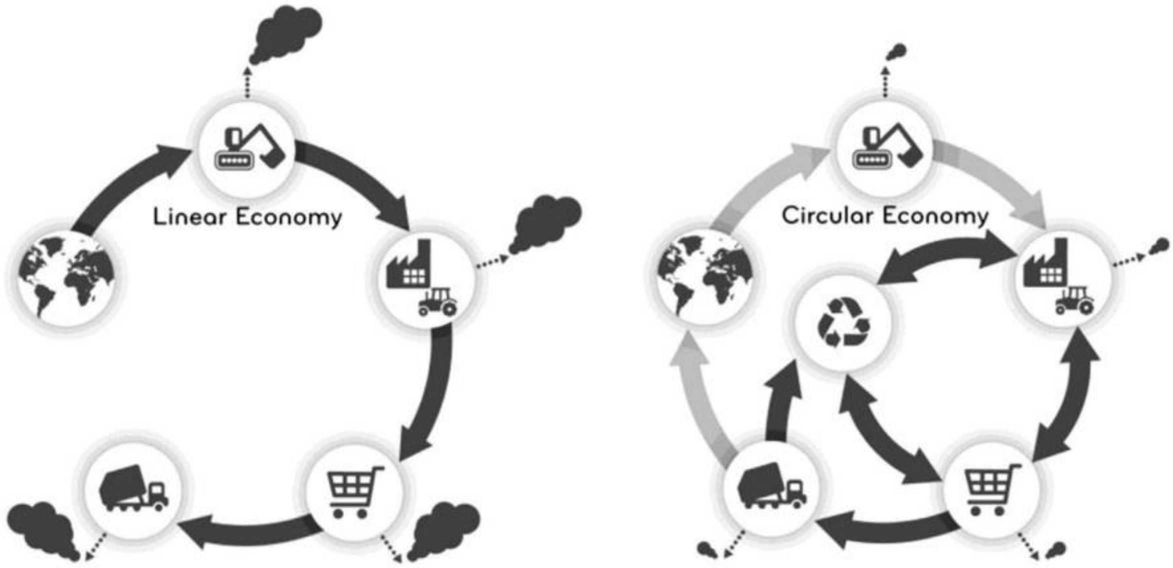

Figure 3: Contrasting the Linear and Circular Models
Source: Sauvé et al. 2016:52.

In the LE model, resources are extracted, processed, used, and ultimately for the most part discarded as waste. At the end of such a cycle, waste is disposed of by incineration or landfill; in both cases materials are withdrawn from circulation or destroyed, resulting in significant environmental damage. In contrast, the CE model is clearly resource-oriented. Sauvé and others (2016) argued the CE considers all inputs and outputs of the production process, although with a significant emphasis on waste management. Moreover, ARUP (2016) described the CE model as an ecosystem where natural capital is preserved and enhanced, renewable resources are optimized, waste is prevented, and negative externalities are designed out. Thus, materials, products and components are held in repetitive loops, maintaining them at their highest possible intrinsic value.

According to Fischer and Pascucci (2017) transitioning from a LE into a CE requires the emergence of new rules which need to be aligned to CE principles and practices, as described in the *3R's Principles of the Circular Economy* section. When implementing CE principles and practices in companies and firms within the private sector, the transition goes beyond just changing existing ecosystems, it involves also considering new forms of internal collaboration within the organizations, which calls for internal adaptation to new interdependencies and complexities (Grandori & Soda 1995, Grandori 1997 in Fischer 2017). Thus, the transition process towards circularity could enable interesting conditions for: 1) organizational innovation; 2) collaboration and trade; and 3) rethinking the way in which regulations, laws, and property rights operate, which may finally allow the identification of sustainable solutions. Fischer and Pascucci (2017) argued the main challenges are to understand: 1) how to facilitate such transition when it is constrained by an institutional system that is aligned with the status quo of a linear economy; and 2) the role of inter-firm collaborations in this process.

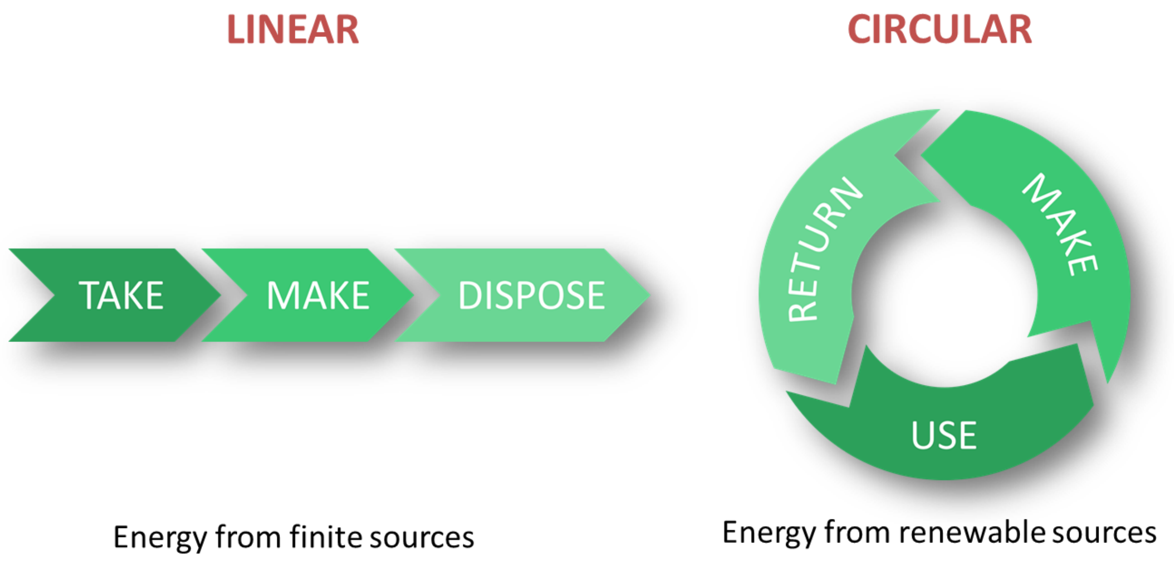

Figure 4: Transition from Linear to Circular Economy
Source: Own elaboration.

The CE's commitment is, briefly, to enable a transition from the take-make-dispose pattern to a use-make-return pattern, as illustrated in Figure 4. Thus, resources are preserved and continuously reintegrated into the production process, as far as necessary and as far as possible. The transition, however, is not an easy task. The current linear model creates institutional barriers that should be removed for enabling a transition in to a CE (Ghisellini et al. 2016). Institutions could shape economic actors' decision-making, and they are at the core of how firms, consumers, and other stakeholders interact and collaborate at a more general level (Fischer 2017). Moreover, Sauvé and others (2016) stated that finding the proper ways to internalize the full environmental costs is certainly an important challenge for the CE. The authors suggested that a set of measures must be put in place to ensure reverse flows of products post-consumption and close the loops when desirable.

III. Debating the Circular Economy

This section and the subsequent sections discuss the concept of circular economy (CE). The concept has become popular among scientists and specialists recently. The latter is evident when noting the rapid increase in peer review publications, institutional publications, and consultancy reports of on the topic during the last years emerging from the different disciplines. Thus, this section is divided into two subsections; the first one reviews the CE concept in the scientific literature, and the second one from the institutional and the grey literature on the topic.

1. Scientific Literature

Although some authors argue that the circular economy (CE) concept has its origins in the sixties, the discussion about the meaning of the concept in the scientific field is much more recent. According to Kirchherr and others (2017) the CE concept is trending both among scholars and practitioners; the authors argued that the latter is shown by the rapid growth of peer-reviewed articles on the topic[4]. The Table 1 presents a summary of previous reviews of the circular economy concept and the corresponding focus.

[4] According to Kirchherr and others (2017) more than 100 articles were published on the topic in 2016, compared to only about 30 articles in 2014.

Table 1: Previous reviews of the CE concept

Year	Authors	Focus
2016	Ghisellini et al.	Summary of 155 articles on CE
2016	Lieder and Rashid	Summary of CE literature on the manufacturing industry
2016	Sauvé et al.	Comparison of CE concept, environmental sciences and sustainable development
2016	Lewandowski	Conceptualization of circular business models
2017	Murray et al.	Comparison of CE concept and sustainable business
2017	Geissdoerfer et al.	Comparison of CE concept and sustainability
2017	Kirchherr et al.	Understanding of CE concept
2017	Pomponi and Moncaster	CE for the Built Environment – Research framework

Source: Own elaboration based on Kirchherr et al. 2017

a) 3R’s Principles of the Circular Economy

The literature review shows a lack of consensus about the principles of the circular economy (CE). In the scientific discussion, the principles are also defined as 3 main "actions" on the basis of which the CE emerges (see Preston 2012, Ghisellini 2016). The so-called 3R's principles are: reduction, reuse and recycle and are described in detail in Table 2. The institutional literature, on the other hand, identifies another set of principles that are discussed at length in the *Grey Literature* section.

Table 2: 3R's Principles.

Principle	Key features
Reuse	The EU[5] (2008) defines it as: "any operation by which products or components that are not waste are used again for the same purpose for which they were conceived". Reuse of products could enable a circular supply chain because, if compared with the manufacture of new products, it could provide greater environmental benefits, namely: fewer resources are required, less energy is needed, and less labour is wanted. Since less products are needed/produced, there's also a reduction recycling or disposal volumes.
Reduction	It aims to minimize the input of primary energy, raw materials and waste through the improvement of efficiency in production[6] and consumption processes e.g. by introducing better technologies, or more compact and lightweight products, simplified packaging, more efficient household appliances, a simpler lifestyle, among other reduction strategies.
Recycle	The EU (2008) defines it as: "any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes. It includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations". It could also decrease the environmental impact related to product manufacturing. Recycling of waste offers the opportunity to benefit from still usable resources and reduce the quantity of waste that need to be treated and or/disposed of.

Source: Own Elaboration based on Ghisellini (2016:15-16)

The 3R principles have a strong environmental motivation and are focused mainly in two processes within the supply chain. On the one hand, the reduction of raw material consumption; on the other hand, the reduction of environmental impacts generated by the treatment and disposal of waste. Thus, the implementation of 3R principles seeks to generate a closed loop within the supply chain through the reincorporation of materials and products in the supply chain for as many times as possible.

Some critics argued that the CE is, in general, is identified with the recycling principle, although that principle is not precisely its strength. Accordingly, Stahel (2013, 2014 in Ghisellini 2016) argued that

[5] Directive 2008/98/EC, available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32008L0098&from=EN, checked 30.07.2018.
[6] The so called 'eco-efficiency' concept, discussed in the *Eco-efficiency* section.

the recycling principle, may be the least sustainable solution compared to the other principles of the circular economy (namely, reduction and reuse) in terms of resource efficiency and profitability.

From a critical perspective it is argued that processes such as recycling waste cannot last forever. In some cases, recycling is limited by nature (entropy law), material complexity, and abuse[7] (Stahel 2013 in Ghisellini 2016). While the foregoing also applies to the reuse principle, both principles share the general objective of waste reduction. In the built environment research, different alternatives to the traditional construction practice that can significantly contribute to the reduction could be found. Accordingly, ARUP (2018) mention some innovations in the value chain that are already being implemented in the construction of CE inspired buildings, namely: 3D-printing, reuse of structural steel, and recyclable insulation with recycled content. Moreover, ARUP's report showed certain business models that could enable a paradigm shift, such as: take-back schemes, cradle-to-cradle certified building materials, and facade leasing.

Taking the discussion further that the 3R's principles, Kirchherr and others (2017) distinguished several 'R' principles or frameworks have been used in academia as well as by practitioners. Accordingly, the 4R framework which is at the core of the European Union (EU) Waste Framework Directive (EU 2008) introducing the 'Recover' principle as the fourth R. Furthermore, Potting and others (2017) identified a set of so-called 'R-strategies', that have been developed to achieve less resource and material consumption in product chains and could make economy more circular. The Figure 5 shows a list of the R-strategies analysed by Potting and others in the Netherlands context. The authors argued that the R-list present a range of strategies ordered from high circularity (low R-number) to low circularity (high R-number). R0 and R1 strategies decrease the consumption of natural resources and materials applied in a product chain by less product being needed for delivering a same function (Potting et al. 2017).

[7] Regarding the number of times a material can be recycled, according to Ghisellini (2016), cellulose fibres, for example, may be recycled 4e6 times, contrary to metals that could be recycled unlimited. Moreover, low levels of recycling are achieved for Rare Earth metals as it is hard to develop economies of scale, while some types of plastic waste are not recyclable due to the presence of contaminants as ink and metals (Prendeville et al. 2014 in Ghisellini 2016).

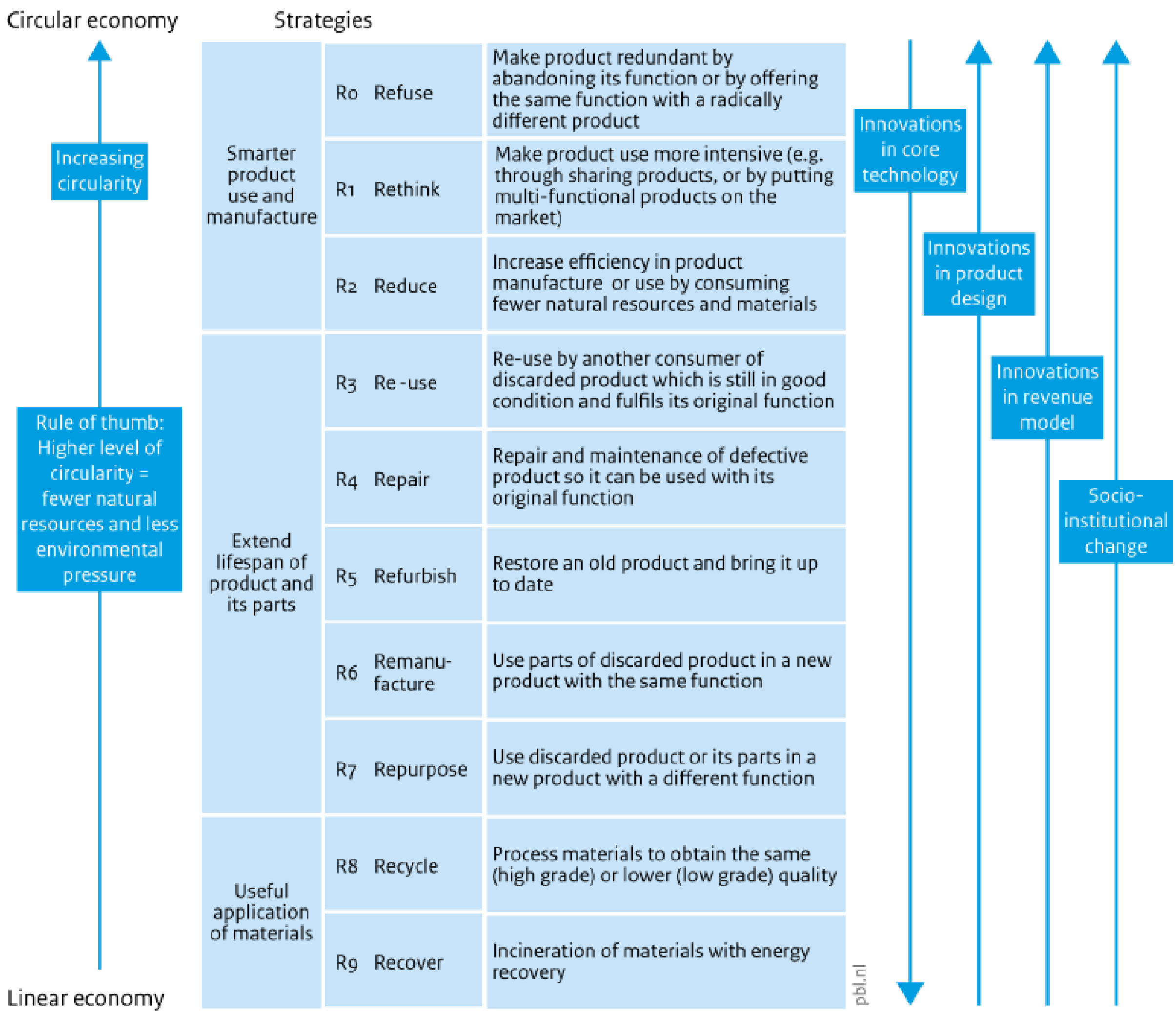

Figure 5: Circularity strategies within the production chain in order of priority.
Source: Potting et al. (2017:5)

b) Systems Perspective and Levels of Analysis

The work of Kirchherr and others (2017) outlined the systems perspective (SP) as a core principle of the circular economy (CE). From their point of view, the SP may have replaced the R-framework mentioned in the previous section. Such assumption is based on a frequency analysis of CE definitions in peer reviewed publications where SP was explicated in 42% of definitions examined with Charonis (2012:2 in Kirchherr et al. 2017) who argues that CE "is understood as a system that is designed to be restorative and regenerative". Moreover, Kirchherr noted a significant emphasis on the SP in CE definitions since 2012 and onwards, possibly induced by Ellen MacArthur Foundation (2013b) that mentions it in their understanding of the CE (see the *Grey Literature* section).

Table 3: Levels of Organization from a Systems Perspective

Level/System	Key features
Macro	related to social aspects; is where production and consumption become integrated; incentive for CE must be phased in with societal and stakeholders' interests.
Meso	looks at interactions among different firms or industries; each benefit from by-products; is analogous to ecological industry concepts.
Micro	focuses on a particular firm or industry; based on relatively standard sustainable development initiatives; applied through a linear thinking; aims at lowering firms' environmental footprint.

Source: Own elaboration based on Sauvé et al. 2016, Kirchherr et al. 2017

Considering a SP also implies different levels of analysis and organization, the relevant literature shows. The Table 3provides an overview on three different levels of organization where fundamental changes should simultaneously happen at the micro, meso and macro system, which underscores the holistic systemic change that CE requires. The work of Kirchherr and others (2017) emphasizes the SP focus on the macro-system, whereas the meso-systems level is even more prominent, indicating that CE is since 2012 increasingly seen as an endeavour that requires efforts particularly at the regional level.

Other authors propose a gradation in the CE concept, setting the highest level (the macro-level) very close to sustainable development in terms policy implementation. Using China as a case study, Sauvé and others (2016) divide the CE into three levels of organization as mentioned before: micro, meso and macro. The authors pointed out that China, highly stimulated by the country's resource supply and environmental problems, has been one of the early adopters of CE as a national development model and included a set of instruments applied at each level.

Finally, the research of Ghisellini and others (2016) analysed the CE development in cities, provinces or regions. The authors suggested four different urban systems that required a particular focus when implementing CE driven initiatives, namely: the industrial system, the infrastructure system delivering services, the cultural framework, and the social system. In general, the aforementioned urban systems belong to the micro and meso organizational levels in Kirchherr's and Sauvé's perspective.

2. Grey Literature

The Circular Economy (CE) concept was initially proposed outside government and to date it has been driven predominantly by academics, NGOs and private business[8] (Andrews 2015).

Accordingly, the Ellen MacArthur Foundation (EMF)[9] is without question one of the leading referents when it comes to pushing the transition to a CE. The Foundation has published a range of publications on the topic, including a book by Webster (2015) and a series of reports (see EMF 2012, 2013a, 2013b, 2014, 2015a, 2015b, 2015c, 2016a, 2016b, 2017). Thus, the Foundation has framed the most renowned definition within the current grey literature, characterising, more than defining CE as:

- "a circular economy is one that is restorative and regenerative by design and aims to keep products, components, and materials at their highest utility and value at all times, distinguishing between technical and biological cycles" (EMF 2015a:2)

Similarly, the following CE definitions are to be found in the grey literature:

- "realization of [a] closed loop material flow in the whole economic system" (Geng and Doberstein 2008: 231);
- "a circular economy is one that is restorative by design, and which aims to keep products, components and materials at their highest utility and value, at all times" (Webster 2015:16)
- "the core of [the CE] is the circular (closed) flow of materials and the use of raw materials and energy through multiple phases" (Yuan et al. 2008: 5);
- "design and business model strategies [that are] slowing, closing, and narrowing resource loops" (Bocken et al. 2016:309).

[8] Accordingly, Andrews (2015) claimed that over 90 non-governmental stakeholders including retailers have joined The Circular Economy 100, a scheme to share best practice and develop a CE. The later reflects the need for enabling the stakeholder engagement for pushing the CE forward, which is a relevant task of this research. The Circular Economy 100 could provide an idea of the stakeholder constellation, their roles, and their initial interests on the topic. On this basis, similar actors are to be found in the German and Berlin contexts. For further information, see The Circular Economy 100 (2016).

[9] The EMF is a charity dedicated to promoting the global transition to the CE. The Foundation also acts as a collaborative hub for businesses, policy makers, and academia.

The definitions above, stressed the holistic and systemic approaches (discussed in the *Systems Perspective and Levels of Analysis* section) and emphasised the need for closing the loops within the supply chain with the support of innovative business models. Moreover, based on the contributions listed above, Geissdoerfer and others (2017) provide a more comprehensive CE definition, namely:

- "we define the CE as a regenerative system in which resource input and waste, emission, and energy leakage are minimised by slowing, closing, and narrowing material and energy loops. This can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling" (Geissdoerfer et al. 2017:759).

The latter CE definition is in line the discussion about the R's framework in the *3R's Principles of the Circular Economy* section. Therefore, the need for considering the CE as a holistic approach that draws from the interaction of key closed loops is pointed out as a relevant aspect in the grey literature.

Drawing on earlier works, the Foundation developed the system, or a so-called 'butterfly' diagram based on the notion that material flows can be divided into two interacting loops: the technical and biological resource cycles, as described in Figure 6. According to Smol and others (2015) within a CE, products and industrial processes are designed in such a way that materials are nutrients in a perpetual flow of either biological or technical metabolisms. The subsections below describe both cycles from the CE perspective in detail.

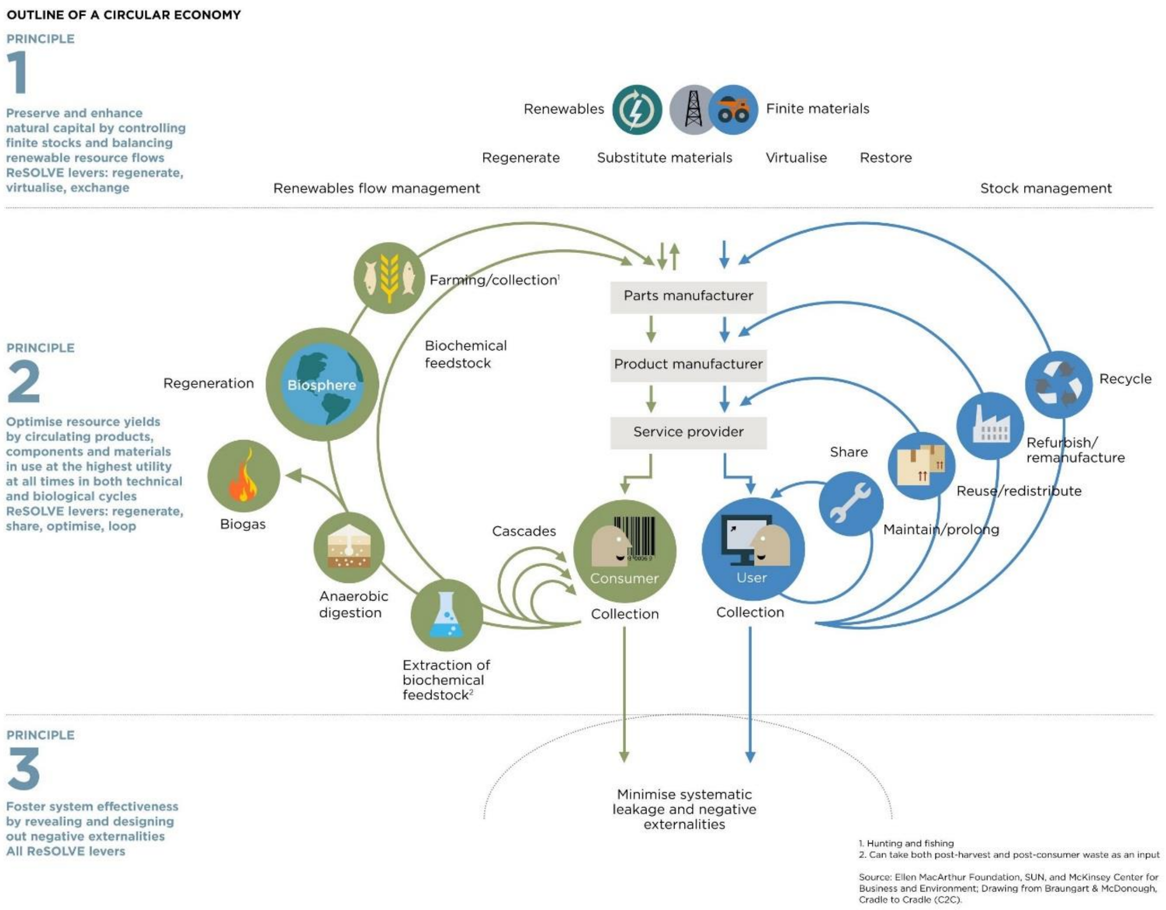

Figure 6: Circular Economy Value Chain

Source: Ellen McArthur Foundation (2016:5)

a) Biological Cycle

According to ARUP (2016) within the biological cycle (on the left side of the diagram), renewable and plant-based resources are used, regenerated and safely returned to the biosphere — as in composting or anaerobic digestion. Moreover, biological nutrients are biodegradable materials that are safe to return to the biosphere to feed biological processes, such as food, cotton, and timber (Smol et al. 2015).

b) Technical Cycle

Within the technical cycle (on the right side of the diagram), man-made products are designed so that at the end of their service life – when they can no longer be repaired and reused for their original purpose their components are extracted and reused, or re manufactured into new products. This avoids sending waste to landfill and creates a closed-loop cycle. Technical nutrients are materials that can remain in a closed-loop system of manufacturing, material recovery, and reuse (Tukker 2013). These are often synthetic or mineral materials and are used in many consumer goods such as electronics, furniture, and cars.

c) Circular Economy Principles

The bio-economy is a growing sector with the potential to lower raw materials consumption, reduce waste and generate higher-value products for sustainable biological re-use (ARUP 2016). The latter could significantly contribute to achieving a CE. Accordingly, the Foundation suggested that within the CE system, the use of toxic materials should be omitted, especially from products that are consumed or returned to the biological cycle (EMF 2013a). In an ideal CE, products are designed while considering possibilities to reuse products, cascade (parts of) products, and to harvest pure materials at the end of a product's life cycle (EMF 2013a). Finally, according to Fischer (2017) the required energy to support activities in both cycles should always come from a renewable source.

According to the Ellen McArthur Foundation, the CE rests on three principles, as detailed in the Table 4 below.

Table 4: EMF's Circular Economy Principles.

Principle	Key features
Preserve and enhance natural capital by controlling finite stocks and balancing renewable resource flows	dematerialising utility – delivering utility virtually; resources are selected wisely; technologies and processes use renewable or better-performing resources; natural capital is enhanced by encouraging flows of nutrients within the system.
Optimise resource yields by circulating products, components, and materials at the highest utility at all times in both technical and biological cycles	designing for remanufacturing, refurbishing, and recycling; keeping technical components and materials circulating in; tighter, inner loops (e.g. maintenance, rather than recycling); preserving more embedded energy and other value; extending product life and optimising reuse; Sharing in turn increases product utilisation; encourage biological nutrients to re-enter the biosphere safely for decomposition; products are designed by intention to be consumed or metabolised by the economy and regenerate new resource value.
Foster system effectiveness by revealing and designing out negative externalities	reducing damage to systems and areas such as food, mobility, shelter, education, health, and entertainment; managing externalities, such as land use, air, water and noise pollution, and the release of toxic substances.

Source: *Own elaboration based on EMF (2015:5-7)*

In cases where these CE principles are fully applied, the major objectives, as outlined below by Kobza (2016:113–114), should occur:

- Waste does not exist; nature restores biological materials via composting or anaerobic digestion. Technical materials are designed for a circular purpose and thus they can be reused, remanufactured or recycled in order to keep their resource and energy value at maximum level within the system;
- Diversity is an advantage; a larger number of businesses implies a greater variety of economic opportunities and thus it builds strengths to economic changes;
- Use of renewable resources and energies; due to their capacity to be always available naturally and being more environmentally-friendly. Moreover, they tend to be less cost intensive and decrease the global demand of primary materials at the global market;

- Systemic approach; economy is a network and involves all stakeholders.

Finally, the review of grey literature showed that the CE concept has also gained traction with policy-makers, influencing governments and intergovernmental agencies at the local, regional, national, and international level. According to Geissdoerfer (2017:759) Germany was a pioneer in integrating CE into national laws, as early as 1996, with the enactment of the "Closed Substance Cycle and Waste Management Act" (*Kreislaufwirtschafts- und Abfallgesetz, KrW-/AbfG*[10]); although the instrument focuses in waste management and recycling, mainly, it already shows interesting steps towards the right direction. This was followed by Japan's 2002 "Basic Law for Establishing a Recycling-Based Society" issued by the Japanese Environment Agency[11], and China's 2009 "Circular Economy Promotion Law of the People's Republic of China[12]", that was mentioned in the sections above. Moreover, supranational bodies have also incorporated circular economy concerns e most notably the EU's "2018 Circular Economy Package[13]".

Nonetheless, according to Preston (2012) the term 'circular economy' is applied inconsistently by governments and companies, despite growing interest in the link between resource efficiency and competitiveness. The latter calls for developing a common understanding of CE and its key components would help to lay the groundwork for wider take-up of the concept, encourage cooperation and avoid confusion.

[10] Available at https://germanlawarchive.iuscomp.org/?p=303, checked 30/07/2018.
[11] Available at http://www.env.go.jp/recycle/low-e.html, checked 30/07/2018.
[12] Available at http://www.lawinfochina.com/display.aspx?id=7025&lib=law, checked 30/07/2018.
[13] Available at http://ec.europa.eu/environment/circular-economy/index_en.htm, checked 30/07/2018.

IV. Key CE Concepts for the Built Environment Research

As discussed in the previous sections, activities along the supply chain in the construction industry generate significant impacts. Beyond the environmental impacts, energy consumption - and its emissions associated - and resource consumption of the sector are also significant. The previous sections also discuss the need for a paradigm shift, from linear to circular, in the current economic model that also involves the construction industry; the need for a comprehensive and holistic transition was also stressed. The shift should be able to address the existing complexity between extractive, productive, and manufacture activities, and business models within the construction industry's supply chain. On the other hand, the literature review accounts for inherent characteristics of the industry that could prevent the transition towards the circularity of the industry; mainly: conservative structures in the construction industry and the traditional construction practice which contribute significantly to the existing linear model. Thus, when looking closely at the construction industry became clear the need to explore innovative concepts that enable a transition in the value chain towards a more sustainable and resilient model. This section and the following subsections discuss concepts of the circular economy, found in the theoretical discussion, that could contribute to the transition towards the circularity of the construction industry.

For the purposes of the Kopernikus E-Navi Project, it is intended to discuss the concepts found in the theoretical discussion – presented later in the *Further work* section – with professionals and experts within the construction sector in Berlin. Therefore, it is relevant for the research to capture in the next phase, through a qualitative inquiry, key stakeholders' opinions and to discuss the potential offered by the circular economy as an alternative model to the current linear model. Moreover, it will be relevant to identify, in the opinion of these actors, the main barriers to a potential implementation of concepts and business models inspired in the circular economy. Based on this information, it is intended to develop in a later stage a set of recommendations for public policy development that could enable a paradigm shift in the construction practice towards the circularity of the industry.

1. Cradle-to-cradle inspired buildings

The Cradle-to-cradle (C2C) concept was developed by Braungart and McDonough (2002). According to Wilts (2016) the concept is more comprehensive than the basic circular economy concept or the blue economy one. The concept aims at dividing materials and resources into two cycles, the biological and the technical (see Figure 7). In both cycles, all materials should be completely environmentally friendly and able to circulate permanently within the supply chain. Waste materials in an old product become the "food" for a new product. In the biological cycle materials are returned to the biosphere in the form of compost or other nutrients, from which new materials can be created. In the technical cycle materials that are not used up during use in the product can be reprocessed to allow them to be used in a new product. Moreover, building appliances should also be considered under a lease scheme (as described further in the following sections) where service providers (heating, hot water, etc.) are responsible for updating building´s appliances whenever this is necessary.

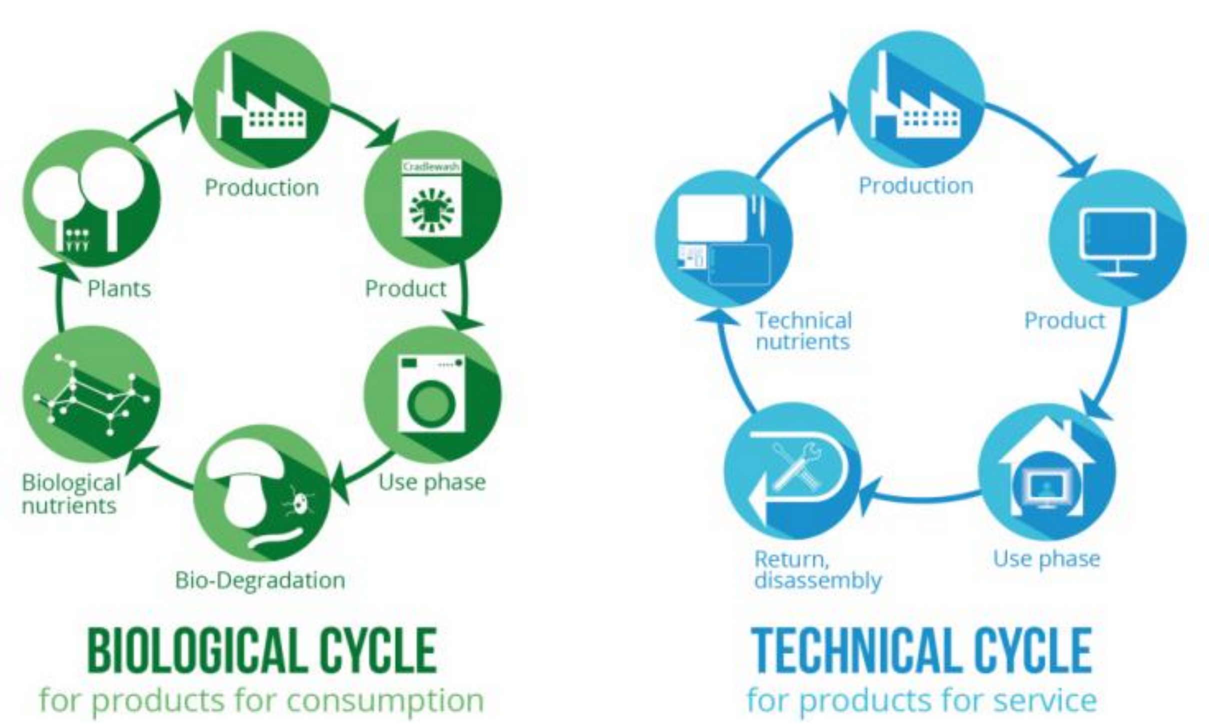

Figure 7: C2C – Two nutrient cycles.
Source: https://www.epea.com/cradle-to-cradle/

The relevance of C2C concept in the built environment is that it considers the use of energy (and its related CO_2 emissions) in the construction materials manufacturing phase as well as in the use phase of the buildings. According to Wilts (2016) all materials should be fully preserved or completely degradable, aiming at not producing waste at all. Moreover, during recycling process the properties of the substances should ideally be improved. In the specific case of construction materials, this implies thinking carefully about the use of materials in the different phases of the construction process. Organic components of a product, like wooden building components, should end up on the compost and thus in the biological cycle. Moreover, durable goods are designed in such way, that they can be fully reused, for example by chemical or mechanical processes. The function of the building elements determines, in many cases, the useful life of the construction materials. On the one hand, there are materials that have a long lifespan, such as the structural elements of the building, and others that have a shorter lifespan, such as finishes on walls and floors, which need frequent maintenance and replacement. Thus, it is relevant to consider, from the design stage of the building, how and when the useful life of construction materials, building components, and the building itself will end their lifecycle. In order to get to the raw materials, the companies have to take back the products. For example, this would be possible by a deposit system or by renting or leasing of products. In the field of residential construction, the above is relevant depending on the business model in which construction companies and housing associations deal with the management of their real estate products. In the case of state-owned housing associations in Berlin, as in the case of HOWOGE and GESOBAU, the responsibility for the maintenance and reconditioning of buildings is the responsibility of the company and not of the tenants. In other business models, the owners of the property have the responsibility of maintenance and reconditioning. When the user of the property is not the owner, the above creates the so-called "split incentives" (Ostertag 2012), or "principal-agent" (Papineau 2015) phenomena.

According to McDonough and Braungart (2002), another relevant aspect is that the C2C concept involves a complete switch from fossil fuels to solar energy or other renewable energy sources. The later emphasizes the relevance of the implementation of the C2C concept in the decarbonization of the sector. Thus, the idea of C2C-inspired buildings arises as a certification system[14] for providing architects and builders to assess the building elements that could introduce C2C criteria. Such certification system can be complementary to other building certification systems, such as DGNB, LEED or BREEAM[15]

[14] Further information about the C2C certification scheme for the Built environment could be found at: https://www.c2ccertified.org/drive-change/built-environment)
[15] A detailed analysis and discussion about building certifications schemes, like DGNB, LEED or BREEAM, could be found in the work of Mercado (2015).

The Figure 8 shows some elements that a C2C-inspired building incorporates in its design and construction. Such elements set them apart from traditionally constructed buildings. Among other characteristics, the following stand out:

- Use as few materials as possible that can circulate in biological or technical production cycles, thus serve as a resource while their effects are positive for humans and the environment.
- Use of renewable energies, C2C inspired buildings should provide more energy over the long term than they consume – creating an energy-positive building.
- Use of bioclimatic design techniques to take advantage of local conditions.

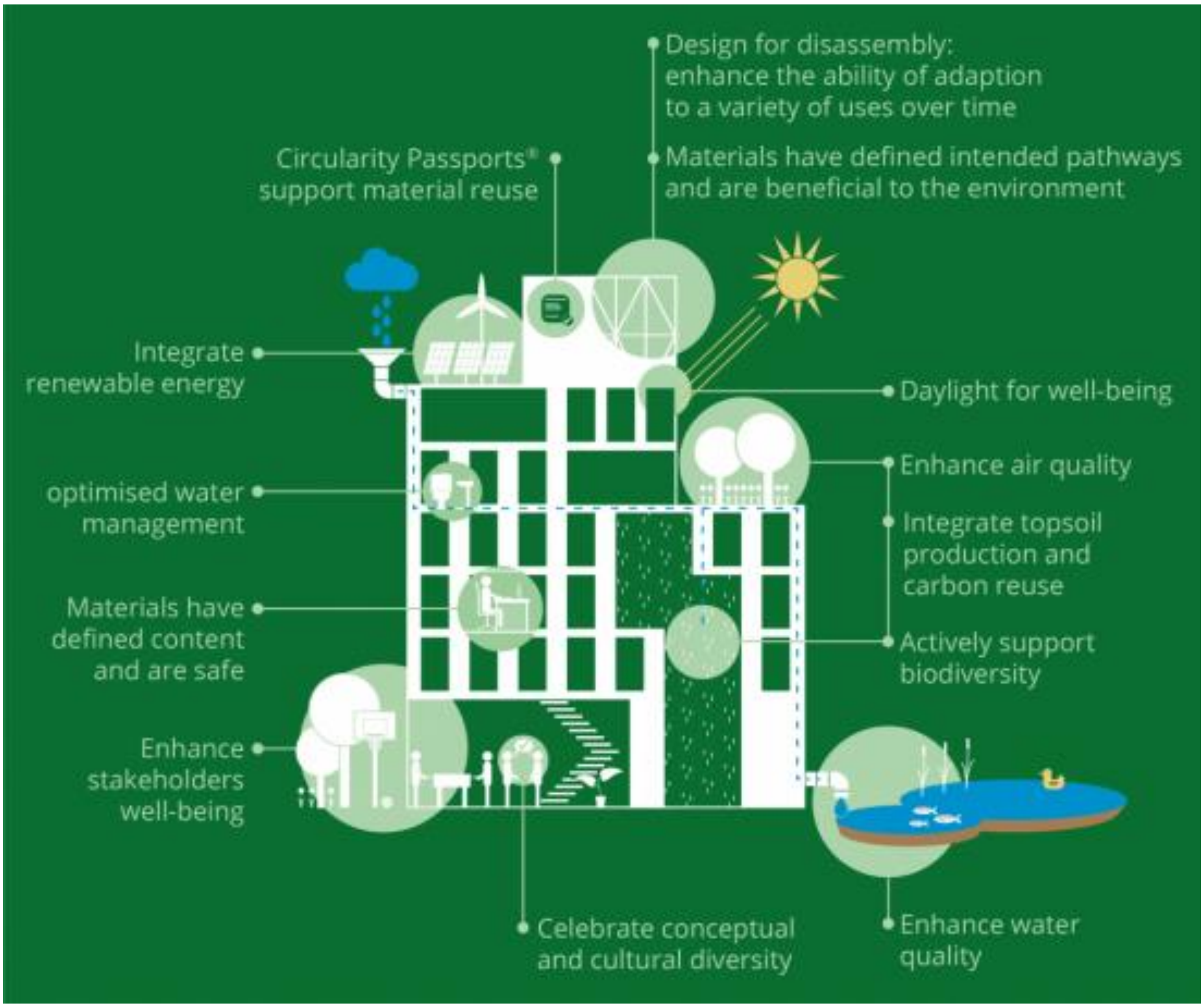

Figure 8: C2C-Inspired Building

Source: https://www.epea.com/c2c-sectors/buildings/

The literature review suggests great scepticism among critics whether the C2C concept can really be implemented or if it is always sustainable. Bjørn and Strandesen (2011) pointed out the most relevant criticism arguments are twofold: too expensive and not feasible for all products. Another valid argument is focused in lack of detail on the implementation of the concept in the production chain which calls for an active stakeholder involvement along the value chain.

2. Zero Waste

Despite the growing global recognition of the environmental impacts associated with the generation and management of waste across industries, the construction industry, and, in particular, the construction and demolition (C&D) sector, continues to generate a large amount of waste (Chileshe et al. 2012). The global concern is also reflected in the European context. According to Gonçalves (2008) Europeans need between 2 and 3 planets worth of resources to sustain their current lifestyles. Consequently, Europeans' resource consumption has led to generate 2.7 billion tonnes of waste in 2012, and only 40% was reused, recycled, composted, or digested (EMF 2013). Moreover, C&D waste[16] accounts for approximately 25-30% of all waste arising in the EU (EC 2016). Accordingly, Chileshe and others (2012) argued the reasons for seeking a state of zero waste in the built environment become clear in terms of reducing costs and environmental load and achieving a closed-loop material flow by means of resource recovery.

Due to the complexity of the building process, reducing the amount of waste is about far more than just ordering the right quantity of construction materials. According to ARUP & BAM's report (2016) current construction practices have waste built into the buildings' design. This become evident where standard material sizes are used, for example sheet materials and traditional masonry. The later calls for implementing innovative concepts and taking coordinated actions aimed at significantly reduce the sector's waste production.

The zero waste (ZW) concept seeks similar goals as C2C, namely: the reduction of waste generated in the built environment. Moreover, ZW can also be regarded as a target to be achieved using various circular economy approaches (Wilts 2016). The so-called ZW-movement (see Wilts 2016, Chileshe et al. 2012) is now global and brings together quite different aspects extending from simply reducing

[16] Construction waste is defined as: *"building debris, rubble, earth, concrete, steel, timber, and mixed site clearance materials, arising from various construction activities including land excavation or formation, civil and building construction, site clearance, demolition activities, roadwork, and building renovation"* (Shen et al. 2014 in Chileshe et al. 2012:286).

residual landfill waste through to comprehensive waste-avoiding product design. From the built environment perspective, the above implies thinking, early from the design phase of a building, the potential amount of waste that a building could generate during its life-cycle and the way in which it will be disposed. Thus, ZW is relevant when considering the demolition of buildings, since they constitute a significant portion of the construction waste generated by the sector. Moreover, Chileshe et al. (2012) suggest some drivers for achieving a “state of zero waste” in the construction sector, namely: building procurement teams, empowered work teams, lean designing, education and training, awareness of waste-management systems, senior management commitment, technological innovation, changes to organizational culture and individual behaviour change.

Within the context of the construction-project life-cycle, construction waste is further described by Chileshe and others (2012) as the amount that does not add value to the process and would normally end up in landfill. According to the authors, other C&D waste is generated during the occupancy and operation of buildings, and in the last phase of a project´s life-cycle, namely building demolition. In the context of buildings, Lehmann (2010) argues that ZW means that buildings are fully demountable and fully recyclable at the end of their life-cycle, so that the site can return to be a green field site after use. Henceforth, ZW could be understood as a philosophy that would vary according to different organizations' way of thinking.

Within the context of construction industry, Chileshe and others (2012) note reference to the age-old problem of waste management (WM) and the construction industry's tendency to be averse to change. The later shows one of the major difficulties for introducing innovations in the construction practice. Moreover, an effective implementation of WM could reduce the embodied energy used for the manufacture and transportation of materials, which is a significant share of energy consumption in buildings' life-cycle (see Troy et al. (2003) and Yan et al. (2010) in Chileshe et al. 2012).

3. Blue Economy

The blue economy is considered in the literature as an economic philosophy. It was first introduced in 1994 by Prof. Gunter Pauli when asked by the United Nations to reflect on the business models of the future in preparation for COP3 in Japan[17]. Nowadays, substantiated by over 180 concrete cases[18], it is increasingly clear that it is possible to generate more revenue, while generating more jobs and still compete on the global market. It basically aims at doing sustainability better, by implementing a zero-waste philosophy (discussed at length in the *Zero Waste* section) and innovative business models inspired by nature jobs and stable economies that are 100% sustainable can be created.

According to Pauli (2010) the power of the blue economy is that is injects money back into the local economy, and contrary to traditional belief, it offers high quality products at a lower cost price. The blue economy goes, therefore, beyond the Globalized and the Green Economy and proposes a shift towards a competitive business model that responds to the basic needs of all with what is locally available. It highlights the need for a model that allows producers to offer the best at the lowest prices by introducing innovations that generate multiple benefits, not just increased profits.

Pauli (2010) presents the most tantalizing prospects for realizing a low-carbon, resource-efficient, and competitive economy in the 21st century. It is remarkable that some of the greatest opportunities for jobs will come from replicating the waste-free efficiency of ecosystems. Pauli encourages to look at the natural world in order to solve many of the sustainability challenges humanity faces. Moreover, the blue economy described by Pauli (2010), underpins business models based on the cascades found in ecosystems[19], where the waste product of one metabolic process forms the input for the

[17] The COP3, the Conference of Parties to the UNFCCC, took place in Kyoto in December 1997, during this meeting the Kyoto Protocol was signed.
[18] These self-sustaining projects ranging from the regeneration of 8 hectares of rainforest in the Colombian savannah to the transformation of waste rock into paper that can be recycled for thousands of years. They offer strong business models that generate jobs and strengthen local economies while being 100% sustainable. See Pauli (2010) for detailed information about the cases. Many of the cases are related to construction and energy use of buildings, e.g.: Case 14: Black to stay Cold; Case 15: Hot Water for 25 Years (minimum); Case 37: Insulation Paint; Case 44: Building with Bamboo; Case 52: Branding Waste; Case 76: Cellulose as Insulation*;* to name a few.
[19] In this sense, the blue economy proposes principles derived/inspired by nature. According to Pauli (2010) the blue economy has its roots in concepts like deep ecology, permaculture, and sustainability that planted early seeds of green thinking. The author argues that such ideas though us to appreciate the use of sustainable materials in our structures and products. Although, Pauli states further, we have begun to understand the importance of sustainable process few know how to make it economically viable. If one can

next. When applied to industry that means returning by-products and waste to the process and circulating them as long as possible. Extending the life-cycle of resources and materials can reduce waste (Wilts 2016).

However, the implementation of blue economy principles in existing business models also responds to the characteristics (mainly size, customer portfolio, and experience) of the companies that operate in the market. According to Pauli (2010) the Blue Economy is not tailored to the large corporations, which have an established business model that will be hard to change. It rather inspires the young and the entrepreneurial minds and offers a broad platform of innovative ideas that have been implemented somewhere in the world to demonstrate the potential of implementing alternative business models.

4. Eco-efficiency

The term 'eco-efficiency' was coined by the World Business Council for Sustainable Development (WBCSD) in its 1992 publication called 'Changing Course'. The WBCSD[20] argues eco-efficiency is reached by the delivery of competitively priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impacts and resource intensity throughout the life-cycle, to a level in line with the earth's estimated carrying capacity (BCSD 1992). In short, eco-efficiency it is concerned with creating more value with less impact. Hence, the reduction in ecological impacts translates into an increase in resource productivity, which in turn can create competitive advantage.

According to Ghisellini (2016) eco-efficiency could also be understood as a business concept, which focuses on the economic and environmental dimension of sustainability and disregarding the social

begin to understand and utilize nature´s brilliance, economy, and simplicity, one can emulate the functionality embedded in the logic of ecosystems and achieve success unrivalled by current massively globalized industries.

[20] The following three objectives are defined by the WBCSD regarding eco-efficiency: 1) Reduce the consumption of resources. The material and energy consumption should be reduced through enhancing recyclability. Producing products with higher quality and longer life times may also lead to improvements within the area; 2) Reduce the impact on nature. Improvements can be performed using renewable resources which are sustainably managed, as well as minimizing emissions, waste disposal, and toxic substances; and 3) Provide customers with higher quality products and services. The customer benefit can be improved through providing the user additional services of the product such as e.g. functionality or/and increased overall life time. It is however important that higher customer benefit must not interfere with the two former objectives (see BCSD 1992).

dimension. A contrasting concept, according to Ness (2008 in Ghisellini 2016:15) is "resource efficiency", which implies resource reduction and increasing economic and social well-being at the same time. The later presents an anthropocentric approach to resource consumption, while eco-efficiency strives for an economic- and bio-centric one.

Moreover, eco-efficiency describes a vision to produce economically valuable goods and services while reducing the ecological impacts of manufacturing and production. In other words, eco-efficiency means producing more with less. Critical aspects of eco-efficiency, according to WBSCSD (see BCSD 1992, and DeSimone & Popoff 1997), are:

- A reduction in the material intensity of goods or services;
- A reduction in the energy intensity of goods or services;
- Reduced dispersion of toxic materials;
- Enhanced material recyclability;
- Maximized sustainable use of renewable resources;
- Extended durability of products;
- Increased service intensity of goods and services.

The abovementioned critical aspects are relevant for the construction industry and for the built environment, both because of the use of resources for construction materials production and manufacture, as well as for the services provided by the housing sector.

The eco-efficiency of a building, on the other hand, is defined as the ratio of the building performance and conformity to the environmental pressures induced by the technical solution that fulfil the client's requirements (Häkkinen et al. n.d.). These requirements cover both the performance of the building[21] and its conformity[22]. From this perspective, the building eco-efficiency is studied with help of output - input approach, where the output is dealt with based on building performance and con-

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[21] Indicators for performance of the building are: indoor condition, service life, adaptability, safety, comfort, accessibility, and usability (Häkkinen et al. n.d.:6)
[22] Indicators of conformity of the building are: location, spaces, and services (Häkkinen et al. n.d.:6)

formity, while the input is dealt with on basis of environmental pressures. Thus, eco-efficient construction brings about the required performance of a building with the least unfavourable ecological and economic impact.

5. Sufficiency

The Wuppertal Institute[23] in Germany argues that 'sufficiency' (from Latin sufficere = sufficient) stands for an 'intelligent and prudent use of resources'[24]. While efficiency and consistency – concepts discussed below – are already common measures in sustainable construction, sufficiency has not yet established itself. Nonetheless, according to the Institute, only with a moderate and restrained handling of building materials as well as the existing buildings, the climate goals can be achieved by 2050 and avoid rebound effects.

The term 'sufficiency' is defined in different ways in the literature, according to Wilts and Palzkill (2015). Accordingly, Gröne (2016) claims there is no common definition of 'sufficiency' and discusses the concept in contrast to the concepts of 'efficiency' and 'consistency', arguing that the three concepts are the pillars of sustainable development strategies. The term 'efficiency' is described in the literature as a course of action where the input-output relation is improved; it means doing something better. The term 'consistency', on the other hand, seeks qualitative changes in production and consumption by implementing: resource substitution, adaptation to renewable resources, and circular economy (Huber 2000 in Gröne 2016); it basically means doing something different.

From a more environmental point of view, Fischer and Grießhammer (2013) argued the term 'sufficiency' refers to changes in consumption patterns which facilitate operation within the ecological bearing capacity of the earth, whereby utility aspects of consumption are changing. The later stresses the significant role that a sustainable resource consumption might play in achieving sufficiency. Moreover, according to Gröne (2016) 'sufficiency' implies a voluntary demand reduction of energy intensive goods and services; furthermore, it calls into consideration the absolute level of output or consumption per se and not in relation to the input (Muller 2009 in Gröne 2016).

[23] The research focus of the Wuppertal Institute is on resource, climate and energy challenges in their interactions with the economy and society. At the institute, interest is paid to innovations for the decoupling of natural consumption and prosperity development.
[24] Source: www.wupperinst.org/a/wi/a/s/ad/3048/

According to Schneidewind and Zahrnt (2014 in Gröne 2016) sufficiency as a concept raises the question for levels of 'enough' and helps to explore the potential of making it easier to live a good life. In a nutshell, sufficiency means doing less/enough.

The research of Stengel (2013) explores sufficiency strategies in different sectors of the economy. According to the author, achieving sufficiency in the housing sector does not seem to be impossible, especially since the number of inhabitants is declining in many Western countries and new multi-family buildings and houses in most cases might not be necessary. When referring to the condition of the buildings, refurbishing and energy-retrofitting of the existing building stock – in many regions with low or shrinking population growth – seems to be ecologically more appropriate than the space-intensive, energy and raw material consuming construction of new buildings – even if they are passive houses or entire eco-settlements. Moreover, electric appliances and the user's energy behaviour could also play a role in achieving sufficiency in the housing sector (Stengel 2013:58-59). The potentials for implementing sufficiency strategies become clearer when considering the resource consumption of the construction industry in a global comparison (as described in *The limits of Resource Consumption* section). As a result, knowledge about material and composites and their impact on the life-cycle of buildings gain in importance to the whole construction industry.

The specialized literature identifies social and cultural aspects of the population/society that may play a decisive role in determining the sufficiency thresholds. In general, a predominant role is given to what is meant by 'sufficient' - which results from a complex social construct that is defined and measured based on individual consumption standards. In terms of housing, 'sufficiency' defines, among other normative values, the minimum surface and the quality of living spaces. Obviously, these thresholds should also be defined in conjunction with standards within public policy, however, sometimes it is also the private sector – through the supply of real estate products – who defines them. Thus, the consumer takes from the real estate offer what best suits their preferences and economic possibilities; usually the last prevails before the first.

V. Circular Business Models

The previous sections discuss the need for a change in the way resources are consumed worldwide to sustain the current unsustainable economic model. In the built environment and in the construction industry, the foregoing calls for a paradigm shift in the construction practice that enables a more efficient use of resources along the value chain in the industry. This section and subsections discuss different business models that could improve resource management and decrease waste production, but also reduce costs and improve the performance of companies operating in the construction industry.

A paradigm shift in the current model, from linear to circular, could generate relevant benefits for key players within the construction industry. The report of ARUP and BAM (2016) identifies some benefits that could be obtained when implementing different CBMs in different stages of the value chain. The Figure 9 shows the potential benefits that the implementation of CBMs could generate for four groups of key actors within the construction industry, compared to the linear model.

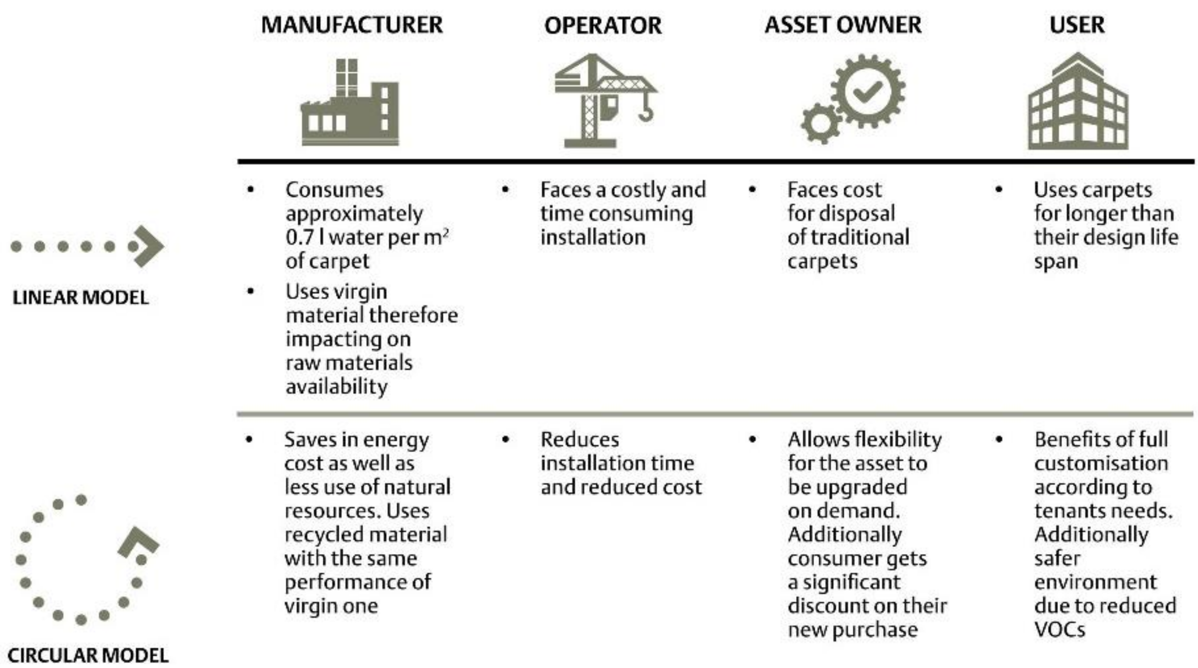

Figure 9: Benefits to stakeholders in Circular Business Models.
Source: ARUP & BAM (2016:28)

In the literature review, business models were found in different implementation phases during the whole life-cycle of a building/product; either in its initial phase, as ideas or innovative concepts, or already during the operation or end-of-life phases. Moreover, it is thought that CBMs could become competitive in the industry by taking advantage of the potential offered by the circular economy in the sector. However, the specialized literature also discusses areas of research or strategic business perspectives that allow accelerating the process of adopting principles of the circular economy in the construction industry, as described in the following sections.

Considering that the circular economy is about moving from a linear system of waste to a circular one where resources are used endless, its implementation in the construction industry allows achieving relevant benefits in the sector. Such more regenerative model affords a viable business opportunity to successfully tackle environmental priorities, drive performance, innovation and competitiveness, and stimulate economic growth and development. Embracing such business opportunity in the housing industry, calls for innovation in the prevailing business models. The literature review reflects that the idea and concept of the so-called Circular Business Models (CBM) can be traced to the early 1950s (see ARUP & BAM 2016, Bocken et al. 2014, EMF 2016, Fischer & Pascussi 2017, Geissdoefer et al. 2017, Ghisellini et al. 2016, and Pan et al. 2015). Briefly, a comprehensive definition that covers different aspects of a CBM is: a business model that in the built environment sector strives for three main aspects, namely: 1) using fewer materials and resources for producing products and/or services, even from the design phase; 2) extending the life of products and/or services through refurbishment and remanufacturing; and 3) closing the loop of products' life by recycling. In short, the CBMs seek to reduce, retain, and recycle building materials in the current value chain.

Depending on the stage of the building lifecycle when the CBMs could be engaged, they can be grouped into three main categories, namely: design, use, and recovery. It is important to note that the last category refers to recovery and not to the end of useful life. This is relevant because it reflects one of the most important features of the circular economy: the fact that, within the circular model, the use of resources does not come to an end, but rather they are reintegrated into the value chain. Thus, the buildings' life-cycle is extended, either after a stage of reconditioning or a change of its use, or through the recycling of resources/materials.

Table 5: Circular Business Models - Opportunities and Challenges

	Opportunity	Challenges
Circular Design ***Development and planning phase of a built asset***	Products, systems and the entire built structures are designed to last longer with a higher residual value. Therefore, they shall be easier to maintain, repair, upgrade, refurbish, remanufacture or re-cycle with respect to the traditional ones. Additionally, new materials can be develop and sourced, particularly bio-based, that ai less resource intensive or fully recyclable. the same context, new processes are bein veloped to increase the reuse potential anc cyclability of construction and industrial prc ucts, by-products, and waste streams. There is an opportunity for designers to er gage with potential partners who may have interest in the development (or parts of) post initial use. This may link with the "use" and "recovery" CBMs to ensure the benefit of the design is realized.	There are technological, market and opera-tional risks. These include a lack of data for the product performance as well as a de-gree of uncertainty on the operational costs of the asset. Market risks are associated with customer acceptance of reused / recycled products. Product obsolescence is often part of the design as customers want the newest model within a short time frame; therefore, products are designed with short lifespans. There will need to be a change of mindset to move away from business models based on this principle. Larger upfront investments, in respect to tra ditional linear models, will be needed to re-duce the need for raw materials, improve the product performance and increase the resid ual value at the end of life.
Circular Use ***Operational phase of an asset***	These models aim at keeping control over an asset and retaining its value. Product-to-service models allow a change from manufacturing a product to a number of new opportunities, such as providing leasing and sharing services. Additionally, they include extending the service life of products and components, providing ser-vices to facilitate the tracing, marketing and trade of secondary raw materials. This gen erates new opportunities for companies to both expand the client base through cus-tomer loyalty and to increase the long-term revenues through additional services such as maintenance, repair, and replacement c parts and components.	Assets need to be viewed with a great fo-cus on Operational Expenditures (OpEx) instead of Capital Expenditures (CapEx), which will have obvious consequences on the operating capital and potential implica-tions on taxation. As opposed to a higher ROI - associated to the willingness of cus-tomers to pay more for an asset that offers higher performance - circular use models would require companies to operate with lower cash flows due to a longer time for returning from the initial investment. The result is the need for either investors or fi-nanciers to be willing to expose themselves to higher loans. However, financial institutions do not tradi-tionally have sufficiently fine tools to price th risk adequately, which can result in high in-terest rates or even refusal to grant loans. The risks increase as there are uncertainties related to the future residual value of an as-set due to market price fluctuation of raw ma terials, as well as uncertainties of customers demand and absence of suitable legal struc-tures.

Circular Recovery ***End of the product service life***	Revenue is generated by transforming existing products into new ones adding value reducing costs, or reducing waste. The development of a platform to enhance revers logistics is essential in this specific case	These models rely on material reuse / recycling being more cost / time effective than extracting virgin material. Often the cost and challenge of reverse logistics prevents recaptured materials from being reused. Although there are fewer financial constraints for these models, the regulatory framework in construction might represent an obstacle. Regulation around waste management, product performance and health and safety all create barriers to recapturing materials. Engagement with regulators will play an important part in the development of these CBMs.

Source: Own elaboration based on ARUP & BAM 2016:23-26

Implementing CBMs in the construction industry is not an easy task, mainly because it involves breaking paradigms within an industry fundamentally adverse to changes, as it was mentioned above. Thus, there are specific challenges in each of the categories listed above (design, use, and recovery) but also very interesting opportunities for all the actors along the value chain. The Table 5 details different opportunities and challenges for each of the aforementioned categories. Finding the challenges within Berlin's construction industry and discussing about the opportunities with key stakeholders and decision makers will be a following task for the researchers within the Kopernikus Project.

According to ARUP and BAM (2016) it is likely that for a circular economy to function these different types of CBMs will need to interact and work together[25]. The later implies that there is an interesting potential for the development of synergies between different companies through the implementation of CBMs along the value chain in the different stages of the life-cycle of buildings. Thus, companies will not work alone in a built environment based on a circular economy and each company could expand the services offered or collaborate with others to maximize value and optimize processes along the value chain.

[25] ARUP and BAM (2016) provide an example, in the case of a light fitting for buildings, where the potential of different CBMs implementation is highlighted. By implementing a 'product as a service' CBM the lighting manufacturer retains ownership of the fittings and is incentivised to upgrade the fittings over time to maintain maximum efficiency. This in turn could benefit the user as there should be no decline in lux levels and they benefit from up-to-date technology. However, the full circular benefit is only realised if the business model has allowed for product and process design change, so that the light fittings are demountable and upgradable to reduce the use of virgin resources.

1. Circular Design

Business models in this group are implemented at the development and planning phase of a built asset. The sections and subsections below describe some CBMs found in the literature review that could be implemented before beginning the construction phase of the building.

According to ARUP and BAM (2016) main challenges in this category of CBMs are found in three fields, namely: 1) technological, mainly related to lack of data of product performance; 2) market risks, mainly involving customer acceptance of reused/recycled products; and 3) operational risks, mainly associated with the initial costs of circular products[26].

Design Thinking

The design stage is usually considered as the initial stage in buildings' life-cycle. Given that we live in a world that is increasingly urban, the way in which the built environment is preconceived plays a predominant role when it comes to thinking, from a holistic perspective, about how resources will be used during the buildings' construction and operation phases, but also how resources are meant to be disposed once the useful life has ended. Thus, more than a business model itself, design thinking is a principle to consider when thinking about the implementation of circular economy principles in the built environment.

The term 'design thinking' could be traced back to the late eighties. According to Dorst (2011) the concept has been part of the collective consciousness of design researchers since Rowe used it as the title of his book in 1987[27]. Following, the first symposium on design thinking research was an exploration of research into design and design methodology, viewed from a design thinking perspective (Cross et al. 1992 in Dorst 2011). Dorst (2011) claims that multiple models of design thinking have emerged since then, based on widely different ways of viewing design situations and using theories and models from design methodology, psychology, education, etc. Together, these streams of research create a rich and varied understanding of a very complex human reality.

According to Brown (2009 in Andrews 2015) design thinking is a collaborative process by which the designer's sensibilities and methods are employed to match people's needs with what is technically

[26] For further detail about opportunities and challenges for Circular Design CBMs, refer to ARUP and BAM (2016:23-26)
[27] See Rowe, P. (1987): Design thinking. Cambridge Mass.: MIT Press.

feasible and a viable business strategy. In short, design thinking converts need into demand. Such process, according to Brown and Wyatt (2010) is best thought of as a system of overlapping spaces rather than a sequence of orderly steps. Brown and Wyatt argue that call these spaces, rather than steps, because they are not always undertaken sequentially. Projects may loop back through inspiration, ideation, and implementation more than once as the team refines its ideas and explores new directions. Accordingly, there are three spaces to keep in mind when thinking of the process: 1) inspiration, considered as the problem or opportunity that motivates the search for solutions; 2) ideation, pointed as the process of generating, developing, and testing ideas; and 3) implementation as the path that leads from the project stage into people's lives.

Moreover, according to Plattner and others (2011) The heart of the design thinking process lies at the intersection of technical feasibility, economic viability, and desirability by the user. Accordingly, it was suggested that the inquiries of design thinking research extents to all aspects related to these three dimensions. Thus, although the focus of design thinking is focused on the design process seeking the solution of predominantly social problems (for example, the scarcity of resources or combating climate change) it is important for the design process that the solutions be robust and feasible, as mentioned above.

Eco-design

Eco-design and life cycle analysis (LCA) are important and related tools that enable a circular economy. Both tools are to be applied/considered before the building process begins in order to choose the best option among alternatives.

Eco-design is defined in the specialized literature as an approach where environmental considerations are integrated into the product design and development (see Prendeville et al. 2012 in Sauvé 2016). Nonetheless, the integration of environmental considerations into the design and development process is challenging. Since reducing environmental impacts in one stage of the life-cycle of the product could increase these elsewhere, there is a need for a thorough and in-depth assessment of alternatives.

For instance, using raw materials that emit fewer atmospheric pollutants during the manufacturing of a product could lead to a more complicated recycling or reuse at the end-of-use or end-of-life. It may also be environmentally sound to replace a functional piece of equipment for a newer one that offers a better environmental performance. Environmental gains in a specific life stage of a product should not be made to the detriment of impacts at other stages. An LCA is therefore an indispensable tool of eco-design and essential to properly compare and evaluate different options to be implemented within a circular economy approach (Sauvé 2016).

Eco-design has been enforced in the European context since 2009. The Directive 2009/125/EC of the European Parliament establishes a framework for minimum eco-design requirements which goods that consume energy must meet before they can be used or sold in the EU. It does not apply to transport used to carry people or goods.

Moreover, together with energy labelling, eco-design could be an effective EU-tool for improving the energy efficiency of products because they could help eliminate the least – environmentally and energy – performing products from the market; thus, contributing significantly to the EU's 2020 energy efficiency targets. It also supports industrial competitiveness and innovation by promoting the better environmental performance of products throughout the Internal Market. The following aspects of the directive are relevant for implementing the circular economy approach in the built environment.

- Eco-design requirements cover all stages of a product's life: from raw materials, manufacturing, packaging and distribution to installation, maintenance, use and end-of life. Covering, as mentioned in the sections above, the covering extensively the life-cycle of buildings.
- For each phase, various environmental aspects are assessed by bodies designated by EU countries. They verify aspects such as the materials and energy consumed, expected emissions and waste and possibilities for reuse, recycling and recovery. Thus, aiming at closing the loops along the value chain.
- Manufacturers must construct an ecological profile of their products and use this to consider alternative design possibilities. The later, calls for a comprehensive stakeholder engagement along the value chain.
- Products which satisfy the requirements bear the CE marking and may be sold anywhere in the EU. As any other certification scheme, the later could be a significant driver for innovations in the material manufacture and the construction industry.

According to the Alliance for Circular Economy Solutions or ACES (n.d.) the EU's Eco-design Directive has achieved up to date significant energy efficiency savings and it is seen as the catalyst for the transition towards greater resource efficiency, requiring manufacturers to design products for easier reuse and repair. The latter are essential strategies for achieving circular economy goals.

2. Circular Use

Business models in this group are implemented at the operational phase of a built asset. The following sections and subsections describe CBMs found in the literature review that could be implemented during the use or operation phase of the building lifetime. CBMs in this category aim at maintaining control over an asset and at retaining its value over its lifespan. According to ARUP and BAM (2016) the main challenges for implementing CBMs in this category are related to the longer time for returning of the initial investment, which in turn would require companies to operate with lower cash flows. The later will require for investors or financers to be willing to expose themselves to higher loans. Thus, at least in the initial stages of inception of the CBMs, the role of national governments in the generation of adequate incentives will be fundamental to ensure that CBMs become competitive in the market[28].

Product-as-service Models

The business model refers to the provision of services instead of products. For example, the vertical mobility service within a building instead of selling the elevator box with all the appliances; or the thermal conditioning service instead of the heating system; to name a few. In general, in Berlin's residential sector, there are some similar business models already in place, mainly for heating and conditioning systems[29]. Basically, the idea of a customer paying for an outcome rather than a means to that end sounds attractive.

This CBM aims at delivering performance rather than products and the ownership of the product is retained by the service provider. The primary revenue stream comes from payment for performance delivered. According to ARUP and BAM (2016), the later applies most obviously to mechanical plant, lighting, and fit out, but can potentially be extended to all parts of a building and infrastructure.

According to Gerholdt (2015) through the product-as-service business model, customers use products through a lease or pay-for-use arrangement[30] versus the conventional buy-to-own approach which

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[28] For further detail about opportunities and challenges for Circular Use CBMs, refer to ARUP and BAM (2016:23-26)

[29] The work of Horng (2017) provides a detailed analysis business models implemented in Berlin for overcoming the so-called 'split incentive' dilemma.

[30] As an example, Gerholdt (2015) argued that Philips sells lighting as a service, in which the company aims to reach more customers by retaining ownership of the lights and equipment, so customers do not have to pay the upfront costs of installation. Philips also ensures the sound environmental management of its products by taking them back at the appropriate time for recycling or upgrading.

implies a more linear model. The product-as-service model, thus, is attractive for companies that have high operational costs and ability to manage maintenance of that service and recapture residual value at the end of life. Accordingly, Fischer (2017) argues that when concerning product-as-service business models[31], chain coordination is a more limited issue in the interaction/alignment with customers (either B2B or B2C).

An example for the product-as-service CBM in Berlin´s housing sector can be found in HOWOGE's and GESOBAU's business model that focuses on rental housing[32]. In the business model, the property of the dwelling – in this case seen as real state products – remains with the housing association while the benefits for the users are in the service – in the case of housing, the benefits are satisfying basic shelter needs. By retaining ownership, the housing associations also retain the responsibility for maintenance and 'updating' (in this case retrofitting) the real-estate products for ensuring a better service.

[Product] Lifetime Extension

According to ARUP and BAM´s report (2016) this CBM aims at extending the service life of products, components and systems through engineering solutions including easy disassembly and reassembly, repair, maintenance and/or upgrade. Moreover, the product life extension CBM could help companies to extend the lifecycle of their products and assets to ensure they remain economically useful. The added value that this type of CBM could have within the value chain of the construction industry may be observed in the lifespan of building materials. Material that otherwise would be wasted is maintained or even improved, such as through remanufacturing, repairing, upgrading or re-marketing. Thus, by extending the lifespan of the product for as long as possible, companies can keep material out of the landfill and discover new sources of revenue.

Sharing platforms

[31] In order to provide an example of product-as-service business models, Fischer (2017) provides detailed information about Turntoo, a social enterprise, that introduced the concept 'product-as-service'. According to Fischer, the vision of Turntoo is to treat products as 'storerooms' for re-usable resources. The ownership of products remains with the producer and consumers only pay for the service of using a product, often in the form of a lease contract. After the use-period the product returns to the company that can either sell the service again, refurbish it or re-cycle the materials, depending on the situation. For further details about Turntoo, refer to Fischer (2017:29-30) or www.turntoo.com, where CBMs in the housing sector are presented and discussed.

[32] HOWOGE and GESOBAU are state-owned housing associations (*Wohnungsbaugenossenschaft*) operating in Berlin. Their main business areas are the rental of apartments and commercial premises as well as the management of residential property.

This business model generates an increased utilization rate of products or systems by enabling or offering shared use, access or ownership. At the same time, it enhances off-site design and the use of collaborative production facilities. The sharing platform model is centred on the sharing of products and assets that have a low ownership or use rate. Companies that leverage this model can maximize the use of the products they sell, enhance productivity and value creation.

In general, business models in this group are to be found broadly, since they derive from the sharing economy; some examples are: transportation (Lyft, RelayRides, BlaBlaCar), lodging (Airbnb), and neighbours helping neighbours (TaskRabbit, NeighborGoods).

Tracking facility

This model aims to provide services to facilitate the tracking of materials, components and parts of a system so that they can be marketed and traded in secondary raw materials markets (ARUP & BAM 2016).

Sell and buy-back

In this case, a product is sold on the basis that it will be purchased back after a period of time (ARUP & BAM 2016).

3. Circular Recovery

Business models in this group are implemented at the end of the product service life. The sections and subsections below describe some CBMs found in the literature review that could be implemented when the building's lifetime comes to an end. The revenue in this category of CBMs is generated from the transforming products into new products, in the reduction of costs, and/or in the reduction of waste. The main challenge for these CBMs is that they depend on the material recycling or reuse, paradoxically under the current conditions, could be more cost and time effective than the extraction of raw materials[33] (ARUP & BAM 2016).

[33] For further detail about opportunities and challenges for Circular Recovery models, see ARUP and BAM (2016:23-26).

Reverse Logistics

Reverse logistics is a closed-loop process of planning that considers remanufacturing, refurbishment, repair, reuse or recycling to recover and process materials and products after the point of consumption (ARUP 2016, ARUP & BAM 2016, Cognizant 2011).

According to the Ellen McArthur Foundation (2016) companies willing to implement the circular economy approach, for expanding their supply chain to include the return of used products and materials for recovery, must understand the requirements of their reverse infrastructure[34]. The Figure 10 shows how would the value chain could look like from a circular economy perspective. In the construction industry, the most significant difference between the linear and circular supply chains lays in the introduction of reuse, repair, remanufacturing and recycling of building and building materials; thus, the linear value chain becomes circular. Although the circular approach is enabled at the design stage, as discussed in the sections above, there is a need for implementing a set of CBMs for remanufacturing and recovering building materials at the end-of-life stage. The later could enable that the production and construction processes switches from using raw materials, as it is traditionally done, to using remanufactured components and recycled materials.

The Ellen McArthur Foundation (2016) promotes the so-called Reverse Logistics Maturity Model (RLMM). The RLMM focuses on three key components, namely: 1) front end, includes reverse logistics processes and network, with related planning and monitoring; 2) engine, refers to refers to the recovery of returned products, including recovery strategy, inventory control, and material evaluation; and 3) back end, refers to remarketing the recovered products in secondary markets, ranging from related market development and planning, to monitoring of recovered products. In the view of RLMM developer's, reverse logistics design calls for a holistic approach. Therefore, engine and back end components are included in the RLMM whereas both aspects go beyond strict reverse logistics. With such integrative approach, it is expected that the shift from a process management perspective to a comprehensive business model perspective could be supported.

[34] The Ellen McArthur Foundation provides a very valuable contribution towards unlocking the value of the circular economy approach through reverse logistics. On its 2016 report called 'Waste not, want not - Capturing the value of the circular economy through reverse logistics", the Ellen McArthur Foundation (EMF 2016) provides a detailed analysis of reverse logistics as a key step in capturing the value of end-of-life goods. The report presents a CBM called Reverse Logistics Maturity Model (RLMM). Within this CBM three demand-driven archetypes are mentioned based on product type, namely: 1) low value extended producer responsibility; 2) service parts logistics; and 3) advanced industrial products (see pp.6-9).

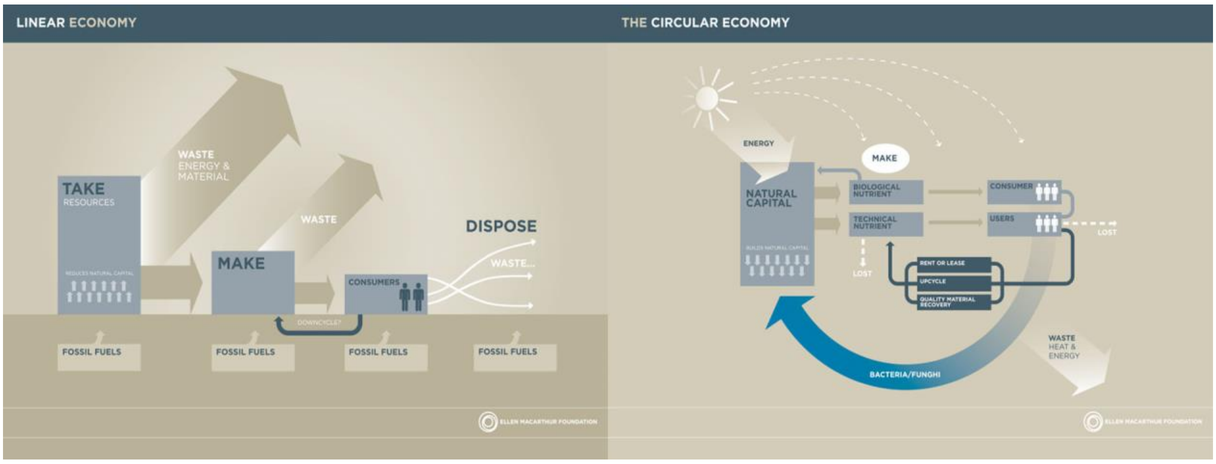

Figure 10: Circular Economy Value Chain

Source: Ellen McArthur Foundation

In order to enable business to measure the implementation process, the RLMM supporters suggest measuring the RLMM components across three dimensions that reflect decision-making levels within a company, namely: strategic, tactical and performance. The later structure, described in Table 6, could facilitate businesses to build the needed capabilities to address return, recovery and remarketing goals at strategic and tactical level. Moreover, performance objectives to support the monitoring of a return management's planning and execution could also be set up (EMF 2016).

Table 6: RLMM Components and Dimensions.

	Strategic dimension	Tactical dimension	Performance dimension
Front End	reverse logistics strategy maturity, business and functional integration	reverse logistics network structure and planning, definition of requirements and objectives for products return	measuring the responsiveness and visibility of returned items within the reverse logistics flow.
Engine	recovery strategy and how it is aligned with business goals	helps to assess the inventory control process for returned materials	returned material evaluation process and how it affects the recovery process and product design

Back End	evaluates the business knowledge for product remarketing at secondary markets	covers remarketing planning and pricing for recovered product.	targeted at assessing availability and use of secondary markets' demand and remarketing data.

Source: Own elaboration based on EMF (2016)

Supply Chain Management

To define the concept of 'supply chain management' (SCM), Schrödl and Simkin (2014) discuss fundamental contrasts between SCM and logistic research (LR) found in the literature. The following main aspects are discussed:

- The relationship between buyers and suppliers; On the one hand, LR presumes a rational cooperation between the parties (buyers, suppliers, and service providers) that seeks an optimal solution for inventory, transport, and information flow; On the other hand, SCM focuses on the relations between the parties when considering behavioural and political dimensions of trust and power, as well as conflict and dependence between supplier and buyer.
- Costs and investment periods; While LR focuses on minimizing the total cost, SCM cares about long-term profitability of serving customers and their customers.
- The traditional focus of LR was intra-organizational, while SCM became inherently inter-organizational.

Moreover, considering the relationship between organizations, Cooper and others (1997 in Schrödl & Simkin 2014) define SCM as: "The integration of business processes from original suppliers to the end-user that provides products, services, and information that add value for customers". Thus, according to Schrödl and Simkin (2014), SCM was essentially concerned with the external logistical integration of customers and suppliers.

CBMs in this category seek an integration between firms that operate in certain market segments where common benefits can be enhanced through strategic integration within existing networks. The foregoing could, however, derive in competition not only between firms, but also between supply chains and networks. In the case of the construction industry, supply networks are formed based on the flows of materials, services, and information within the value chain; thus, all elements of the supply network are interconnected thanks to the support of modern information and communication technology (see Schrödl & Simkin 2014).

The following sections discuss alternatives to the SCM models.

Green Supply Chain Management

Since the Brundtland Report was released in 1987[35] and provided an official definition of sustainable development (SD), environmental awareness in business has grown significantly. The scientific and institutional literature discussed different dimensions that are covered by the SD concept (see Mercado 2010:32-37), the most broadly accepted are three, namely: environmental, social, and economical. According to Schrödl and Simkin (2014) the aforementioned dimensions made their way into many industry concepts such as Green Supply Chain Management (GSCM). Thus, GSCM evolved as a sub-area of Sustainable SCM, mainly because it sets environmental management as a driver for protecting the environment from the externalities related to the industry activities (Schrödl & Simkin 2014, Chin et al. 2015). The main difference between the 'classical' SCM is, therefore, that by integrating environmental thinking into supply chain management, GSCM brings the circle to a close, mainly by adding recycling as well as end-of-life management of the product.

Schrödl and Simkin (2014) argued that GSCM can be divided into two blocks, Green Design and Green Operations. While the first one focuses on environmentally conscious design and life-cycle assessment, the second one is dedicated to manufacturing and remanufacturing, reverse logistics and network design as well as waste management. From this perspective, GSCM aims at minimizing or eliminating wastages[36] along the supply chain.

According to Chin and others (2015) GSCM plays a vital role in influencing the total environment impact of any firm involved in supply chain activities; it could therefore contribute to sustainability performance enhancement. Following the publication of 'Our Common Future' (WCED 1987) the increased awareness of green practices has triggered firms to act in an ethically and socially responsible manner in their supply chains. With these practices in mind, firms develop environmental management strategies in response to the changes of environmental requirements and their impacts on supply chain operations (Chin et al. 2015).

[35] The Brundtland Report, called 'Our common future', defined for the first time, officially, the concept of sustainable development as: "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." (WCED 1987: 42). According to Mercado (2010:29-30) although the concept has guided the debates on the concept of sustainable development during the following years, its practical implementation has often been criticized.
[36] Including: hazardous chemical, emissions, energy, and solid waste.

Reverse Supply Chain or Circular Supply Chain

According to Kumar and Chatterjee (see Cognizant 2011) Reverse Supply Chain (RSC) refers to movement of goods and resources from customer to vendor, while the traditional supply chain considers the movement of goods and resources from vendor to customer. Thus, RSC is closely related to reverse logistics which, as mentioned in the sections above, is a closed-loop process of planning, implementing and controlling the efficient and effective inbound flow and storage of secondary goods and related information for recovering value or proper disposal (see ARUP 2016, ARUP & BAM 2016, Cognizant 2011). According to Cognizant (2011:1), some typical examples of RSC[37] include: product returns and management of their deposition; remanufacturing and refurbishing activities; management and sale of surplus, as well as returned equipment and machines from the hardware leasing business. In such examples, the resource goes at least one step back in the supply chain; for instance, products move from customer to distributor or manufacturer, or resources are recycled, selected, and reinserted in the supply chain. The Figure 11 shows a schematic representation of a generic RSC for a commercial product return. In this model, products and/or resources are returned to the seller/manufacturer, who then send them to a so-called 'returns evaluation location'; at this station an assessment will take place to determine the optimal commercial disposition for the future of the product. In the construction industry and the housing sector, the above is relevant when determining the future of real estate products. At the end-of-life of a building, the reconditioning of the building or its demolition will be decided. From the RSC perspective, some of the elements of the building could be returned to the manufacturer for recycling or reconditioning (depending on the product) and then reinserted in the supply chain; otherwise, a proper disposal should take place.

[37] According to Cognizant (2011:2) there are several types of RSC and they could be implemented at different stages of the product cycle. Nonetheless, they could be organized to be implemented in five key process: 1) Product acquisition, Obtaining the used product from the user by the reseller or manufacturer; 2) Reverse logistics, transporting products to a facility for inspecting, sorting and disposition; 3) Inspection and disposition, assessing the condition of the return and making the most profitable decision for reuse; 4) Remanufacturing or refurbishing; returning the product to its original specifications; and 5) Marketing, creating secondary markets for the recovered products.

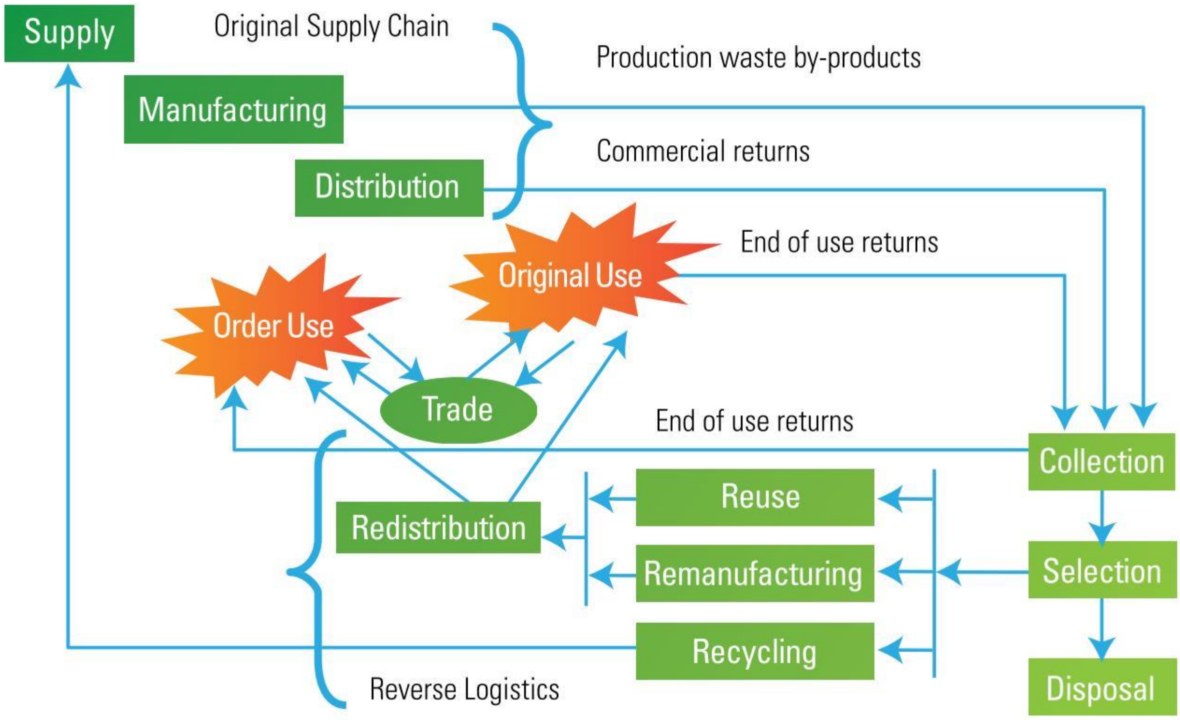

Figure 11: Reverse Supply Chain.
Source: Cognizant 2011:2

From this standpoint, Sobotka and others (2017) argued that the basis for expansion of RSC is separate waste collection. Accordingly, expanding the logistic chain to include many waste recipients can bring a significant added value to the business. Material recovery requires mainly market analysis and some process to take place at the construction site, namely: cleaning, crushing, screening, cutting, drying. Recovery of construction products for structural purposes, on the other hand, requires higher quality, and consequently more refined methods of processing and testing of materials and products (Sobotka et al. 2017).

As mentioned in *The Role of the Built Environment* section the impacts generated by construction industry in the environment have generated increased environmental awareness within companies operating in the sector; which in some way is reflected in the corporate reports issued in general on a voluntary basis. Moreover, companies could be adopting this green influence on RSC because customers have shown they value companies with strong social and environmental corporate policies. In any case, the growing awareness should be seen as an opportunity for further development.

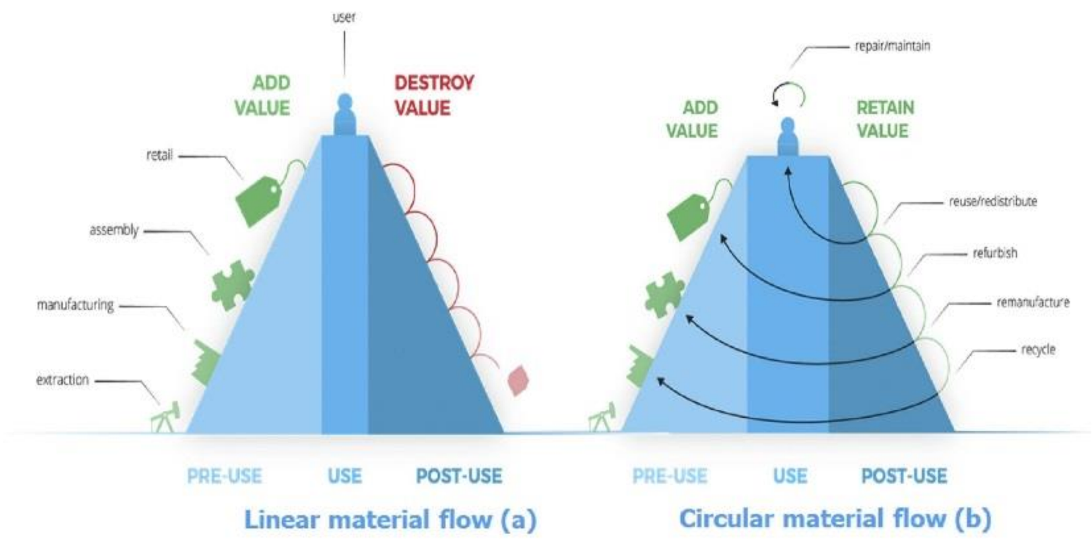

Figure 12: Linear vs Circular Supply Chain
Source: Fischer and Pascucci 2017:20.

As discussed in *The limits of Resource Consumption* section, the world's resources are finite. Moreover, also as discussed before, implementing circular economy approach in the construction industry implies a transition from the traditional: raw material extraction, manufacturing, construction-site/consumer, waste process, towards a: construction-site/consumer, manufacturing, construction-site/consumer process; avoiding and minimizing, therefore, waste and raw material extraction. In other to shed more light on this topic, the literature discuses a similar concept to RSC, the so-called Circular Supply Chain (CSC) which includes the entire reverse logistics process (Genovese et al. 2017, Nasir et al. 2017, Fischer & Pascucci 2017). The Figure 12 shows the how the material flow in the supply chain could shift from linear (on the left hand) to circular (on the right hand). More importantly, it highlights how the CSC could retain the value of the resources in the supply chain by reinserting products and resources back to the supply chain after its use, either by repair/maintain, reuse/redistribute, refurbish, remanufacture, and/or recycle[38]. From this perspective, activities near the use phase need the least amount of energy to create value because the products only need (minor) alterations (EMF 2014).

[38] Such processes were broadly discussed in the *3R's Principles of the Circular Economy* section.

Circular Supplies

According to GreenBiz[39], the circular supplies business model is particularly relevant for companies dealing with scarce commodities, in which scarce resources are replaced with fully renewable, recyclable or biodegradable resource inputs. Therefore, companies dealing within the construction could be suitable for implementing such models. Moreover, according to ARUP and BAM (2016:22) circular supplies models focus on the development of new materials to enhance renewable energy, bio-based, less resource intensive or fully recyclable materials. The later could play a relevant role within the construction industry, when considering alternative less resource-intensive building materials.

Support lifecycle

Consumables, spare parts and addons to support the lifecycle of long-lasting products (ARUP & BAM 2016:22).

Recapture material suppliers

Recaptured materials, components and parts of a system are sold to be used instead of virgin or recycled materials. For example, cement replacement in concrete (ARUP & BAM 2016:22).

Recycling facility

This model focuses on transforming waste into raw materials. Additionally, revenue can be created through pioneering work in recycling technologies (ARUP & BAM 2016:22).

Recovery provider

Provides take-back systems and collection services to recover useful resources from disposed products or by-products (ARUP & BAM 2016:22).

Refurbish and maintain

Used parts and components are refurbished and maintained so that they can be sold (ARUP & BAM 2016:22).

[39] GreenBiz.com

VI. Further Work and Implications

Based on secondary data analysis, this section and sub-sections show how the research is successful in shedding light on the state-of-the-arts regarding the circular economy for the built environment research. The following sections discuss the main findings and future research steps.

1. Summary of findings

The Built Environment, the Linear Model, and the Limits of Resource Consumption

The research shows, based on different sources, that the linear way in which resources are being consumed worldwide is approaching its limit; available resources are finite. The current economic model is based on a linear model, known as take-make-dispose, characterized by: 1) being predominantly resource-intensive; 2) strongly focused on economic gain, leaving aside social and environmental aspects; 3) creates strong environmental impacts, such as pollution, high levels of CO_2 emissions, considerable volumes of waste, and loss of resources.

Globally, the construction industry is one of the most important consumers of resources and energy accounts for 50% of global steel production and consumes more than 3bn tonnes of raw materials) and a relevant generator of CO_2 emissions (nearly half (46.7%) of all CO2 emissions in 2009 came from the Building Sector). So far, measures have been implemented to mitigate sector emissions, focusing mainly on the construction and use phases of buildings' life-cycle; namely: 1) improving buildings' thermal envelope and implementing energy efficient HVAC systems. However, the analysis and implementation of measures in early stages of building's life-cycle (i.e. conception, design, manufacturing of construction materials) is just emerging, mainly in the political discussion and practical activity. The latter shows an important gap and a relevant opportunity for the preparation, discussion and subsequent implementation of research-based policies in the sector.

The Circular Economy Approach – an Emerging Concept

The research conducted an in-depth review of the circular economy concept, that has been installed in research about the built environment. The review reveals that the origins of the concept go back to the seminal work of Boulding in the mid-sixties, who suggests the implementation of a cyclical ecological system instead of a wasteful linear economic model. The literature mentions that the scheme proposed by Boulding had inspired later the conceptual discussion of sustainable development. Critics argue that the circular economy concept could be seen as an operationalization of sustainable development. Moreover, the specialized literature analyses differences and similarities between both concepts from various perspectives, mainly because both concepts are illuminated – mainly – from the environmental economy and the industrial ecology.

For some experts in other fields, such as environmental economics, sustainable development is a concept (or an objective) that remains independent from past unsuccessful initiatives and, more importantly, independent from the linearity of the production–consumption model, or the so-called take-make-dispose pattern. Sustainable development could be seen as a society objective defined at the macro-level; on the other hand, the circular economy approach is mainly defined at the micro-level through a model of consumption and production. In this respect, the circular economy approach is no different from sustainable development, the literature argues. Both rely on intervention by some authority, which in turn depends on a set of political-economic issues (namely: public good problems, externalities, open access, etc.) that go beyond the theoretical concepts. The latter calls for an active stakeholder engagement discussed in the sections below.

The circular economy model promotes resiliency of resources. It aims to replace the traditional linear economy model of fast and cheap production and cheap disposal with the production of long lasting goods that can be repaired, or easily dismantled and recycled. A model of production based on a circular economy may seek to extend the useful life of the product. It favours the possibility of repair, refurbishment and reuse of products before their actual end-of-life (when it will be recycled into materials that become raw resources). The circular economy model aims to emulate processes similar to those that occur in natural environments, where waste is reduced, and most is recuperated by another species. Competition and cooperation among species occur in nature, thereby maintaining the efficiency of natural ecosystems and certainly providing flexibility and adaptability. Applying this approach to economic systems could help ensuring healthy competition and maximum efficiency of usage of available resources.

Circular Economy Principles

The relevant literature discusses the principles of the circular economy. The Table 7: Circular Economy Principles for the Built EnvironmentTable 7 presents in the column on the left three fundamental principles put forward by the EMF foundation and in the column on the right the principles of the circular economy reflected in the built environment, namely: 1) the end of the life cycle of the buildings should be "designed out", considering a period of periodic renovation and reconditioning; 2) the materials used in the construction are diverse and the components of the buildings are made to last for a long time; and 3) the energy that feeds the building systems comes entirely from renewable sources and the users of the buildings are energy prosumers.

Table 7: Circular Economy Principles for the Built Environment

	CE – General Principles (EMF)	CE – Principles for the Built environment
1	Designed out waste	CE – Principles for the Built environment
2	Build resilience through diversity	Buildings end-life/retrofit is planned
3	Rely on energy from renewable sources	Building components/materials are durable (i.e. long-lasting)

Source: Own elaboration based on EMF (2013a:22)

By complying with the principles of circular economy for the built environment, the construction industry could achieve the construction of circular buildings. The Figure 13 shows the components of a circular building and the required timeframe for a renovation to take place for each building component. Thus, more robust components and less easy to replace, such as the "structure" component, are designed to last longer (60 to 120 years); on the other hand, lighter elements, but also of greater use and that therefore could deteriorate sooner, like the "stuff" component, have a shorter replacement period. In this way, the relevant literature highlights the importance of thinking from the design stage in those periods and what will happen to the components once the cycle is completed. In most cases, materials and components return to the production chain through disassembly and recycling. Thus, they are generating closed cycles that are widely mentioned in the literature.

Figure 13: Towards Circular Buildings

Source: www.usefulprojects.co.uk.

Circular Economy – Towards its Implementation

In recent years, the circular economy concept has been widely discussed in several perspectives, namely: the scientific literature (mainly from industrial ecology, as a way towards sustainability), the gray literature (where the Ellen MacArthur Foundation is leading the discussion), and politics (in recently implemented national and regional policies, mainly focused on waste reduction, China and the EU are the referents globally). The implementation of circular economy concepts in the private sector is being carried out slowly through business models and start-ups. This is due to the insecurity generated by the implementation of innovative business concepts and models.

The research shows that the construction industry is characterized by being particularly resistant to changes, which makes it difficult to implement a paradigm shift in the construction practice towards a circular industry. Thus, to enable its implementation, a broad discussion with the decision makers and key actors involved in the industry is needed. In addition, due to the relevance of local stakeholders' perception, who represented meso-perspective between the individual and the political sphere, a participatory research design for further scientific inquire needs to be elaborated. Moreover, recent publications focused on research on the built environment[40] argued the responsibility of taking actions towards the implementation of criteria of the circular economy within the production chain rests mainly in three groups of key players: policymakers, investors, and construction clients.

The research identifies key circular economy concepts – namely: C2C, zero waste, blue economy, eco-efficiency, and sufficiency – that could help its clarification towards a potential discussion with key stakeholders. Furthermore, beyond the theory, the review of secondary source of information collects a series of circular business models – the circular business models are grouped in: Circular Design, Circular Use, and Circular Recovery – that could provide an overview of the ongoing implementation of the concept in the built environment. Thus, this information is relevant for providing the decision makers a group of concrete cases, based on international experience, that can show: 1) the feasibility of operationalizing theoretical concepts in practice; 2) the existing innovation potential; and 3) available business opportunities.

Thus, it is of relevance for the research to explore in detail the opinions of the actors involved in the Kopernikus E-Navi project and to involve external actors to the project discussing about the potential implementation of concepts and business models of the circular economy. The results of this research should be considered as discussion starters. Future empirical research will be needed to generate deepen knowledge and carry out comparative studies to account for similarities and differences at a local level. Likewise, the research reveals barriers that could slow down the implementation of circular economy initiatives; thus, the circular economy approach would not be immune to failures, misuse, ambivalence and green-washing. However, the circular economy offers a conceptual framework that enables the development of contractual agreements between the users and providers of products and services that can improve incentives and lead to more eco-efficient uses of resources.

[40] See ARUP (2018).

2. Further work

As mentioned in the introductory section of this report, the research design considers several consecutive phases. In this report, a series of concepts and business models from the circular economy – that could enable a transition in the construction industry towards circularity that allows, in the long term, to reduce the consumption of resources and emissions from the sector – have been identified. It is argued that once these goals are achieved, the sustainability of the sector can be achieved. Moreover, it has been shown that successful cases, where criteria and business models of the circular economy have been implemented, are cases with a deep environmental awareness and involvement. However, environmental awareness is not everything and there are also economic and social motivations that contribute to accelerate the adoption of business models.

From the theoretical perspective, it has been seen that although the concept of the circular economy is not new. It is a concept that has gained recent attention both in the academic debate and in the institutional discussion and public policy. Thus, the research was able to identify in the relevant literature a series of concepts and business models that aim at enabling a paradigm shift in the construction industry. Looking for an interaction between theory and practice, the next step in the research design seeks to capture the opinion of industry experts about the research findings. It is intended to conduct a series of workshops, focus-groups, and personal interviews to present relevant research findings to key players and decision makers in the Berlin's construction sector. In order to achieve this goal, a parallel work conducted by IKEM within the Kopernikus E-Navi project identifies a set of more than sixty key stakeholders within Berlin's building sector[41]. It is expected that such events will be organized after the summer break in 2018.

So far, the research has built a research framework, based on the circular economy, for the built environment research. Thus, the further work beyond the active involvement of key actors within the research context, it is intended that the research framework will be useful for further research that may emerge from it. For this reason, it is contemplated that based on this research a research line could be generated that enables further cooperation and joint research between IKEM researchers and researchers from other academic institutions involved in the Kopernikus E-Navi project.

[41] See „Energieeffizienz im Gebäudesektor in Berlin: Interaktion von verschiedenen Schlüsselakteuren"

Accordingly, and from a quantitative perspective, IKEM is currently analysing the embodied energy of building materials used in Berlin`s housing stock. Thanks to the active involvement with the Kopernikus E-Navi project partners, valuable information was collected to conduct a life-cycle assessment of buildings' energy performance. The overall aim of the analysis is to explore whether alternative materials could reduce the sector's emissions already from the design and construction stage of the buildings. Likewise, it seeks to analyse building’s whole life-cycle and to find alternatives for disposal and/or recycling of building materials that minimize waste production in the sector. This step is currently ongoing on a pilot basis thanks to the information provided by GESOBAU. The dissemination of the preliminary results is expected within this year, following a discussion of the findings with the key stakeholders and involved research partners.

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