IKEM

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Making Resources in the Construction Industry go Round and Round

Implementing the Circular Economy in Berlin

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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Introduction

Scope

The German Climate Action Plan 2050 sets targets for reducing greenhouse gas emissions and especially the construction sector provides the highest target about a reduction of 67-68% by 2030. Within the framework of the Kopernikus ENavi 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, from a qualitative standpoint with key players from Berlin's construction industry, the implementation of emerging concepts, methodologies, and business models in the field of circular economy that could enable a transition from the traditional linear practice of construction towards a circular construction. Facing an innovation process is not an easy task; therefore, the research seeks, 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 qualitative methods. Primary data was collected by analysing expert's opinion regarding IKEM's research findings in the field of the circular economy for the built environment, within the Kopernikus ENavi project (see Mercado 2018). By applying qualitative research techniques, for data collection (survey and focus groups) and data analysis, expert`s opinions in their roles as key-players within Berlin´s construction industry was collected. Specifically, it was sought to explore and discuss the implications, barriers, and relevant drivers for a potential transition towards the circularity in the industry.

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 circularity. 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[1] 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.

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 four main sections. The first section and subsections present the research design. The selected tool for primary data collection was an online survey. Therefore, the subsections present the sampling methods and the criteria for data analysis. Finally, the criterion for data triangulation, based on focus groups and secondary data analysis are further discussed.

The second section and subsections provide a short overview about the theoretical framework. As mentioned before, this report recovers IKEM's previous research in the field of the circular economy for the built environment, within the Kopernikus ENavi project. Therefore, the subsections provide the reader with an overview about the research context presented to the survey participants, namely the prevailing linear model of production and the growing need to decouple economic growth from resource consumption; the current trends on resource consumption that are exhausting the Earth's natural resources; and key concepts, principles, and business models of circular economy are further summarized.

The third section discuss the research findings. The survey results were discussed in a focus group with experts in the field. The outcomes of the discussion were the discussed with secondary data for

[1] See ARUP (2018).

enabling data triangulation. The last section and subsections present some final remarks and provide an outline of further research and key implications within the Kopernikus ENavi project.

Acknowledgments

IKEM and the author would like to thank company representatives involved in Berlin's construction sector for their interest in the topic and for participating in the online survey. In addition, IKEM and the author would like to thank representatives from re!source Stiftung e.V. and Deutsche Umwelthilfe e.V. for their generous contribution as experts in the field of resource management and the circular economy. The participation of company representatives in the survey as well as experts in group discussion was made freely and without expecting any kind of remuneration. Likewise, company representatives that participated in the online survey did it anonymously.

I. Research Design and Methods

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. Aiming at making the research process transparent and traceable, the sections and subsections below present and substantiate the research approach and aims, and the methodological steps taken throughout the research for achieving the research goals.

1.1 Research Approach and Aims

The report is part of a series that seeks to find an alternative path to achieve the reduction of CO_2 emissions in the built environment through the implementation of emerging principles, concepts, and business models from the circular economy in the construction sector. The main overall goal of IKEM's research in the field of the circular economy 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, in a first publication in 2018, the abovementioned elements were identified when analysing the state of the arts of the circular economy approach in the built environment research (see Mercado 2018).

The implementation of emerging principles, concepts, and business models from the circular economy approach in the construction industry depend largely on the key players in the sector, as any other innovation process. Therefore, the main objective of the research is to analyse expert`s opinions in their roles as key-players in Berlin's construction industry. Specifically, the research sought to explore and discuss the implications, barriers, and relevant drivers for a potential transition towards the circularity in the industry.

1.2 Methods – Strategy for a Qualitative Inquiry

The following sections and subsections present the methodological design and instruments for data collection, the criteria followed for the analysis of the results, as well as the steps and measures taken for the triangulation of the information. Likewise, the criteria for the selection of the sample are presented, which followed a selective sampling strategy that is detailed in *Data Collection and* Sampling section.

The methodological design of qualitative research followed a traditional deductive approach that combined two quantitative tools for data collection; moreover, it enabled the triangulation of the obtained results and the discussion. The first, first tool was an online survey, whereas the second was

a focus group with experts. The analysis and interpretation of the data followed a thematic content analysis, as detailed in the *Data Analysis and Data Triangulation* section.

1.2.1 Data Collection Instrument

Information was gathered by asking people questions. The main instrument used to collect data was an online survey. The process of creating the survey followed the work of Groves et al. (2009) where sequential steps were taken until data was collected. The online survey was elaborated in Microsoft Forms and sent out via email to a self-built mailing list. The survey was improved based on two rounds of feedback provided by peers, members of IKEM´s communications team, and experts in the field, before it was sent out. The *Annex II – Online Survey Constructs, Measurements, and Questions* present the survey design and all the logical steps taken to derive survey questions and measurements from constructs and research questions.

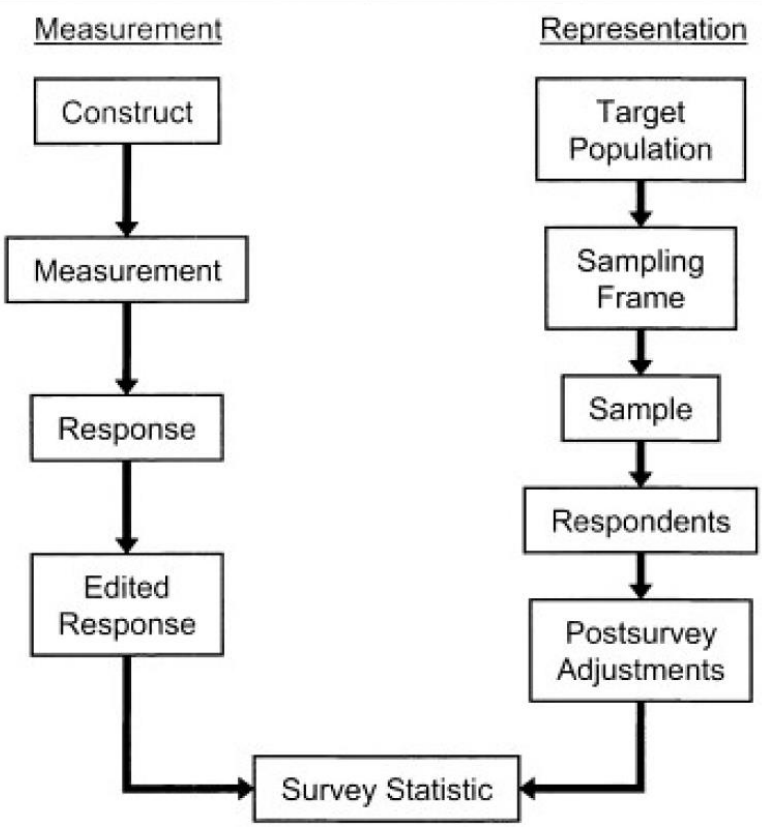

Figure 1 Survey Lifecycle

Source: Groves et al. (2009:42)

The following sections and subsections will describe the steps taken for ensuring the quality of the survey from the design. From a design perspective, survey designs move from abstract ideas to concrete actions (Groves et al. 2009:41). This process is carried out within the so-called *Survey Lifecycle*, as described in *Figure 1*. In the specific case of this research, as mentioned in the previous sections, abstract ideas were collected in a previous report, namely: emerging principles, concepts, and business models from the circular economy (see Mercado 2018); the concrete actions, on the other hand, are referred to collecting expert's opinions regarding the potential implementation of the circular economy approach in Berlin's construction industry.

During the design phase of the survey, which enabled moving from design to execution, the following steps were taken.

Step 1 – Identifying Research Questions:

Research questions, in this sense, are the objectives of the study, the uncertainty the research wants to resolve. For the specific case of the research, research questions were elaborated based on the report carried out previously by IKEM within the framework of the Kopernikus ENavi project (see Mercado 2018) which identifies a narrow set of elements on which expert opinion is of interest. Thus, the first step in the design of the survey consisted in the identification of research questions aiming at capturing expert's opinion in Berlin's construction industry.

Step 2 – Defining Survey Constructs:

Constructs are the elements of information that are sought by the researcher; in some sense, constructs are ideas and can be abstract (Groves et al. 2009). In the case of the survey in question, the constructs were developed based on the research questions identified in the first step following a deductive approach.

Step 3 – Selecting Measurements:

Measurements are ways to gather information about constructs from respondents; are more concrete than constructs, since they are often the questions posed to a respondent. A critical aspect is that they aim at producing the answers reflecting the constructs that the survey is trying to measure (Groves et al. 2009). In the specific case of the survey, the measurements were either 1) Multiple Choice, when the expected answer was to some extend pre-defined; 2) Scale, where the respondent can answer in neutrality over a question being asked; or 3) Open Question, when the respondent can elaborate freely his/her answer.

1.2.2 Online Survey Design

The online survey was structured in seven sections. The first section aims at describing the general background of the respondents, for providing a clear understanding of where the answers are being provided. Between the second and forth section, the principles, concepts, and business models from the circular economy are presented to assess the awareness of the respondents in the topic. The fifth section deals with the existent institutional framework that could, in the opinion of the key stakeholders, enable the implementation of the principles, concepts, and business models from the circular economy. Finally, the sixth and seventh sections addressed the barriers and drivers for the implementation of emerging principles, concepts, and business models from the circular economy in Berlin's construction industry. The following sections describe in detail the contents of each section of the online survey and rationale.

Survey Section 1 – Company description

Table 1 Survey Section 1 – Overview

Research Question(s): - Which is the stakeholder background? In which part of the building's lifecycle does it play a role/has an influence? - Are small companies more interested in changing paradigms in the construction industry?
Construct(s): - Perceived company/stakeholder's role in the value chain - Perceived willingness to change paradigms
Measurements - Multiple Choice, Scale

Source: Own elaboration

This section seeks to gather descriptive information to gain insight into the general characteristics of the company in which key informants operate, as described in detail in the *Table 1* below. Furthermore, the information collected in this section makes it possible to establish connections between the position the company occupies within the supply chain and possible implementation of principles, concepts, or business models of the circular economy.

Section 2 – Knowledge/awareness of the Circular Economy Approach

This section aims at gathering expert's opinion about the impacts of the prevailing linear model in which the construction industry is immersed. It also seeks to know the perception of experts about the impacts (mainly environmental) generated by the construction industry activities along the supply

chain, that is, from the stage of extraction of raw material to waste management, as detailed in the *Table 2* below.

Table 2 Survey Section 2 – Overview

Research Question(s): - What are the perceived consequences of the current linear model by stakeholders of the construction industry?
Construct(s): - perceived effects of the linear model in key stakeholder's business/activities - perceived amount of raw materials necessary to produce one unit of construction materials - perceived amount of raw materials that go to waste at the end-life phase of the products life cycle - perceived economic model where the industry is immersed: The Linear Model or the "take-make-dispose" model
Research Question(s): - How resource/energy/CO_2-intensive do stakeholders think the construction industry is?
Construct(s): - perceived increased input of raw materials to manufacture construction materials - perceived drivers for an increase in the volume of building construction [population growth, migration, others] - perception of necessary energy to construct buildings and satisfy building's energy consumption - perception of CO_2 produced by the industry - perception of environmental impacts generated by the industry
Measurements - Multiple Choice, Scale, Open Question

Source: Own elaboration

Section 3. Knowledge/awareness about key concepts of the Circular Economy

Table 3 Survey Section 3 – Overview

Research Question(s): - How knowledgeable are the stakeholders about the circular economy concept, key features, and principles?
Constructs: - perception about the circular economy - perception about 3R's principles: Reduce, Reuse, Recycle - perception about cradle-to-cradle - perception of material flows/loops: Biological Cycle and Technological Cycle and its differences - perception about cradle-to-cradle inspired buildings - perception about Zero-waste principle - Perception about Eco-efficiency
Measurements - Multiple Choice

Source: Own elaboration

Starting from the third section of the online survey, questions are asked specifically about the circular economy approach. Since the concept of the circular economy is still an emerging one, some of the informants may not know precisely what it is about. Therefore, the first step of the section provides detailed information about concepts and principles of the circular economy (which were identified previous in IKEM's report (see Mercado 2018) which analyses the main concepts and principles of the circular economy applied in the built environment research). Later, in a second step, informants are asked about the information presented in the first step. The constructs of the third section are detailed in the *Table 3*.

Section 4. Knowledge/awareness about Business Models of the Circular Economy

As in the fourth section of the survey was conducted in two consecutive steps: the first provides information about business models of the circular economy (the circular business models (CBM) were identified in the IKEM report (see Mercado 2018) and focus on three main stages of the life cycle of buildings, namely: design, use, and recovery). In the second step, questions are asked about informants' knowledge of the information presented in the first step. The *Table 4* presents the constructs and measurements for answering the research questions in the fourth section of the survey.

Table 4 Survey Section 4 – Overview

Research Question(s): - Which Circular Business Models are known to the construction industry and which ones could be implemented?
Construct(s): - Perception about Circular Business Models - Perception about Circular Design Business Models - Perception about Circular Use Business Models - Perception about Circular Recovery Business Models
Measurements - Multiple Choice

Source: Own elaboration

Section 5. Institutional Framework

The fifth section of the survey seeks to understand the role played by the local and national institutional framework in the implementation of principles, concepts, and business models of the circular economy in the local context. It also seeks to examine the role that networks can play in the dissemination of information among industry actors, as described in the *Table 5*.

Table 5 Survey Section 5 – Overview

Research Question(s): - Which is the existing institutional framework?
Construct(s): - Perceived institutions in place - Perceived institutional impact in pushing the discussion forward - Perceived role of the trade and professional associations - Perceived role of the networking and cooperation
Measurements - Open Questions

Source: Own elaboration

Section 6 & 7. Barriers and Drivers

Table 6 Survey Sections 6 and 7 – Overview

Research Question(s): - Which are the barriers/drivers for implementing CE principles and business models in the construction industry?
Construct(s): - Perceived barriers - Perceived drivers
Measurements - Open Question

Source: Own elaboration

The sixth and seventh sections ask the opinion of key informants about the main barriers and drivers to implementing circular economy principles, concepts, and business models in the local construction industry. Therefore, only open-ended questions were asked to allow informants complete freedom to elaborate their answers. The *Table 6* above presents the constructs and measurements for answering the research questions in the sixth and seventh sections of the survey

1.2.3 Data Collection and Sampling

This research sought to explore Berlin's key stakeholders' awareness of the principles, concepts, and business models from the circular economy in the construction industry. Generally, when conducting a survey, information is collected from only a subset of the population to be described (a sample) rather than from all members. In the specific case of this research, it was intended that information should be collected from selected stakeholder groups regarded as interesting information providers and illuminative – that is, they offer useful manifestations of the phenomenon of interest (Patton 2002:40). Hence, a set of key players working in Berlin's construction industry, was selected because they were information-rich, and they could be helpful to determine whether: 1) they are aware of circular economy approach, in general; and 2) they are currently implementing circular business

models or would they consider to do so. Consequently, the selection of potential respondents in this research did not sought a statistical representativeness from a sample to a population. Rather, following Yin (2009), individual cases or respondents are to be selected as: "*a laboratory investigator selects the topics of a new experiment*" (Yin 2009:38). Thus, a sample of potential respondents was selected from the entire population of the construction industry, to meet the research interests and expectations.

Table 7 Stakeholder's Groups

Contracting and planning	- Building contractors - Housing companies - Building refurbishment companies - 'Green' Architects
Foundations and Framing	- Metal construction - Steel construction - Window & door mounting - Timber construction - Dry construction - Cement

Interior Rough-in	- Mechanical roughs
	  o Electrical and lighting
	  o HVAC systems
	  o Heating supply
	  o Plumbing
	- Installations
	  o Insulation
	  o Kitchen assembly

Finishing work	- Bathroom furnishings - Flooring - Paint – interior & exterior - Plastering – interior & exterior
Other	Building associations

Source: Own elaboration

Accordingly, a data base of companies working in the construction industry in Berlin was built based on information available in the internet. The stakeholders are grouped into 5 subgroups as can be seen

in the *Table 7* above. Data was collected from 186 companies in the construction market in Berlin. From each company the contacts details were collected, including website address, email address, and name of the company's general manager; the data collected was then used to send the access link to the online survey. The aim was to have a homogeneous distribution of all the groups in the sample, however, some groups, such as the cement industry for example, have relatively fewer companies in the Berlin market. The complete list of the contacted stakeholders is to be found in the *Annex I* – .

The survey was sent out per email on 07.05.2019 and 23.05.2019. None functioning email addresses during the first batch were removed from the mailing list before the survey was sent out the second time. The partition in the survey was completely anonymous, which allows to guarantee that the information has been freely given.

1.2.4 Data Analysis and Data Triangulation

Online Survey

The different response formats to the survey questions were evaluated in a descriptive manner, to answer the research questions and constructs elaborated in each section. The multiple-choice questions made it possible to concretely identify and measure the information sought by each construct/research question. The survey questions were presented in a rating scale format[2] they made it possible to indicate the trend in which the opinion of the respondents is inclined, in other words, a general representative opinion about the topic in question. On the other hand, when survey questions were presented in a dichotomous scale format[3], the question was always followed by 'why?'; this enabled responder to explain the underlying reason for his answer in a written form.

Focus Group

As mentioned in the *Data Collection and Sampling* section, the research design considered qualitative tools for data collection, namely: an online survey and focus groups. Although the primary instrument for data collection was the online survey, the implementation of focus groups as a second tool served two main purposes. On the one hand, focus groups are often used to gain a more realistic perspective of the research field (Flick 2009). On the other hand, triangulation refers to the use of multiple methods or data sources in qualitative research to develop a comprehensive understanding of

[2] A rating scale provides more than two options, in which the respondent can answer in neutrality over a question being asked.
[3] A dichotomous scale is a two-point scale which presents options that are absolutely opposite each other. This type of response scale does not give the respondent an opportunity to be neutral on his answer in a question.

phenomena (Patton 1999, Caillaud & Flick 2017). For those reasons, a focus group was carried out on June 21st, 2019 at IKEM's offices in Berlin. During the meeting, the main results of the online survey were discussed with key experts in the field to assess the representativeness and relevance of the responses obtained.

Content Analysis

The main objective of the data analysis is to make sense of the empirical data. The empirical data accounts for the responses to the open questions asked in the online survey and transcripts of the focus group with experts. The data were entered in MAXQDA[4], and a comprehensive process of data coding and identification of themes was undertaken. This process is also known as Thematic Content Analysis. According to Fereday & Muir-Cochrane (2006) is a search for emerging themes as being important to the description of the phenomenon under study. The process involves the identification of themes through "*careful reading and re-reading of the data*" (Rice & Ezzy 1999:258). It is a form of pattern recognition within the data, where emerging themes become the categories for analysis (Fereday & Muir-Cochrane 2006). The data analysis was an iterative and reflexive process; this interactivity, applied throughout the process of qualitative inquiry, was differentiated in three main stages: transcription, analysis, and reporting.

[4] MAXQDA is a professional software for qualitative and mixed methods data analysis.

II. Theoretical Background

As mentioned in the *Introduction* section, the research is a sequel to an earlier research carried out between 2017 and 2018 by IKEM within the framework of the Kopernikus ENavi project[5]. The research was focused on the implementation of concepts, principles, and business models and circular economy in the construction industry. Therefore, the conceptual framework compiled in the earlier research, is the basis for exploring the opinion of relevant actors in the construction industry. Likewise, the design of the online survey, which was presented in detail in the previous sections, also retrieves this conceptual framework to: 1) elaborate the research questions, constructs, and measures of the online survey; and 2) provide such information during the survey, so that the respondents have a homogeneous knowledge when answering the survey.

Thus, the following sections and subsections present a very synthetic summary of this information, so that the reader can follow the knowledge line that led to the creation of the online survey, and so that this document is understandable on its own.

1.1 The Built Environment, the Linear Model, and the Limits to Resource Consumption

IKEM's research (see Mercado 2018) showed, 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 CO_2 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' lifecycle; namely: 1) improving buildings'

[5] This section and its subsections provide a very condensed summary of the work done by the author in a first IKEM report within the framework of the Kopernikus ENavi project. To see the complete bibliographical reference, see Mercado (2018).

thermal envelope and implementing energy efficient HVAC systems. However, the analysis and implementation of measures in early stages of building's lifecycle (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.

1.2 The Circular Economy Approach – an Emerging Concept

The research conducted an in-depth review of the circular economy (CE) concept, that has been installed in research about the built environment. The review reveals that the origins of the CE concept go back to the seminal work of Boulding (1966) who suggests the implementation of a cyclical ecological system instead of a wasteful linear economic model, as shown in the *Figure 2* below. The scheme proposed by Boulding had inspired later the conceptual discussion of sustainable development, as the literature review showed. Critics argue that the CE 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.

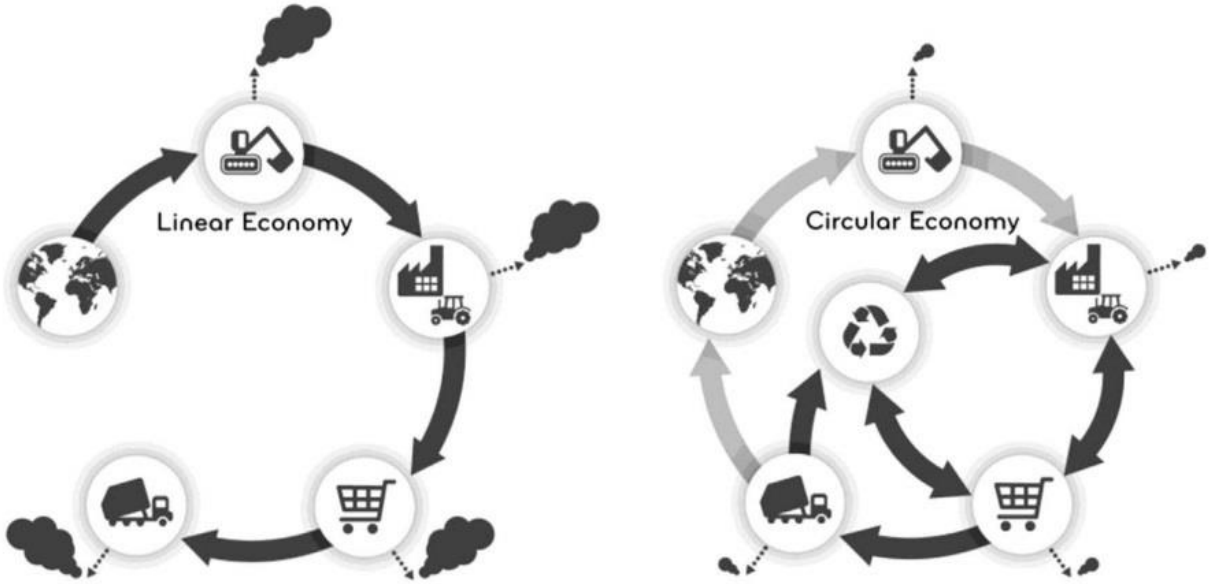

Figure 2: Contrasting the Linear and Circular Models
Source: Sauvé et al. 2016:52.

The CE model promotes resiliency of resources. It aims to replace the traditional linear economy (LE) 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 CE 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 CE model aims to emulate processes like those that occur in natural environments, where waste is reduced, and most is recuperated by another species. Moreover, competition and cooperation among species occur in nature, thereby maintaining the efficiency of natural ecosystems and certainly providing flexibility and adaptability, the same should take place in the built environment. Applying this approach to economic systems could help ensuring healthy competition and maximum efficiency of usage of available resources.

1.3 Circular Economy Principles

The relevant literature discusses the principles of the circular economy. *The Table 8* presents in the column on the left three fundamental principles put forward by the Ellen Macarthur foundation (EMF) 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 8 Circular Economy Principles for the Built Environment

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

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.

Figure 3 Towards Circular Buildings

Source: www.usefulprojects.co.uk

The *Figure 3* 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.

1.4 Implementing the Circular Economy – the Circular Economy Business Models

The circular economy (CE) concept has been widely discussed from several perspectives, namely: the scientific literature (mainly from the industrial ecology perspective as a concept related to sustainable development), the grey 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). Moreover, the implementation of CE concepts in the construction sector is being carried out slowly through business models and start-ups, as IKEM's research suggested.

IKEM's research (see Mercado 2018) identified key CE 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 examples, 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.

A paradigm shift in the current model, from linear to circular, could generate relevant benefits for key players within the construction industry. The ARUP`s report (2016) identifies some benefits that could be obtained when implementing different CBMs in different stages of the value chain. The *Figure 4* 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.

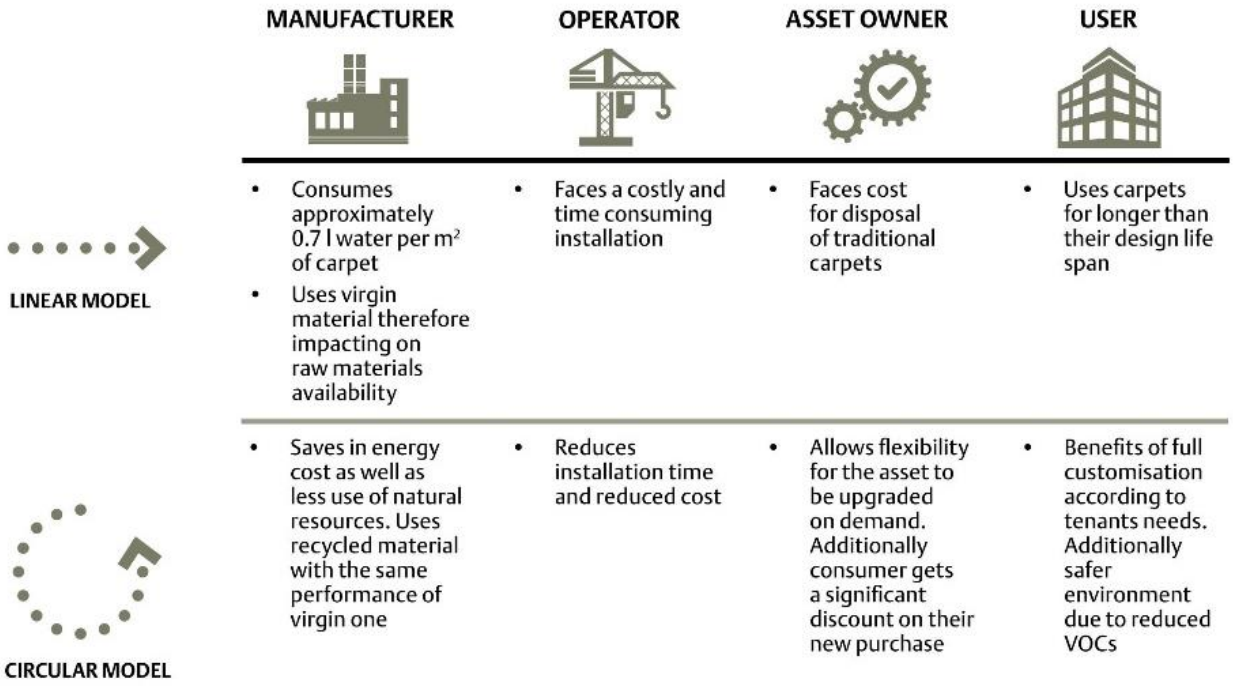

Figure 4 Benefits to stakeholders in Circular Business Models
Source: ARUP & BAM (2016:28)

CBMs could be implemented in different phases during the whole lifecycle of a building or 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 literature also discusses areas of research or strategic business perspectives that allow accelerating the process of adopting principles of the CE in the construction industry.

As mentioned above, 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' lifecycle is extended, either after a stage of reconditioning or a change of its use, or through the recycling of resources/materials.

III. Research Findings and Discussion

The following sections and subsections present the analysis of the main results of the online survey on the role of the circular economy in the construction industry in Berlin, conducted in by IKEM during May 2019. As mentioned in the methodological section, the main results of the survey were discussed in a discussion group between IKEM researchers and experts from re!source and Circular Building UG.

The analysis and discussion of survey findings with experts in the field was fundamental to enable content analysis of empirical information. Thus, thanks to the work carried out in the focus group, it was possible to identify thematic categories for the coding and content analysis as detailed in the respective sections of the methodological chapter. The following subsections and their contents are structured based on the emerging categories of the thematic analysis.

1.1 Response Rate and Survey Participants Description

As mentioned in the data collection sections, the survey was sent twice to a database built within the framework of the research about a selected group of companies in the construction industry in Berlin with information available on the internet. To reach a larger number of respondents, the survey was disseminated through IKEM's newsletter and the EUWID [6]portal. The response rate of the survey was 10 % of the total sample.

All responses came from general managers; mainly from small companies or with less than 50 employees; only fewer responses from companies between 51 and 250 employees. Most companies are either open for innovation or passive about implementing new concepts in their business. This shows indications that small businesses within the construction industry are more open to innovation in their business models and construction traditions within the industry.

1.2 Current Trends in the Construction Industry

Empirical findings show that the residential real estate sector in Berlin will have a significant growth until 2050, continuing with the current trend. Survey respondents mentioned that this growth will be trough the construction of new buildings, as well as the increase in the modernization rates of the existing stock. The following exemplary quotes illustrate the latter.

[6] See: https://www.euwid.de/

Survey Question: Will the construction of new buildings in the city increase significantly by 2050? [Q14]

- *yes, because the user expects larger flats than in the last century (rebound), which the old stock does not offer - or if then by e.g. merging of smaller units…* [Survey Participant]

Survey Question: Will the renovation of existing buildings in the city increase significantly by 2050? [Q15]

- *Yes. (see above) Revitalisation of brownfield sites and rehabilitation of defective buildings or dismantling of existing contaminated or toxic building materials: before. Asbestos in seals and panels / PCP, lindane, DDT in wood preservatives, PAH in adhesives, etc.* [Survey Participant]

According to the BPIE´s report (2015) renovating the German Building stock is not an easy task, but it could be a profitable one for the investors. Nonetheless, it would be feasible with the creation of 1) a comprehensive policy framework including the lowering of transaction costs; 2) increased energy price signals; and 3) implementing targeted subsidies. Once the abovementioned steps are taken, almost of the German building stock, except for residential buildings younger than 20 years, could be renovated with a positive pay-back within the next 15 years. However, the currently existing policy framework seems to be insufficient to achieve the government's long-term goal of decarbonising the building sector as the renovation of only 33% of the floor area is cost-effective within the next 15 years (BPIE 2015).

Empirical evidence suggests that the growth of residential stock in Berlin, whether through the construction of new buildings or the renovation of the existing ones, will follow the current conditions of the linear production model, as discussed in the following sections.

1.3 "Take-make-dispose model" or "linear model" – recyclability

When asked whether the construction industry is immersed in a linear paradigm, most of the survey responders mentioned that are not sure. The key experts, on the other hand, stated that the construction industry is evidently immersed in a linear model. Thus, the processes within the supply chain in the construction of residential buildings in Berlin are currently open processes. Moreover, it was mentioned that the processes are cradle to grave.

The following example, based on the provision of technology for buildings, shows the lack of closed loops in the supply chain of industry.

- *Considering the case of building technology, the product goes from the manufacturer to the wholesaler, from the wholesaler to the craftsman and from the craftsman to the customer. The wholesaler does not know the customers nor his interests. This is the problem of trade, that the trade does not know at all… the customers are always only interested on the suggestions of the craftsmen. If the handyman says to the consumer "that's good for you" they'll take that. But there is no looking right and left and no looking for consequences … the chain is not closed …* [Key expert in the focus group]

It is also important to note that there is no evidence to show that products produced for and by buildings return in any way to the producer. Isolated initiatives by producers who are seeking to close production cycles, such as Phillips[7] and IKEA[8], are still at an early stage and focus on electrical appliances or furniture, so that products that are part of structural elements or other building components, such as doors and windows for example, are still within the linear production model.´

Today, the end-of-life of buildings definitely means the demolition and subsequent disposal of building demolitions. There is a serious problem of recyclability, as illustrated by empirical evidence. The problem has two main components and presents several complexities.

Product Recyclability Potential and Recyclability Readiness

In general, building components are a sum of several building materials. Therefore, when it is intended to recycle any component of it, it is necessary to review which elements or materials are composed, to what extent and which can be recycled. The following quotation highlights this.

- *You must distinguish between recycled products that are used and recyclable products (…) Are the products made of recycled material? They may be made from primary raw materials, but they are completely recyclable. For certain raw materials, there is not enough recycled material to meet the demand. For example, aluminium windows. The recycling rate is about 40%. But you could do 80-90%, only the material is not there. So, you can say that I want recycled material, but then you would have to collect it somewhere else. More importantly, you use products that are recyclable, with a high recycling potential…* [Key expert in the focus group]

[7] For details about product recycling services for Philips see: https://www.philips.com/a-w/about/sustainability/sustainable-planet/circular-economy/product-recycling-services.html
[8] For details about IKEA´s removal and recycling services see: https://www.ikea.com/ms/en_JP/customer-service/about-services/removal-and-recycling/index.html

Material Separation

Depending on the construction system used, most of the building elements are made of various construction materials. The figure below shows, by way of example, the diversity of materials that could constitute a building element in this case an external wall. As can be seen, there is a variety of elements and materials that make it possible to achieve certain optimum criteria of structural and thermal behaviour. The work of bringing all the materials together obviously presents a significant energy effort, so the embodied energy values are also significantly higher.

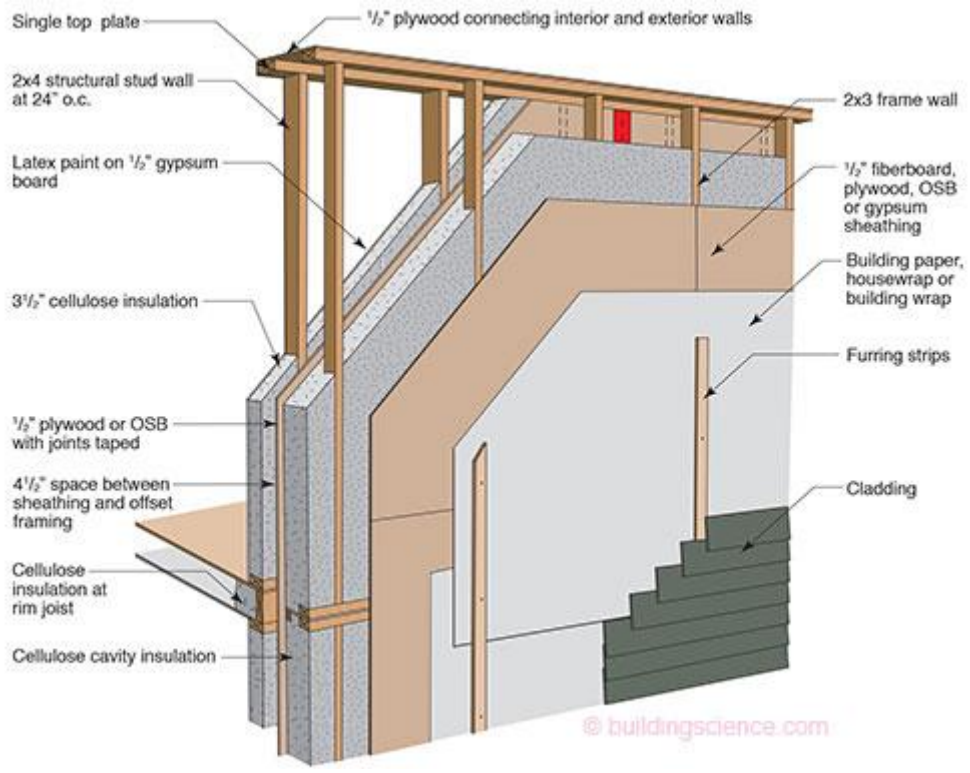

Figure 5 Double Stud Wall Construction

Source: buildingscience.com

Beyond the energy effort that would mean to separate all these materials again when trying to recycle them, it is very likely that the waste can be recycled properly because of the high levels of pollution that there is when joining the different layers. Therefore, the sometimes the only alternative and very often the most common alternative is to dispose the materials. With this, the embodied energy values and the CO_2 capture made in the manufacturing process of the materials is lost. One of the fundamental reasons for this is the lack of availability of the market, which does not have the processes, services, or interests necessary to enable the closure of processes in the construction industry. The quotation below emphasizes what has been said.

- *The recycled materials … a) Can they be recycled and b) are the processes for that? Are there collection organisations, processing organisations that recycle at the same high-quality level? This must be certified, and it must be verifiable that such procedures exist. With paper it is different, there is enough wastepaper, therefore one can say, it is recycled paper. But with many building materials there is not enough material… You always have the primary material coming in, and you have a secondary material. And this is then mixed, if it is, for example, a metal, it is no problem to mix both, because it is identical on an atomic basis.* [Key expert in the focus group]

1.4 Main Impacts of the Construction Industry

IKEM´s recent research showed that a large share of construction materials for residential buildings in Berlin is reinforced concrete. When analysing the embodied energy of reinforced concrete, it becomes clear that it has significantly higher embodied energy values with respect to other building elements/materials. Thus, the cement industry, which is a major player in the construction of reinforced concrete buildings, within the traditional building construction generates significant environmental impacts.

First, the cement industry is a significant but silent source of CO_2 ; according to a recent publication by FAZ (2019) the cement industry is one of the largest emitters of climate-damaging greenhouse gases, but it is still a silent one because is hidden in building' structure and streets all over the world. The World Wildlife Fund (WWF in FAZ 2019) has estimated its share of global emissions at 8 percent, which would be significantly more than the total volume of air traffic.

Second, within building's construction, cement is not used alone as a building material in the construction of individual building elements. It is used in conjunction with mainly water and aggregates such as sand. For now, we will leave aside the discussion about water scarcity, which is a very levant issue on its own. The issue of sand sufficiency to meet the demand of the construction sector has been widely discussed in the scientific literature as well as in grey publications. A recent UNEP publication (2019) states clearly:

- *"The needs and expectations of our societies are driving the demand for sand resources, but a continued responsible supply cannot be assumed without improved governance of global sand resources"* [UNEP 2019:16]

From the perspective of the circular economy, this is once again a call to enable and improve conditions, processes, and business models that allow for an increase in recycling rates for reinforced concrete in general, and cement, sand, and aggregates.

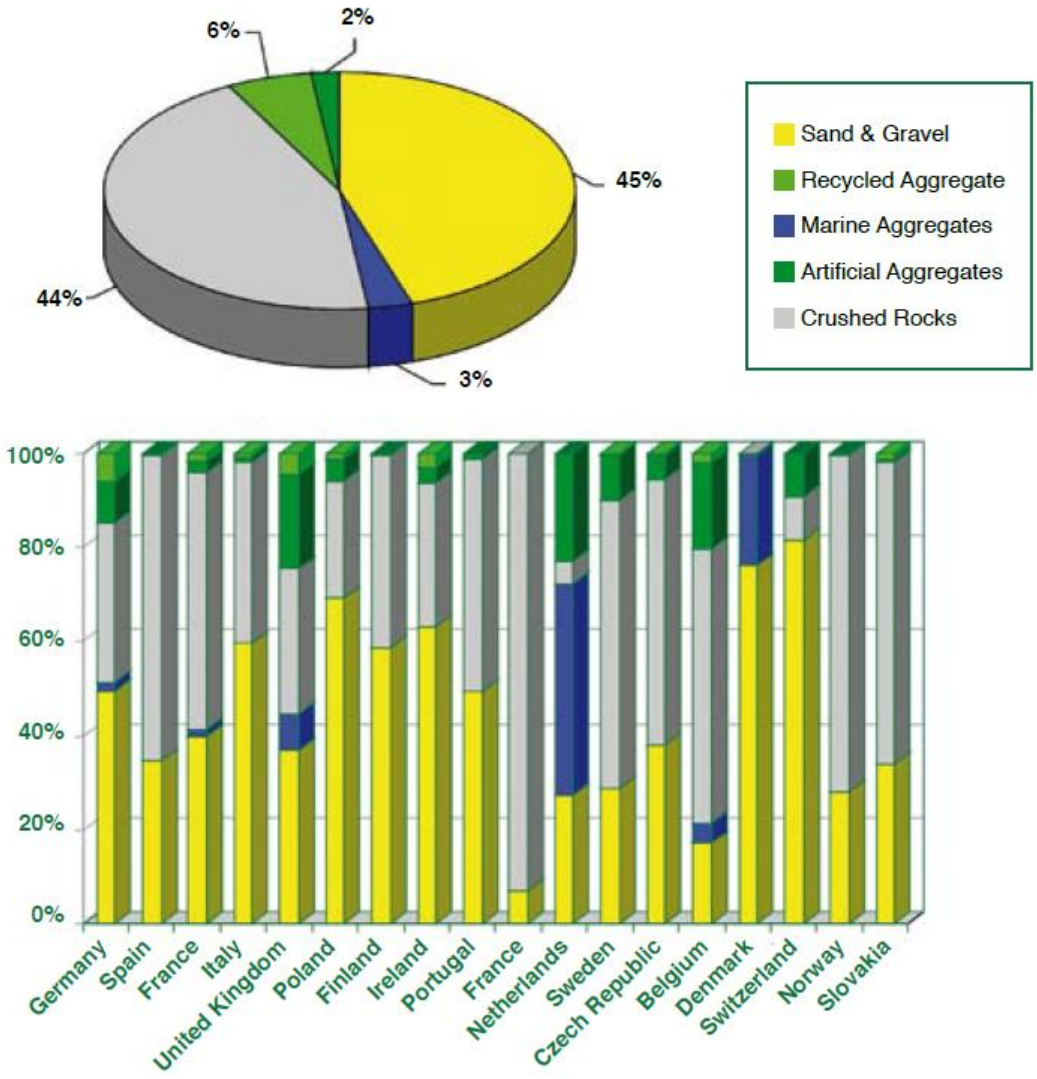

Figure 6 Total production of aggregates used in the Building and Civil Works activity in the EU
Source: UEPG (2006:2)

The European Aggregates Association (UEPG 2006) identifies an interesting potential for construction waste recycling as a significant renewable source of recycled aggregates. Thanks to the continuous improvement of the legal framework, incentives from competent authorities and technical innovation, some European countries have achieved a high recovery rate of construction waste. As shown in the *Figure 6*, nonetheless, the share for recycled aggregates to the total production of aggregates used in the Building and Civil Works activity in the EU remains low (6%). Germany shows the same trend and shows a significant demand for sand and gravel, which is satisficed (partially) from natural local sources, with some with a growth in imports from neighbouring countries.

1.5 Main Barriers and Drivers

Main Barriers

In the opinion of the survey participants, the main barriers to enable a transformation in the construction industry towards circularity of the industry, through the implementation of concepts and business models of the circular economy, focuses on two main topics: the lack of information and the lack of economic attractiveness in the implementation of new business models. The following quotes account for that.

- *Information deficits and difficulties of the industry lobby: DIN commissions draw up the "generally recognised rules of construction engineering" and use various pseudo-legal obstacles to prevent the dissemination potential or competitiveness of natural building materials. --> (e.g.) According to the updated DIN, a calculated surcharge of up to 20% on the potential moisture content of Nawaro insulating materials in the installed state must be added for the hygric and thermal dimensioning - due to the high sorption capacity of these insulating materials (!). The aggregate thus increases the calculated thermal conductivity and then "mathematically" reduces the excellent technical product properties "on paper". In fact, the sorption capacity conductivity is a high advantage to store diffusing moisture in the component for a short time and to dissipate it to the surface of the component by capillarity according to the heat flow; this means that the natural insulating materials tend to behave in a manner contrary to mould, but is unfortunately communicated to the contrary...*
- *Economically unattractive, misguided by regulatory law.*

Main Drivers

According to survey participants, the most important drivers for the implementation of concepts and business models of the circular-flow economy in the construction industry are manifold. The most relevant are listed below.

- *The young generation, such as Fridays for Future, demand the implementation of climate- and resource-saving concepts. They can become the most important driver, as they now openly demonstrate the generation conflict.*
- *NBB as far as understandable for the public - at least not KfW*
- *Political initiatives of individual politicians / actors*

IV. Conclusions and Further Research

A sample of the whole universe of companies active in the construction industry took part in the online survey carried out by IKEM about the possible implementation of an alternative model to the linear model in the supply chain of the construction industry - characterized by an intensive consumption of resources and energy in open processes within the industry - and its potential implementation through principles and business models of the circular economy. The empirical evidence found is not representative of the entire universe of companies active in the construction industry in Berlin, as it shows the perspective of a selected group of actors. However, the results indicate the strong need to implement a paradigm shift in the construction industry towards circularity.

Thus, the results of the research, collected in the opinion of experts, highlight the linear model in which the supply chain of the construction industry in Berlin is immersed. Based on examples of some building materials and processes within the supply chain, evidence is gathered of the linearity that characterizes the traditional form of construction. The lack of information and the availability of products and services in the construction industry are mentioned as major barriers to the enabling of the circular economy in Berlin.

The information presented within the online survey was collected in the international discussion, within the previous research conducted by IKEM between 2017 and 2018. The survey participants and experts in the field share the results obtained and find significant parallels with the Berlin and German reality, which demonstrates the relevance of the research. The following lines of future research can also be identified:

Qualitative Research

As mentioned, data collection focused on a very narrow segment of the construction industry. The next step from a qualitative perspective should be to broaden the sample in search of representativeness. To this end, it is intended to carry out an update of the online survey involving: 1) a significant reduction in the duration of the survey response time; 2) an update of information about the circular economy (mainly principles and business models) contained in German literature; 3) the creation of new cooperation networks to enable the market readiness.

Quantitative Research

One of the barriers detected for the implementation of emerging business models of the circular economy was the lack of economic attractiveness. In order to overcome this obstacle, it is necessary to identify the existing circular business models in the Berlin construction industry and to thoroughly review their financing structure in order to highlight the potential benefits for their implementation in the industry.

Mixed methods

The lack of information about the recyclability of construction products was mentioned as one of the most relevant drivers for the generation of waste from the construction industry, mainly at the end of the life cycle of buildings. To address this issue from research-based generation of policies, it is necessary to conduct research that combines qualitative and quantitative evidence.

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Annex I – Key informants in Berlin's construction industry

#	BRANCHE	ORGANISATION/UNTERNEHMEN
1	Badeinrichtung	Aloys F. Dornbracht GmbH & Co. KG
2	Badeinrichtung	GOLDMANN BADMANUFAKTUR
3	Badeinrichtung	Hornbad GmbH & Co. KG
4	Badeinrichtung	Bad Couture Thomas Klink
5	Badeinrichtung	WEGO Sanitär- und Fliesenfachgeschäft
6	Badeinrichtung	Bergmann & Franz Nachf. GmbH & Co. KG
7	Badeinrichtung	Willimat GmbH
8	Badeinrichtung	Elements GmbH- ELEMENTS BERLIN-CHARLOTTENBURG
9	Badeinrichtung	marmo e terracotta / agape149
10	Badeinrichtung	Peter Baumgarten Einrichtungen
11	Bauunternehmen	CONCRETE Bauunternehmung GmbH
12	Bauunternehmen	ARGE-HAUS GmbH Generalunternehmer
13	Bauunternehmen	ANES Bauausführungen Berlin GmbH
14	Bauunternehmen	Horst Kasimir Bauunternehmung GmbH
15	Bauunternehmen	Ahle, Fischer & Co. Bau GmbH
16	Bauunternehmen	Rösler GmbH Bauunternehmen
17	Bauunternehmen	ASEG Bauunternehmen GmbH
18	Bauunternehmen	Köster GmbH
19	Bauunternehmen	Wörpel Bau GmbH
20	Bauunternehmen	Günther Bau GmbH
21	Beleuchtung	Lichthaus Mösch & Projektgesellschaft mbH
22	Beleuchtung	Lichthaus Mörcke
23	Beleuchtung	ARTYLUX
24	Beleuchtung	LIGHT-TOOL | Design & Programmierung Zimt und Zucker GmbH
25	Beleuchtung	GUSTAV HAHN GmbH
26	Beleuchtung	Rosenthallicht
27	Beleuchtung	Carola Späth Licht + Design
28	Bodenbeläge	Feller GmbH
29	Bodenbeläge	Reste - Eck M.Fürst GmbH
30	Bodenbeläge	Bodenwelten Herz GmbH
31	Bodenbeläge	Teppich Hill Berlin
32	Bodenbeläge	Bodenart
33	Bodenbeläge	Firma Barbara Glischke Parkett & Bodenbeläge
34	Bodenbeläge	Raumhaus GmbH
35	Bodenbeläge	berlin-parkett.de (Krupper & Schäfer GmbH)

#	BRANCHE	ORGANISATION/UNTERNEHMEN
36	Bodenbeläge	VLOORS Berlin (Handyfloor GmbH)
37	Bodenbeläge	TFB Treptower Fussbodenbeläge GmbH
38	Dämmung	isofloc Dämmstatt GmbH
39	Dämmung, Altbausanierung, Stuckarbeiten	Malermeister Kohls
40	Dämmung, Dacharbeiten	Pilch Dachbau GmbH
41	Dämmung, Dachdecker	Dachdecker Holzapfel und Schulze GbR
42	Dämmung, Fassadensanierung, Malerarbeiten, …	Lorenz Malermeister Fassadensanierungs- GmbH
43	Dämmung, Innenausbau, Objektsanierung	Bausanierung Ralf Jahnke GmbH
44	Dämmung, Innenputz, Außenputz	HEIDA BAU GmbH
45	Dämmung, Sanierung	Wissmann GmbH
46	Dämmung, Trockbau, Hochbau, Demontage	KATI GmbH & Co KG
47	Dämmung, Wasser, Elektro, Sanitär, Heizung, Sanierung, …	Bossmann GmbH Berlin
48	Fachmedienanbieter	EUWID
49	Fenstermontage	möller Fensterbau
50	Fenstermontage	FensterBerlins
51	Fenstermontage	Fenster-komm
52	Fenstermontage	MeKo Fenster GmH
53	Fenstermontage	Fenster Möller
54	Fenstermontage	Hans Timm Fensterbau GmbH & Co. KG
55	Fenstermontage	DF Deutsche Fensterbau GmbH
56	Fenstermontage	SKW Fenstertechnik GmbH
57	Fenstermontage	Fenster-Bude
58	Fenstermontage, Türmontage	HASKE - Fenster + Türen
59	Fenstermontage, Türmontage	Roberts Fenster
60	Fenstermontage,Türmontage	jensfrank
61	Gebäudesanierung	MATTIG & LINDNER GmbH
62	Gebäudesanierung	Toll und Toll Bau GmbH
63	Gebäudesanierung	DGI Bauwerk Gesellschaft von Architekten mbH
64	Gebäudesanierung	HWS - Ihr Renovierungsassistent
65	Gebäudesanierung	LorenzBau GmbH
66	Gebäudesanierung	Sainerung & Modernisierung Berlin
67	Gebäudesanierung	Wissmann-Baugesellschaft
68	Gebäudesanierung, Badeinrichtung, Heizung/Wärmeversorgung	Bossmann GmbH Berlin
69	Gebäudesanierung, Badeinrichtung, Maler, Heizung/Wärmeversorgung	PB-Bau Berlin GmbH
70	Gebäudesanierung, Badeinrichtung, Trockenbau, Maler	J.A. SANNER DIENSTLEISTUNGEN
71	Gebäudesanierung, Putzunternehmen	Bausanierung Ralf Jahnke GmbH
72	Heizung/Wärmeversorgung	BTB Blockheizkraftwerks- Träger- und Betreibergesellschaft mbH Berlin

#	BRANCHE	ORGANISATION/UNTERNEHMEN
73	Heizung/Wärmeversorgung	Helmut Schmidtchen e.K.
74	Heizung/Wärmeversorgung	VESTER + NIEMANN GmbH
75	Heizung/Wärmeversorgung, Fernwärme	Fernheizwerk Neukölln AG
76	Heizung/Wärmeversorgung, Fernwärme	Vattenfall GmbH
77	Heizung/Wärmeversorgung, Sanitär	Barthlomeyczik Heizung & Bäder GmbH
78	Heizung/Wärmeversorgung, Sanitär	Janke Heizungs- und Sanitärbaugesellschaft mbH
79	Heizung/Wärmeversorgung, Sanitär	Leuthäuser & Scharfe Sanitär und Heizungs GmbH
80	Heizung/Wärmeversorgung, Sanitär	Aquapower - Berlin Heizung - Sanitär GmbH
81	Heizung/Wärmeversorgung, Sanitär	Firma Böttcher
82	Holzbau	Elite Holzbau GmbH & Co KG
83	Holzbau	ABW oikoartec GmbH
84	Holzbau	MHB MONOLITH- und HOLZBAU GmbH
85	Holzbau	neues gesundes bauen.
86	Holzbau	Öko & Co. Holzbau Berlin Brandenburg
87	Holzbau	Schumann Construction GmbH
88	Holzbau	Zimmerei Carsten Wesolowski
89	Holzbau	WILLRODTS Naturholz & Ingenieurbau
90	Holzbau	HOLZ-SYSTEME BRENDEL
91	Holzbau	Kaden + Lager
92	Innen- Außenputz	Bussmann GmbH
93	Küchenmontage	Ammann Montageservice
94	Küchenmontage	Muvito Küchenmontage
95	Küchenmontage	Möbelmontagen Berlin
96	Küchenmontage	Küchenaufbau Berlin
97	Küchenmontage	Mirko Kelsch Küchen- & Möbelmontagen
98	Küchenmontage	Thomas Köhler Küchenmontagen
99	Küchenmontage	1A Montageservice Berlin
100	Küchenmontage	Küchenwelten Oppelt GmbH & Co. KG
101	Küchenmontage	KUMOTA Küchenmontage
102	Küchenmontage	Viktor Küchenmontage
103	Küchenmontage	Montage- und Möbelservice
104	Maler	Boche Malermeister GmbH
105	Maler	Oliver Grondowsky - Maler- und Lackierermeister
106	Maler	Peter Stock Malermeister GmbH & Co. KG
107	Maler	Knospe Malereibetrieb GmbH
108	Maler	Die Anstreicherinnen
109	Maler	Heinrich Bodden Malermeister GmbH & Co. KG
110	Maler	Leib Malerei GmbH
111	Maler	Malereiwerkstatt GmbH

#	BRANCHE	ORGANISATION/UNTERNEHMEN
112	Maler, Dämmung, Fassadensanierung, Türen, Fenster, …	Wolfgang Lüttgens GmbH Berlin
113	Maler, Fassadensanierung, Bodenbelag, Dämmung	Marotzke Malerbetrieb GmbH
114	Metallbau	Baginski GmbH Metallbau
115	Metallbau	Metallbau Kessler GmbH
116	Metallbau	Wehner Metallbau GmbH
117	Metallbau	Müller Metallbau
118	Metallbau	Müller Metallbau GbR
119	Metallbau	WS Metallbau
120	Metallbau	A.S.T-Metallbau GmbH
121	Metallbau	Wrusch Metallbau
122	Metallbau, Stahlbau	Arens GmbH Metallbau + Bauschlosserei
123	Metallbau, Stahlbau	SGB Ingenieur- und Stahlbau GmbH
124	Metallbau, Stahlbau	Becker Stahlbau Berlin GmbH
125	Metallbau, Stahlbau	FERROTEC GmbH Metallbau Messebau Ladenbau
126	Metallbau, Stahlbau	Habermann Metallbau GmbH
127	Metallbau, Stahlbau	L&S Metall- und Stahlbau GmbH
128	Nachhaltige Architekten	agu | Goldmann Landschaftsarchitektur
129	Nachhaltige Architekten	Hascher Jehle Assoziierte GmbH
130	Nachhaltige Architekten	Hirschmüller Schindele GbR
131	Nachhaltige Architekten	werk A architektur
132	Nachhaltige Architekten	Kolb Ripke Gesellschaft von Architekten mbH
133	Nachhaltige Architekten	MARS Gesellschaft von Architekten mbH
134	Nachhaltige Architekten	Peter Ruge Architekten GmbH
135	Nachhaltige Architekten	Deimel Oelschläger Architektenpartnerschaft
136	Putzunternehmen	Rasack GbR Innen & Außenputz
137	Putzunternehmen	Sebastian Rost -Meister und Restaurator im Stuckateurhandwerk GmbH
138	Putzunternehmen	KATI GmbH & Co KG
139	Putzunternehmen, Innen- Außenputz	KARRASCH BAU
140	Putzunternehmen, Innen- und Außenputz	NIEMANN BAU GmbH & Co. KG
141	Putzunternehmen, Innen- und Außenputz	ADFA Außen- und Innenputz GmbH
142	Putzunternehmen, Innen- und Außenputz	SAGA Bau
143	Putzunternehmen, Innen- und Außenputz	Romeo Zaccaria GmbH
144	Putzunternehmen, Sanierung	konsensus-Baugesellschaft mbH
145	Stahlbau	stabotec steel, move & service GmbH
146	Stahlbau	Simon GmbH Bau- & Industrieservice
147	Stahlbau	REBU Ingenieurgesellschaft für Stahlbauten und Anlagenbau mbH
148	Stahlbau	Stahlbau & Bauschlosserei Nimsz GmbH

#	BRANCHE	ORGANISATION/UNTERNEHMEN
149	Stahlbau	LHW Stahlbau + Schweißen GmbH
150	Stahlbau	R&R Metallbau GmbH
151	Trockenbau, Maler, Heizung/Wärmeversorgung,	JAEGER AUSBAU GMBH + CO KG BERLIN
152	Trockenbauunternehmen	INTRO Berlin GmbH
153	Trockenbauunternehmen	BECK Trockenbau GmbH
154	Trockenbauunternehmen	Mari Padobrin Trockenbau
155	Trockenbauunternehmen	Rami Akustik- & Trockenbau GmbH
156	Trockenbauunternehmen	Björn Schlesiger Akustik- und Trockenbaugesellschaft mbH
157	Trockenbauunternehmen	Aquapren-Berlin
158	Türmontage	BBC Montagen Gmbh
159	Türmontage	JANSSEN TISCHLEREI
160	Türmontage	BI-Bau UG (haftungsbeschränkt)
161	Türmontage	Gutsche & Schaub GbR
162	Türmontage, Fenstermontage	BADEJA
163	Türmontage, Fenstermontage	Nagai Dienstleistungsservice GmbH
164	Türmontage, Fenstermontage	Tischlerei Tinus GmbH
165	Türmontage, Fenstermontage	Tischlermeister Matthias Weber
166	Türmontage, Fenstermontage	TBB Türen Berlin Brandenburg GmbH
167	Verbände	Bauindustrieverband Berlin-Brandenburg e. V.
168	Verbände	Hauptverband der Deutschen Bauindustrie e.V.
169	Verbände	B.A.U. Bund Architektur & Umwelt e.V.
170	Verbände	Bauindustrieverband Ost e. V.
171	Verbände	Fachgemeinschaft Bau Berlin und Brandenburg e.V.
172	Verbände	Zentralverband Deutsches Baugewerbe
173	Verbände	Baugewerks-Innung Berlin
174	Wohnungsbauunternehmen	Wohnungsbaugesellschaft Berlin-Mitte mbh
175	Wohnungsbauunternehmen	HOWOGE Wohnungsbaugesellschaft Berlin GmbH
176	Wohnungsbauunternehmen	WOBEGE Wohnbauten- und Beteiligungsgesellschaft mbH
177	Wohnungsbauunternehmen	STADT UND LAND Wohnbauten-Gesellschaft mbH
178	Wohnungsbauunternehmen	GEWOBAG AG
179	Wohnungsbauunternehmen	Zentrum eg Wohnungsbaugenossenschaft
180	Wohnungsbauunternehmen	degewo AG
181	Wohnungsbauunternehmen	GESOBAU AG
182	Zement	Walter Schmidt Zement GmbH
183	Zement	Spenner Zementwerk Berlin GmbH & Co. KG
184	Zement	SCHWENK Beton Berlin-Brandenburg GmbH
185		Green Constructions GmbH

#	BRANCHE	ORGANISATION/UNTERNEHMEN
186		FEHS

Annex II – Online Survey Constructs, Measurements, and Questions

Section	Research question	Construct	Measurements		
			Introduction/statement	**Question**	**Answer**
1. Company/institution description	Which is the stakeholder background? In which part of the building's life-cycle does it play a role/has an influence? Are small companies more interested in changing paradigms in the construction industry?	Perceived company/stakeholder's role in the value chain	Illustration: *The Construction Value Chain* (Figure 1 High-level overview of the traditional construction sector. Source: BPIE 2016:6).	1.1. My company's role in the value chain is:	Multiple choice: Raw material provider; Product manufacturer; Designer/design engineer; Architect; Building owner/realtor; Contractor; Maintenance company; Demolition company; Recycling company; Other
		Perceived willingness to change paradigms		1.2. My company is open to innovation in its business model	Scale: fully agree – fully disagree
				1.3. My company has __ employes.	Multiple choice: Less than 10 Between 11 and 50 Between 51 and 250 More tan 251
2. Knowledge/awareness about the CE	What are the perceived consequences of the current linear model by stakeholders of the construction industry?	perceived effects of the linear model in key stakeholder's business/activities	Statement: *"the so-called 'take, make, dispose' model or 'lineal model', relies on large quantities of cheap, easily accessible materials and energy"*	2.1. The construction industry is immersed in the linear economic model	Scale: fully agree – fully disagree
		perceived amount of raw materials necessary to produce one unit of construction materials		2.2. The construction industry uses more resources/energy in the following phases	Multiple choice: Raw material extraction; Product manufacturing; Design; Construction; Maintenance; Demolition; Renovation; Other

		perceived amount of raw materials that go to waste at the end-life phase of the products life cycle		2.3. The construction industry generates important amounts of waste in the following phases of the building's life cycle:	Multiple choice: Raw material extraction; Product manufacturing; Design; Construction; Maintenance; Demolition; Renovation; Other
		perceived economic model where the industry is immersed: The Linear Model or the "take-make-dispose" model		2.4. My company's activities are very resource and energy intensive	Scale: fully agree – fully disagree
	How resource/energy/CO_2-intensive do stakeholders think the construction industry is?	perceived increased input of raw materials to manufacture construction materials	Statement: *"the construction industry and the built environment have become the world's largest consumer of raw materials"*	2.5. In my opinion, the construction industry uses __ % of raw materials	Scale Less than 10% 11 to 20% 21 to 40% 41 to 80% More than 80%
				2.6. My company uses __ % of raw materials	Scale Less than 10% 11 to 20% 21 to 40% 41 to 80% More than 80%
				2.7. In my opinion, the construction industry uses __ % of recycled materials	Scale Less than 10% 11 to 20% 21 to 40% 41 to 80% More than 80%
				2.8. My company's uses only recycled materials	Multiple Choice: Yes No Why?
				2.9. My company uses recycled materials in the following stages of value chain	Multiple Choice Raw material extraction; Product manufacturing; Design;

				Construction; Maintenance; Demolition; Renovation; Other
			2.10. My company uses __ % of recycled materials	Scale Less than 10% 11 to 20% 21 to 40% 41 to 80% More than 80%
	perceived drivers for an increase in the volume of building construction [population growth, migration, others]	Statement: *"world's population it is expected to grow from around 4.3 billion in 1980 to over 9.3 billion in 2050"*	2.11. The number of new buildings constructed in the city will increase significantly until 2050.	Multiple Choice: Yes No Why?
			2.12. The number of renovated buildings in the city will increase significantly until 2050.	Multiple Choice: Yes No Why?
	perception of necessary energy to construct buildings and satisfy building's energy consumption perception of CO_2 produced by the industry	Statement: "the construction sector accounts for 25-40% of global CO_2 emissions"	2.13. The production of building materials is an energy-intensive process.	Scale: fully agree – fully disagree
			2.14. Building construction is an energy-intensive process.	Scale: fully agree – fully disagree
			2.15. Buildings use more energy during the use phase than at other phases of their useful life.	Scale: fully agree – fully disagree
			2.16. Buildings demolition an	Scale: fully agree – fully disagree

				energy-intensive process.	
				2.17. Recycling building materials is an energy-intensive process.	Scale: fully agree – fully disagree
		perception of environmental impacts generated by the industry	Statement: *"The linear economic model is characterized by the importance it gives to economic objectives, with little regard for ecological and social concerns (and internalization of these costs)"*	2.18. Building construction produces higher environmental impacts in the following stages:	Multiple Choice: Raw material extraction; Product manufacturing; Design; Construction; Maintenance; Demolition; Renovation; Other
				2.19. How does your company deal with the environmental impacts it produces?	Open question
3. Knowledge/awareness about key concepts of the CE	How knowledgeable are the stakeholders about the circular economy concept, key features, and principles?	perception about the circular economy	Illustration: *Figure 2: Contrasting the Linear and Circular Models. Source: Sauvé et al. 2016:52* Statement: *"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"*	3.1. my company considers the circular economy approach within its business model.	Multiple Choice: Yes No Why?
		perception about 3R's principles: Reduce, Reuse, Recycle	Statement: *"the circular economy relies on 3 main principles: Reuse, reduce, recycle"*	3.2. my company considers the following principles within its business model:	Multiple choice: Reuse Reduce Recycle

	perception about cradle-to-cradle perception of material flows/loops: Biological Cycle and Technological Cycle and its differences	Illustration: *Figure 3: C2C – Two nutrient cycles.* Statement: *"The Cradle-to-cradle (C2C) concept aims at dividing materials and resources into two cycles: the biological and the technical. In both cycles, all materials should be completely environmentally friendly and able to circulate permanently within the supply chain"*	3.3. my company considers the C2C concept within its business model:	Multiple Choice: Yes No Why?
	perception about cradle-to-cradle inspired buildings	Illustration: Figure 4: C2C-Inspired Building. Statement: C2C-Buildings incorporate in its design and construction certain elements that 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	3.4. Under current conditions in the construction sector, it is possible to construct C2C-inspired buildings.	Multiple Choice: Yes No Why?

		energy-positive building. • Use of bioclimatic design techniques to take advantage of local conditions.		
	perception about Zero-waste principle	Statement: *"Europeans' resource consumption has led to generate 2.7 billion tonnes of waste in 2012, and only 40% was reused, recycled, composted, or digested. The Zero-waste principle seeks the reduction of waste generated in the built environment by bringing together quite different aspects extending from simply reducing residual landfill waste to comprehensive waste-avoiding product design".*	3.5. It is possible to achieve a Zero-Waste-State in the local construction industry.	Multiple Choice: Yes No Why?
	Perception about Eco-efficiency	Statement: *"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."*	3.6. My company considers the following aspects of Eco-efficiency	Multiple Choice: • 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. • None of the above
4. Knowledge/awareness about BMs of the CE	Which CBMs are known to the construction industry and which ones could be implemented?	Perception about Circular Business Models	Statement: A Circular Business Models is a business model that in the construction sector strives for three main aspects: 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; 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.	4.1. My company considers circular business models within its business and marketing policies.	Multiple Choice: Yes No Why?
		Perception about Circular Design Business Models	Statement: Circular Design Business Models are implemented in the Development and planning phase of the life cycle of a building, product, or service. Example: Design Thinking is a collaborative process by	4.2. My company considers circular design business models in its own business model	Multiple Choice: Yes No Why? Which one?

		which the designer's sensibilities and methods are employed to match people's needs with what is technically feasible and a viable business strategy. In short, design thinking converts need into demand.		
	Perception about Circular Use Business Models	Statement: Circular Use Business Models are implemented in the Operational phase of the life cycle of a building, product, or service. Example: Product-as-Service 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.	4.3. My company considers circular use business models in its own business model	Multiple Choice: Yes No Why? Which one?
	Perception about Circular Recovery Business Models	Statement: Circular Recovery Business Models are implemented in the End life of the life cycle of a building, product, or service. Example: 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.	4.4. My company considers circular recovery in its own business model	Multiple Choice: Yes No Why? Which one?

5. Institutional framework	Which is the existing institutional framework?	Perceived institutions in place	5.1. Do you know any national or international institution dealing with the circular economy approach? Are they government related or from the private sector?	Open Question
		Perceived institutional impact in pushing the discussion forward	5.2. How could the institutional framework could support the implementation of concepts and business models from the circular economy in the construction industry?	Open Question
		Perceived role of the trade and professional associations	5.3. In your opinion, which role do the trade and professional associations could play in supporting the transition towards a circular industry?	Open Question
		Perceived role of the networking and cooperation	5.4. Are you member or do you know any network that could/it is interested in the circular economy?	Open Question
6. Barriers	Which are the barriers for implementing CE principles and business models in the construction industry?	Perceived barriers	6.1. In your opinion, which are the main barriers for implementing concepts and business models from the circular economy in the	Open Question

			construction industry?	
7. Drivers	Which are the drivers for implementing CE principles and business models in the construction industry?	Perceived drivers	7.1. In your opinion, which are the main drivers for implementing concepts and business models from the circular economy in the construction industry?	Open Question

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