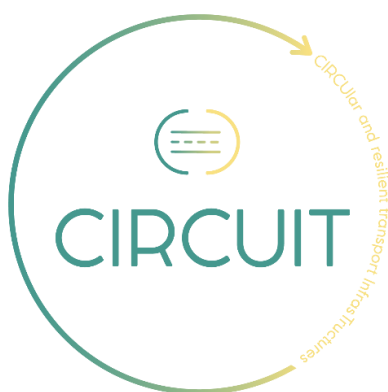


## - CIRCUIT -

**Holistic approach to foster CIRCULAR and resilient transport InfrasTructures and support the deployment of Green and Innovation Public Procurement and innovative engineering practices**



### – Deliverable 1.2–

#### ***Up-stream and down-stream supply chain actors needs***

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## EXECUTIVE SUMMARY

Circular Economy is a restorative and regenerative industrial-economic approach that is founded on resource stewardship through three main pillars: the removal of pollution and waste, keeping products and materials in use as long as possible, and regenerating natural systems (Ellen MacArthur Foundation).

To explain the complexity in the integration of Circular Economy within the built environment, a first high-level analysis of the built environment industry was carried out. Followingly, to identify the barriers and enablers to the adoption of Circular Economy this study is based on (i) a critical literature review of key documentations such as articles, standards, industry reports and white papers; and (ii) a consultation process that includes an online questionnaire and interviews with key relevant stakeholders.

The initial high-level analysis of the construction sector revealed the multiple stakeholders involved at different stages of the life cycle, up-stream and down-stream, creating a **fragmented value chain**. The analysis also showed that the construction industry follows a **linear economy business model**, which is mainly **driven by financial profits**. With specific regard to infrastructure, it was important to mention the following particularities that differentiate it from other construction activities:

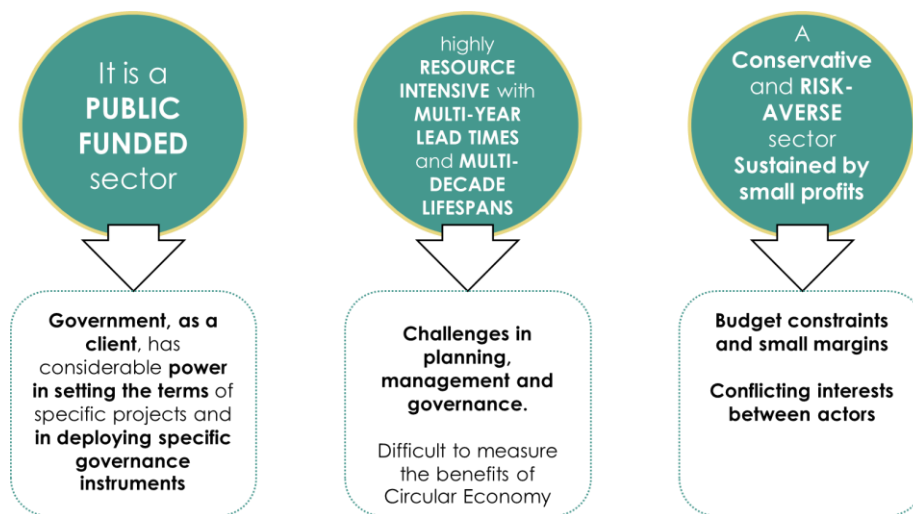


Figure 1\_Singularities of the Infrastructure sector. Source: adapted from Coenen, Visscher and Volker, 2023

A literature review was undertaken as a first step to identify the main strategies, drivers, barriers and enablers to Circular Economy implementation. A critical analysis of the literature suggested that Circular Economy barriers in the built environment can be classified into two main groups, with a greater weight of importance attributed to the first group:

- Barriers related to Institutional-economic-sectoral&social factors.
- Technological and technical barriers.

Overall, 47 barriers were identified, and enablers were proposed to overcome them according to the review's findings. These barriers were classified under the following proposed system:

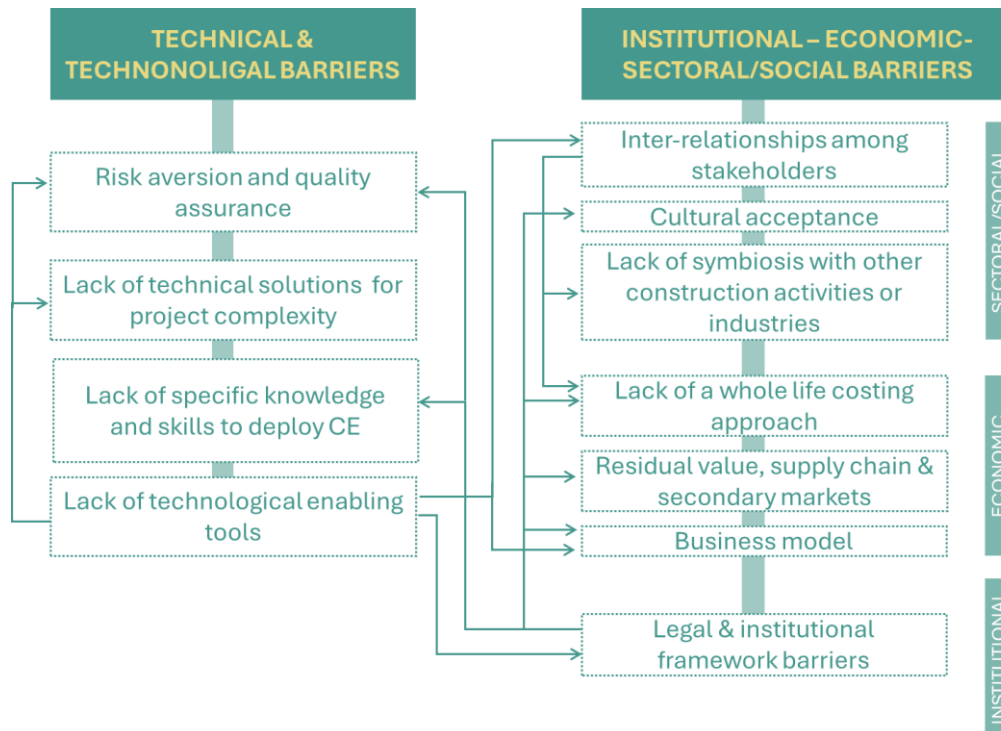


Figure 2\_ Classification of Circular Economy barriers and the inter-relationships between them. Source: Own elaboration

Findings from the literature review confirm that high levels of collaboration and whole-life approach are needed to adopt circularity. **The influence and inter-relationship among stakeholders** are key for the success in the implementation of Circular Economy.

**Economic factors are a determinant aspect** in the deployment of Circular Economy and are defined as “hard” barriers by many authors. These barriers relate to various aspects: lack of a clear business case and profitability, cost considerations (especially the entailed high upfront cost), inadequate fiscal environment and market challenges among others.

Most importantly, as systematically mentioned in most scientific papers, **public institutions play a key role in fostering circularity**, even more so in the case of transport infrastructure, as they are public funded. As-per-today non-flexible or outdated regulations, risk-averse standardization and specifications and lack of institutional incentives and inadequate financial instruments currently discourage the implementation of Circular Economy.

On the other hand, **technical and technological barriers** were also addressed in many publications, highlighting the lack of technologies for quality assurance as the most important obstacle related to the risk averse mentality of this sector.

The following figure illustrates the mentioned main barriers by level of importance:

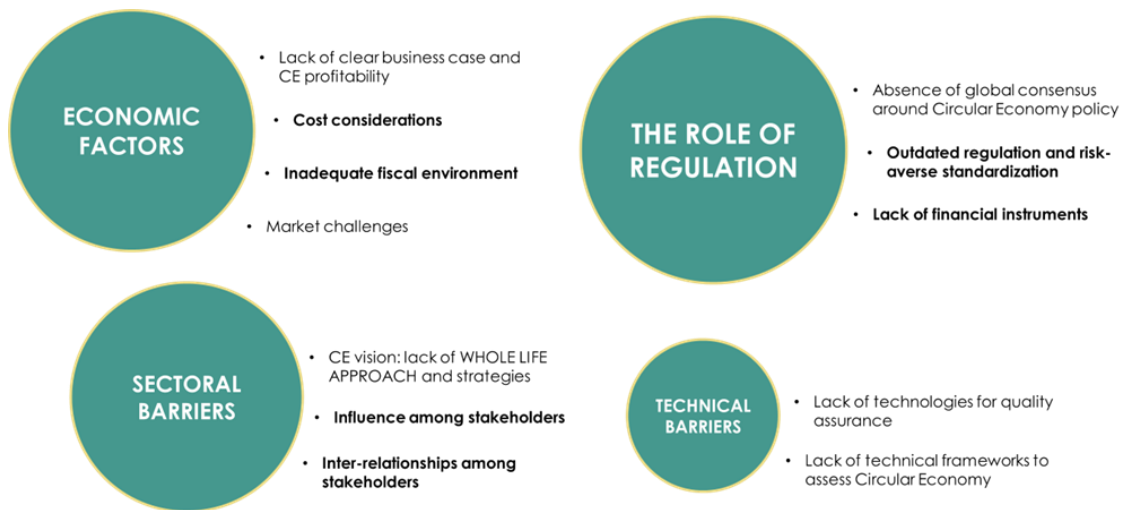


Figure 3\_ Main barriers to the implementation of Circular Economy according to the literature review. Source: Own elaboration.

Following the literature review, an industry consultation process was carried out to better understand what currently happens in practice. Industry actors also identified institutional-economic-sectoral aspects as more relevant barriers to the implementation of circularity than technical ones.

Responses both from the survey and interviews provided additional information on some important aspects that were not reflected in the literature review, giving a specific picture on the difficulties that the infrastructure sector specifically faces. These are summarised in the following bullet points:

- **ESG values are shared by almost all the respondents.** However, these are not a hard enough motivator to implement Circular Economy.
- The current **main motivator** to include Circular Economy criteria in a project is **compliance with legal requirements**.
- The administration is perceived as an independent party with the necessary power to drive market changes through financial instruments. **Regulation, both technical and financial therefore plays a key role.** The role of the administrations is especially important in infrastructure being the client of these projects.
- However, **there is a consensus on the high levels of collaboration among stakeholders and whole-life approach that are needed** to adopt circularity therefore concluding that efforts should be made at all levels.
- Respondents identified **economic impacts and lack of adequate regulation as the main barriers to Circular Economy**, demanding for changes in regulation and financial incentives to promote circularity.
- **Quality concerns** (or lower value of secondary materials) certainly represent a barrier to adopting circular solutions.
- **A balance between durability and adaptation to future needs** should be found and evaluated individually for each project to avoid inefficiencies in resources.

## Abbreviation list

Abbreviation	Definition
AI	Artificial Intelligence
BIM	Building Information Modelling
CE	Circular Economy
CDWM	Construction and Demolition Waste Management
DfD	Design for Disassembly
DPP	Digital Product Passport
EC	European Commission
EPD	Environmental Product Declaration
GPP	Green Public Procurement
GWP	Global Warming Potential
IPCC	Intergovernmental Panel on Climate Change
KPI	Key Performance Indicator
LCA	Life Cycle Assessment
LCCA	Life Cycle Cost Assessment
LCSA	Life Cycle Sustainability Assessment
WLC	Whole Life Cycle

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## Glossary of terms

### **Built environment**

comprises the man-made elements of our surroundings such as buildings as well as infrastructure including transportation, telecommunications, energy, water, and waste systems.

### **Circularity**

An economic concept (also: circular economy) meaning that a product, service or resource is renewed or regenerated, rather than wasted. Key principle of circularity is allowing materials and products to be used more than once in a value chain either processed (e.g. recycled) or unprocessed (e.g. reused).

### **Climate change vulnerability**

The degree to which natural, built, and human systems are at risk of exposure to climate change impacts.

### **Closed loop cycles**

are those in which nearly all materials remain within the system, and are recovered and used by other organisms or processes rather than being lost as waste.

### **Design for Adaptability (DfA)**

An approach to planning, designing, and constructing a building so it can be easily maintained, modified and used in different ways or for multiple purposes throughout its lifetime, extending its practical and economic life cycle.

### **Design for Disassembly (DfD)**

Approach to the design of a product or constructed asset that facilitates disassembly at the end of its useful life in such a way that enables components, materials, and parts to be reused, recycled or, in some other way, diverted from the waste stream.

### **Downcycling**

The recycling of waste where the recycled material is of lower quality and functionality than the original material.

### **Economy of scale**

Economies of scale are cost advantages reaped by companies when production becomes efficient. Companies can achieve economies of scale by increasing production and lowering costs. This happens because costs are spread over a larger number of goods.

## **Economy of scope**

Economies of scope are economic factors that make the simultaneous manufacturing of different products more cost-effective than manufacturing them on their own. Economies of scope can arise from goods that are co-products or complements in production, goods that have complementary production processes, or goods that share inputs to production.

## **Externalities**

Consequences due to activities in the whole life cycle of any work, product or service that have an impact on the society or environment, monetized as a cost. (e.g. additional travel time of road users, additional environmental pollution).

## **Life Cycle**

Consecutive and interlinked stages of a product system, from raw material acquisition or generation from natural resources to final disposal.

## **Life Cycle Assessment (LCA)**

A methodology developed to assess the environmental impacts of a building, component, or material. The assessment compiles and evaluates the energy and material inputs and outputs of the material system throughout its life cycle and assesses the relevant environmental impact.

## **Life Cycle Cost Analysis (LCC)**

An analysis of all the costs that will be incurred during the lifetime of the product, work or service. LCC may also include the cost of externalities such as environmental degradation or greenhouse gas emissions.

## **Life Cycle Sustainability Analysis (LCSA)**

An evaluation of all environmental, social and economic negative impacts and benefits in decision-making process towards more sustainable products throughout their life cycle.

## **Material passports**

provide information on the value of materials and products, their reusable or toxic content and the ease with which they can be disassembled. Information is collected in a database to facilitate the recovery, recycling and/or re-use of materials.

## **Material Flow Analysis (MFA)**

An analytical method to quantify flows and stocks of materials or substances in a well-defined system. It connects the sources, the pathways, and the intermediate and final sinks of a material.

## **Reverse Logistics**

A closed loop approach that uses remanufacturing, refurbishment, repair, reuse or recycling to recover and process materials and products after the point of consumption.

## **Social Life Cycle Analysis (S-LCA)**

A methodology aimed to assess social and socioeconomic impacts that has a technical framework similar to LCA. It is used to evaluate potential positive or negative effects of a product in its whole life cycle in social aspect.

## **Secondary Raw Material (SRM) Markets**

Secondary raw materials are recycled materials that can be used in manufacturing processes instead of or alongside virgin raw materials. SRM Markets enable recyclables to re-enter the production value chain, which reduces dependency on primary resources as a result.

## **Upcycling**

Involves the reuse of a material or product to produce an item of higher value than the original.

## **Value Chain**

A business model that describes the full range of activities needed to create a product or service.

## **Whole Life Carbon**

The entire amount of carbon produced by any particular built asset throughout its life cycle.

## **Whole Life Costing**

Takes account of the cost of a product or service (or built asset) over its life, from determining the need for it through to its eventual demolition and waste management.

## INTRODUCTION

This report will identify major barriers for the use of circular management and GPP for transport infrastructure by screening up-stream and down-stream actors needs and requirements. The barriers are identified and categorized according to their nature, (regulatory, technical, social or economic), based on an in-depth literature review, an online survey and interviews aimed at up-stream and down-stream actors in the value chain. Key stakeholders are identified and interviewed to map the needs related to the implementation of circular economy principles, and obstacles for the 100% reutilisation of construction materials within or across transport modes. Screening of the regulatory framework in EU countries and existing standards was also performed. Based on the identified barriers, a detailed analysis of needs and requirements for the whole value chain are provided.

The Ellen MacArthur Foundation defined the Circular Economy principle as “an industrial system that is restorative or regenerative by intention and design” and then extended as “a new way to design, make, and use things within planetary boundaries”. The Circular Economy therefore aims to extrapolate natural concept of closed loops or biological cycles to industrial systems, by balancing material flows.

The European Commission has recently reported that, by 2050, the world will exploit triple of today's resource demand. In the next 40 years, the world consumption of key materials such as biomass, fossil fuels, metals and minerals is expected to double, while waste generation is estimated to increase by 70% (Kaewunruen *et al.*, 2024).

Specifically, the building sector is a major consumer of natural resources and energy and a significant contributor to global greenhouse gas emissions and waste production. It is responsible for 33% of greenhouse gas emissions, 40% of resource utilisation, and 40% of waste production. With the ongoing expansion of the world's population in urban areas, the demand for new buildings and infrastructure will significantly increase (Aljaber, Martinez-Vazquez and Baniotopoulos, 2023).

When referring to the construction industry, Circular Economy focuses on maintaining materials in a continuous cycle to maximize their value (Abdulai *et al.*, 2024). In the built environment, circularity includes three main principles: (i) durability, referring to building and elemental service life planning, (ii) adaptability, the extension of the service life of the asset as a whole; and (iii) waste reduction and high-quality waste management, as well as future circular reuse of components and parts, or high-quality recycling of elements following deconstruction. (Mitoulis, S.A. *et al.*, 2024).

Due to the concern on significant resources consumption in the construction industry without concerning the physical limit resources, a paradigm shift of linear economy to Circular Economy model is inevitable for conserving the resources and promoting the efficient use of resources (Hossain *et al.*, 2020).

In this regard, transport infrastructure plays a key role due to the large amounts of raw materials and energy involved in their execution and maintenance. According to Grossegger, MacAskill and Al-Tabbaa, (2024), road construction and maintenance represent the second largest accumulated material stock in the built environment after buildings. More than 50 % of road materials used in well-developed road networks are used for maintenance. Based on an industry-wide survey, O’Leary, Osmani and Goodier, (2024) point out that rail infrastructure, as could be referred to transport infrastructure in general, are less commercial and more permanent and as such, should be more relevant than building in regard to value optimization and life extension.

However, even though Circular Economy is acknowledged to help in climate change mitigation, initiatives to date have made limited contribution as stated by the IPCC, (2022).

A shift from the current focus on circular design towards more integral Circular Economy solutions is required, decreasing the demand for resources and increasing the lifespans of existing assets (Coenen, Visscher and Volker, 2023) .

This study therefore aims to analyse the multiple barriers to Circular Economy implementation across the whole life cycle of a transport infrastructure project and taking into account the perspectives of different stakeholders. This study is based on (i) a critical literature review of key documentations such as articles, standards, industry reports and white papers; and (ii) an industry survey findings and interviews with relevant stakeholders and decision makers.

# 1. METHODOLOGY AND SCOPE OF THE RESEARCH

## 1.1 Research methodology

The approach taken for this study was to undertake a literature review as a first step to identify the main strategies, drivers, barriers and enablers to Circular Economy implementation. Results from this literature review were then used to inform a questionnaire that was distributed between identified relevant stakeholders and also online for a wider industry feedback. Followingly, based on relevant subject from the literature and survey responses, in-depth interviews were conducted with key industry stakeholders.

In the literature search process, from the research search, more than 4635 papers had been identified as potentially relevant to this study after an initial screening based on the research field area and type of document. After filtering duplicities and performing a second screening based on titles, 531 articles were left. Finally, 35 papers were found closely related to the scope of the current study after further scrutiny of the abstract, and implications of all these papers were included in the full-text review. The search process followed the PRISMA methodology (Preferred Reporting Items for Systematic Reviews and Meta-Analyses), using the ScienceDirect and Scopus databases with the theme-based specific keywords "circular AND economy AND built AND environment OR construction AND barriers". To tailor the results to infrastructure projects, a second search process was performed using the keywords "circular AND economy AND transport AND infrastructure".

Papers addressing the EU context were prioritised. Barriers and drivers to the implementation of Circular Economy were analysed for the construction sector in general and studies that specifically addressed the transportation infrastructure were analysed in close detail concerning the specifics of this type of projects that differentiate them from other construction activities. Papers addressing a certain aspect that seemed relevant to the study, in regards to a specific enabler for example, were also included in the review.

In parallel, a search for relevant industry reports was carried out, reviewing publications by major engineering and construction companies operating in Europe, major active organisations in promoting the Circular Economy, as well as publications by European institutions and regional public bodies.

The following chart summarises the search process and screening criteria for the literature review:

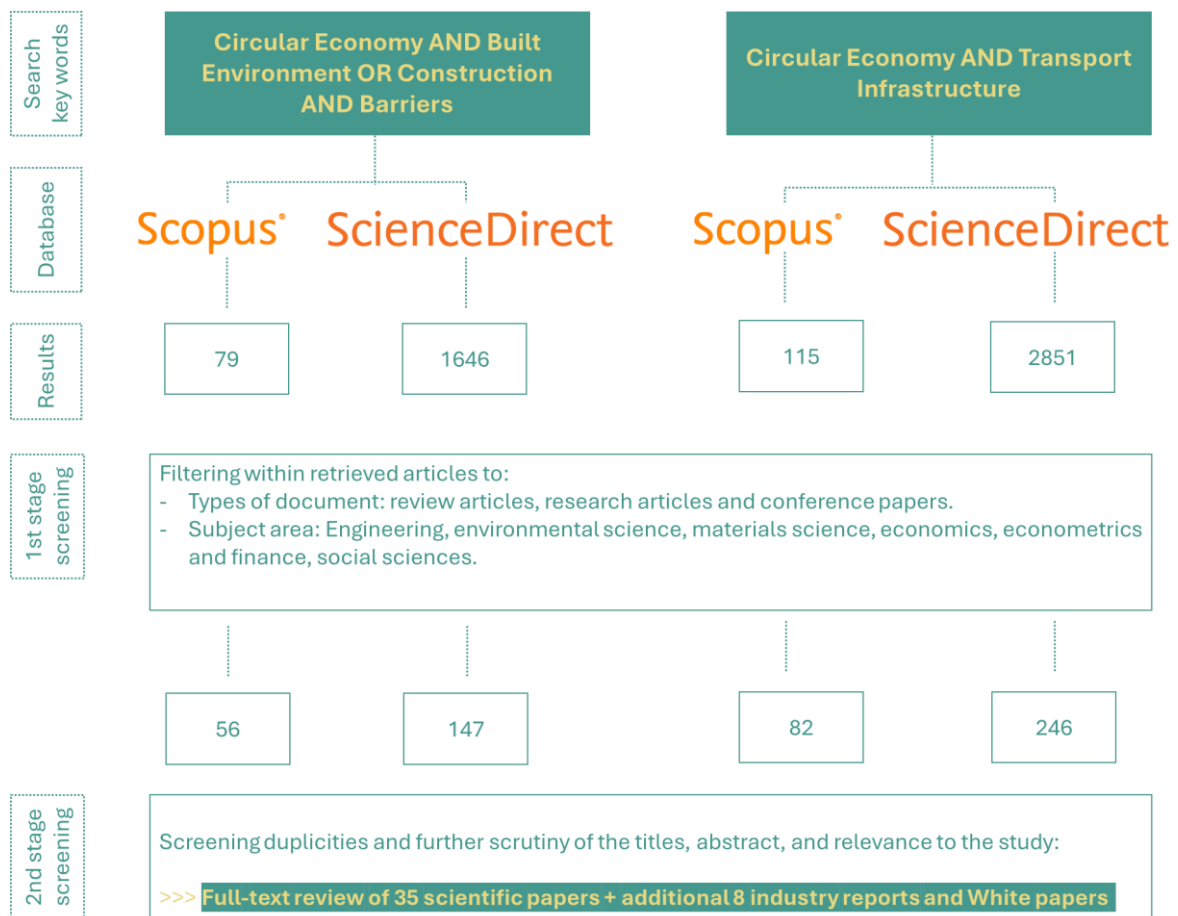


Figure 4\_PRISMA flowchart. Source: own elaboration

As scientific research is mainly done in an academic context and might not reflect the different points of view of various industry actors, an online questionnaire aimed to complete this critical review by providing insights on the importance level that each type of stakeholder gives to each motivation and barrier to Circular Economy implementation. Results from the literature review were used to inform the questionnaire by establishing the motivations and barriers included. The survey was composed of 4 sections, the first including general questions to identify the respondent's role and experience, while the following sections cover motivations, barriers and enablers to the implementation of Circular Economy, as will be explained in detail in section 3.

The purpose of the following one-on-one interviews with key stakeholders was to better understand what currently happens in practice and dive deeper into the identified barriers and possible enablers. The interview's structure comprised 9 sections: the first addressed general definition and objectives of Circular Economy and the following focused on the different identified barriers divided by categories including sectoral, social, economic, political, technical and technological aspects, circular economy strategies, enabling tools, end-of life and C&DWM.

## 1.2 Actors in transport infrastructure sector

Circular solutions are not widespread in the built environment. A better understanding of the barriers to Circular Economy uptake requires a previous understanding of the built environment industry. This section aims to provide a high-level picture on how the construction sector works to set a context that can explain the complexity in the integration of Circular Economy within the built environment, as will be detailed in the following sections. Therefore, this section will briefly cover and simplify the definition of this economic activity, type of business model used, and stakeholders involved in the construction process.

As a simplified definition of the construction sector is that it is based on the development of assets in the built environment, be they buildings or infrastructure. The life cycle of a project can be divided into three main stages:

- **The upfront stage** or in other words the process carried out to practical completion of the asset.
- **The use phase** of the asset.
- **The end of life** of the asset which includes its demolition and waste management.

Normally, these type of developments responds to a business model in which the land owner or developer is responsible for carrying out the upfront stage to its practical completion when at that point, the property is handed over to a new owner or operator that is responsible for the use phase of the project, releasing the initial owner from further responsibility on the built asset after the construction guarantee period is finalised.

The stakeholders in this process are those individuals or organizations that are involved in the project or influence it on a certain level. In that sense, there are two types of stakeholders in the construction sector:

- **Direct stakeholders**, that is those directly influenced, involved and having vested interest. These include the client or owner, project manager and his team, consultants, suppliers, contractors and end users.
- **Indirect stakeholders** that have affect and/or are affected by the project but have no control over the assignment of resources.

The following chart illustrates the stakeholders involved in the life cycle of a construction project and property ownership:

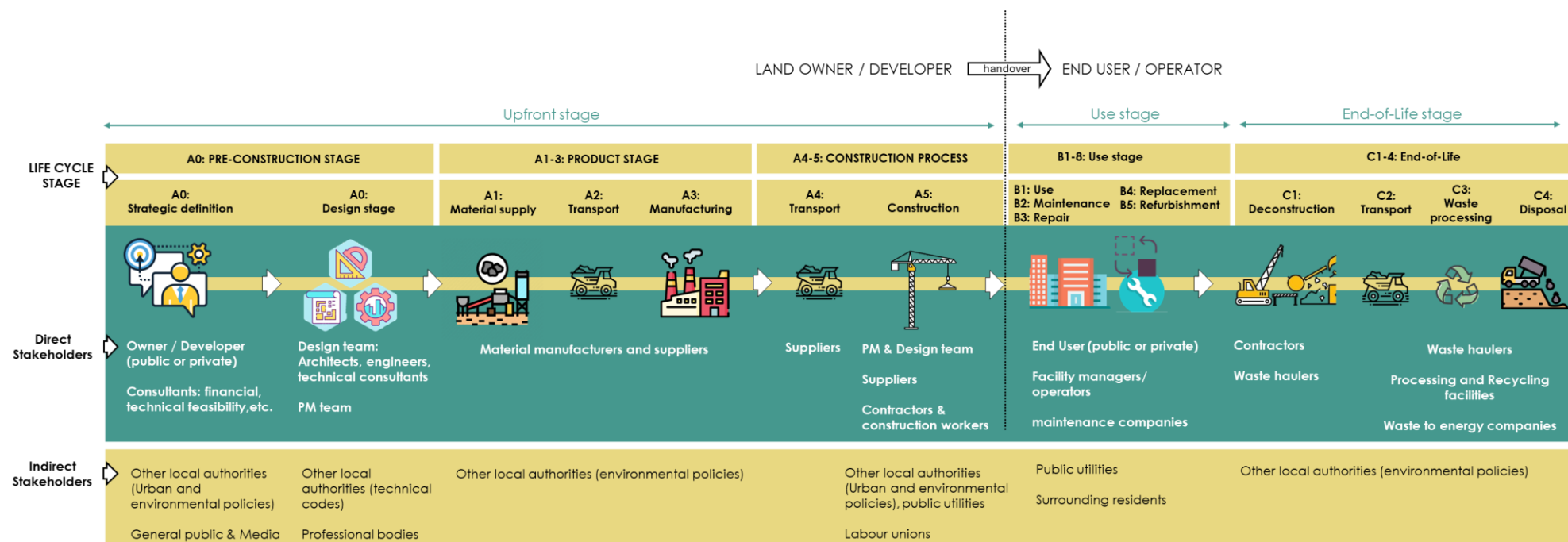


Figure 5\_Stakeholders involved in the Life Cycle of a Construction Project. Source: own elaboration.

This figure illustrates a business model that related to a linear economy, mainly driven by financial profits. High levels of collaboration and whole-life approach are needed to adopt circularity. Task division throughout the fragmented value chain makes it difficult to introduce circular products.

In this traditional business model, the drivers or benefits that each of the different agents seeks and the level of influence they have on the project decision-making is summarized in Table 1:

Table 1\_Roles, Drivers and Influence of the construction sector stakeholders. Source: own elaboration.

ACTORS	CURRENT ROLES	CURRENT DRIVERS	INFLUENCE
Public administration (e.g. Ministry of Transport and Infrastructure)	Governance of public transport infrastructure	Limited budget Quality, guaranteed by technical codes.	High
Real estate developer	Carrying out the project. Establishing project brief and strategies	Profits Quality Added value User demands	High
Design team	Determining the design strategies and solution. Specifying construction solutions and materials.	Meeting the project brief requirements Meeting the performance levels set by technical codes. Profits	High
Construction company	Carrying out the construction process according to the design specifications	Lowest economic offer Profit: cheapest suppliers Fulfilling the guarantee period	Medium
Suppliers/subcontractors	Material supply and construction deployment	Fulfilling technical prescription at lowest possible cost	Medium
Operator (Private or Public body)	Responsible for the proper functioning of the transport infrastructure during its use phase	Price Quality Maintenance costs	High
User	Determining transport usage demands and needs	Price Quality	Low

Within the construction sector, transport infrastructure has its particularities. As clearly explained by Coenen, Visscher and Volker, (2023) infrastructure sectors have several typical characteristics detailed below.

- It is a public sector, purchased, owned and financed by public organizations and therefore influenced by a highly politicized context. Its publicly funded status means that it is subjected to public procurement legislation with strict rules on contracting to ensure transparency and a level playing field.  
In this case, the government, as a client, has considerable power in setting the terms for specific projects and in deploying specific governance instruments (Hueskes, Verhoest and Block, 2017). Nevertheless, infrastructure is designed, commissioned and maintained through a rather fixed system of actors and institutions.
- Infrastructure assets are highly unique, resource intensive, and usually have multi-year lead times and multi-decade lifespans. This leads to challenges in planning, management and governance. Moreover, it is difficult to measure Circular Economy benefits in the infrastructure sector due to these long asset lifespans and lack of clarity as to what circularity is in this context (Coenen *et al.*, 2021).
- It is considered to be a conservative and risk-averse sector sustained by small profit margins due to its public-private nature. Strict contractual conditions set time and budget constraints, as well as fixed targets and specifications for the project. Moreover, infrastructure projects involve a large number of actors with often competing interests and complex interrelationships, which represents an additional obstacle.

These singularities are important to better understand the measures needed to adopt circularity, and are therefore summarised in the figure below:

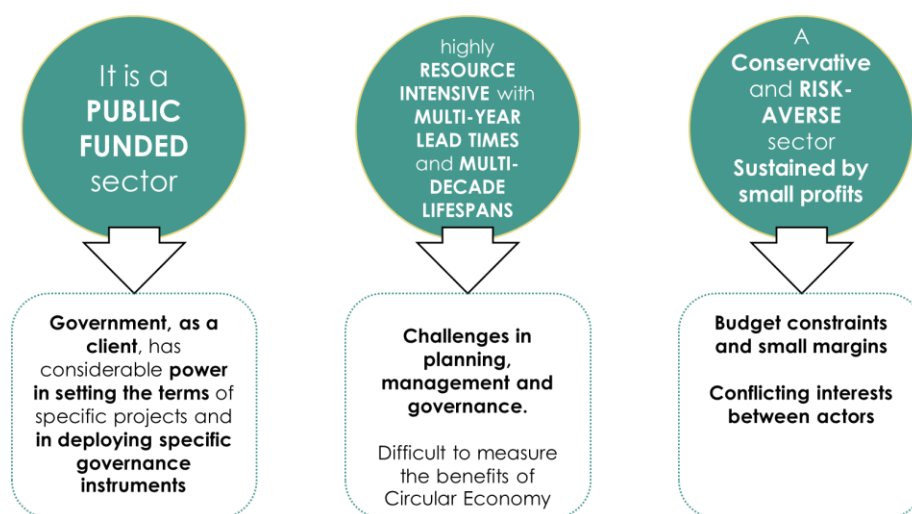


Figure 6\_Singularities of the infrastructure sector. Source: adapted from Coenen, Visscher and Volker, 2023

### 1.3 Benefits and drivers for Circular Economy implementation

The Circular Economy concept offers a chance to make the step change needed. It aims to decouple economic growth from resource consumption. Instead, products and assets are designed and built to be more durable, and to be repaired, refurbished, reused and disassembled. This maintains components and their materials at the highest useful purpose as long as feasible which minimises resource waste. By moving away from the linear model to an ecosystem where natural capital is preserved and enhanced, renewable resources are optimised, waste is prevented and negative externalities are designed out (Luebke and Frow, 2016).

The environmental benefits that derive from Circular Economy are evident, however, this model responds to the broader definition of a sustainable framework as it also presents benefits on a social and economic level.

Arup specifically emphasises that the Circular Economy's main goal is to minimise the negative externalities, including climate change, water, soil noise and air pollution, therefore significantly impacting on human health, well being and productivity, all of which can translate into social and economic benefits (or reduced impacts). Moreover, they claim that this model when applied to the built environment, can avoid rising costs, delays, and other consequences of volatile commodity markets (Luebke and Frow, 2016).

In their report, From Principles to Practices: Realising the Value of Circular Economy in Real Estate, Arup demonstrated that Circular Economy practices can be built into existing real estate business modelling, highlighting the benefits of doing so. The report explores five business models that support an optimal use of resources across a real estate asset's life cycle and showcase the possible economic revenues that can be obtained by each, ranging from 3% to 18% in periods of 10 to 30 years.

Current drivers for the implementation of Circular Economy are mainly related to regulation stemming from the European Green Deal framework. However, as indicated in this section and will be explained in the following section, the enablers to Circular Economy present an opportunity to obtain benefits on different levels and can therefore become drivers for implementation.

## 2 BARRIERS AND ENABLERS FOR THE IMPLEMENTATION OF CIRCULAR ECONOMY

As per Hart *et al.*, (2019a), lack of progress in Circular Economy implementation suggests that barriers exist, which require enabling actions to overcome. Therefore, the aim of this first phase of the literature review is to better understand the specific obstacles that impede the shift to a circular model, and possible solutions to overcome them.

Many of the scientific studies on Circular Economy barriers and drivers in the construction sector address a single life cycle stage and focus on a single Circular Economy strategy. However, Circular Economy should be addressed from a holistic point of view and integrate a series of strategies throughout the whole life cycle of a project.

Therefore, this critical review set out to analyse the multiple barriers across the whole life cycle and considering the different stakeholders' priorities. The potential enablers to overcome the identified obstacles were included as suggested by the different authors.

### 2.1 Classification

There are many dimensions to explore concerning the barriers to adopting Circular Economy and each of the relevant academic papers and industry reports faces the classification differently. The approach suggested in this study, based on a critical analysis of the literature review is that Circular Economy barriers in the built environment can be classified into two main groups:

- Barriers related to Institutional-economic-sectoral&social factors.
- Technological and technical barriers.

Specifically, when referring to the first group of barriers, these include the inter-relationships and influences between stakeholders, regulatory and economic frameworks, as well as wider cultural factors and knowledge gaps. The second group refers to the current technical barriers and technological means needed to streamline implementation of Circular Economy.

Even though technical challenges presumably condition the implementation of Circular Economy as no model can be applied unless it is technically feasible, a more significant part of barriers is actually driven by human needs, economic, social and cultural factors, rather than the technical barriers. This is particularly true to infrastructure projects being public funded, a main characteristic that differentiate them from the wider built environment sector.

In this respect, Hossain *et al.*, (2020) pointed out that to foster Circular Economy, further research and actions should be taken in the following fields:

- (i) Integration of social and economic aspects into the proposed framework,

- (ii) Development of circular value chains which evolves around stakeholders' collaboration as it is crucial for sustainable business model innovation,
- (iii) Development of guidelines for implementation and economic incentives,
- (iv) Establishment of a clearly-defined methodology for Circular Economy evaluation with Circular Economy index or indicators,
- (v) Validation through case studies.

Their conclusion, based on a broad literature review, confirms that out of the 5 major aspects to promote Circular Economy, 3 are related to social and cultural factors (fields i-iii) whereas 2 to technical, or more specifically, knowledge issues (fields iv-v).

As stated by Coenen, Visscher and Volker, (2023), becoming circular as an industry requires not only new technologies but also socio-technical changes, including context-specific reconsideration of relationships, institutions and practices (Singh *et al.*, 2021). As such, socio-technical change towards an inherently more sustainable system is needed, a process which is referred to as a sustainability transition.

O'Leary, Osmani and Goodier, (2024) highlight that client leadership will be key because of their scale, influence and long-term responsibility for asset ownership, but they may require support from government to overcome various structural factors. In the case of infrastructure, Government being the client the level of influence is even greater and could clearly streamline the implementation of Circular Economy through project goals and procurement requirements in contracts.

The absence of shared interest among supply chain participants, lack of incentives, and uncertainties about the current Circular Economy agenda were recognized as barriers to the adoption of CE principles within the construction industry. (Abdulai *et al.*, 2024).

Moreover, Abdulai *et al.*, (2024) highlight that Inadequacies of financial incentives and governmental enforcement (via policy, legislation, or directive) are commonly found to be the most critical obstacles found throughout Europe.

The level of influence of the institutional-economic-sectoral & social factors compared to the technical aspects is the first conclusion drawn from this review. This conclusion informed the online questionnaire and followingly interviews, to be confirmed from the different stakeholders' point of view, as will be further elaborated in section 3.

On a more detailed level of analysis, Circular Economy barriers within the construction sector can be further broken down into specific sub-categories, adapted from classification frameworks suggested by various authors to the specifics of transport infrastructure projects. Barriers have been divided into

thematic categories under the wider classification of Institutional-Economic-Sectoral&social factors and Technical & Technological barriers. However, subjectivity is acknowledged in this categorisation process. Most of the barriers are related to several categories to some extent (and could lead to overlap in the discussion) but were decided to be classified in one and not the other based on the assumption that the main barrier factor is related to either the technical or the Institutional-Economic-Sectoral aspect.

In terms of enablers, some address the improvement of the Circular Economy in general by solving multiple barriers at once and were therefore mentioned repeatedly in the following sections. Other enablers are more related to a specific barrier or even directly correlated with it, the barrier being the absence of the enabler, and were therefore mentioned as possible direct solutions to that specific barrier.

The identified barriers, categorised by the classification system proposed in this study, are summarised below and further detailed in the following sections.

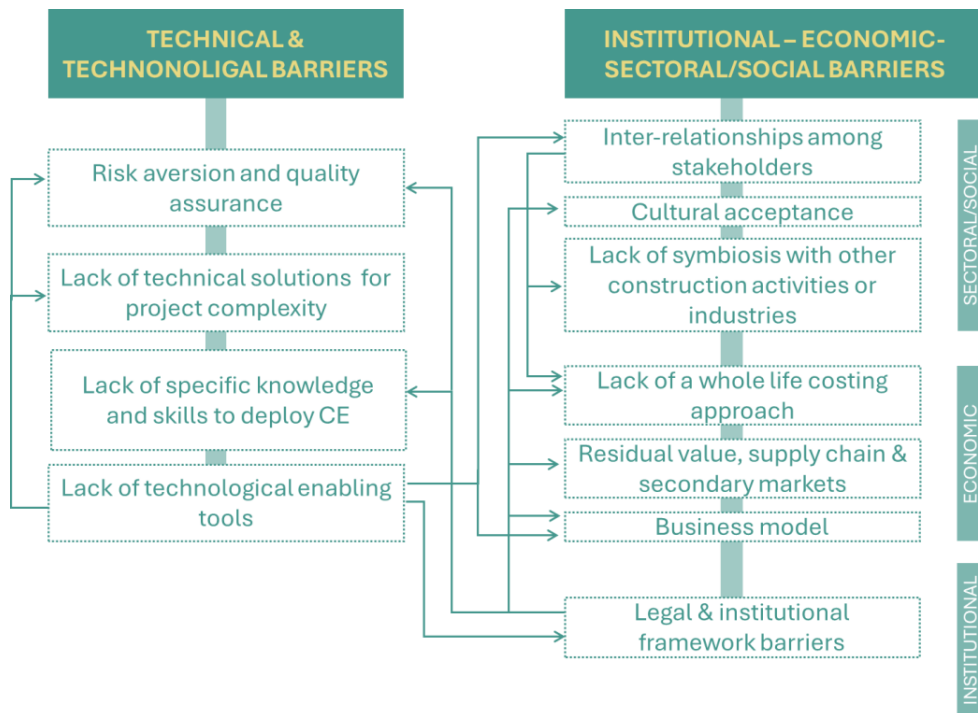


Figure 7\_Classification of Circular Economy barriers and the inter-relationships between them. Source: Own elaboration

## 2.2 Technical and technological barriers and enablers

As previously explained, technical and technological barriers are those that might be referred to as “hard” obstacles that physically or technologically impede the implementing circular strategies within a project. Knowledge gaps that are strictly related to technical aspects were also included in this wider category.

These barriers are discussed below by order of importance as referred to in the reviewed scientific papers.

### 2.2.1 Risk aversion and quality assurance

As designs become more flexible, adaptable and easy to disassemble the built environment aims to become a large “material bank” that can be economically exploited.

As per AlJaber, Martinez-Vazquez and Baniotopoulos, (2023), the quality and performance of materials and products through their lifecycles is essential. If there is a lack of quality assurance processes, there may be concerns about the durability, safety, and reliability of reused or recycled materials. Engineers not willing to take on the liability is the main reason most engineers are reluctant to introduce reused or recycled materials.

Further, Hart *et al.*, (2019b) attribute the less adoption of Circular Economy in construction activities in general to the uncertainties regarding products that have a long lifecycle. They questioned the uncertainties and adaptability, which are significant aspects of Circular Economy in construction. This aspect has a high relevance to infrastructure, having an extended use phase compared to buildings and a clear use.

Specifically in transport infrastructure projects, structural reliability is a key factor for performance and consequently quality assurance presents a major concern when considering Circular Economy, thus limiting its implementation. In many occasions, construction materials, products and elements are required by regulation to have better performance than necessary. Unfortunately, present-day structural codes, either limit the use of recycled materials to a maximum amount, or they strictly forbid their use depending on the nature of recycled materials, which presents a current barrier.

The reuse of existing elements in infrastructure projects could be very complicated in some cases, requiring destructive testing of the element to determine structural strength and ensure safety. Introduction of materials with recycled contents might also present some challenges in terms of the uniformity requirements of transport infrastructure, having a large-scale and repetitive nature. New technologies and testing standards are needed to ensure product quality.

In other cases, the use requirements are not compatible limiting the exploitation of materials between projects under the same infrastructure type. For example, secondary roads have the same design criteria as highways and retaining systems, but the volume of traffic is not the same in both cases. Deep analysis must be done in this field to determine whether it would be possible to reuse elements from the highways in secondary roads at the end of their service life or elements from long span bridges in short bridges over a path.

In this sense, research projects, standardization bodies and public administrations should begin to build scenarios, guidelines and codes where reused elements are included and where no requirement that is strictly necessary is demanded. Structural codes can guide the calculation of elements with recycled contents and establish methodologies for product testing can help engineers overcome these obstacles.

The barriers and enablers mentioned in this section are summarised in Table 2:

### Project complexity

Construction activities in general are complicated due to the multi-layered elements involved in them, their assembly and modifications over time.

Design for durability, design for flexibility and design out of waste are considered as main principals in circular design. When trying to implement these strategies in a transport infrastructure project, some difficulties arise. These projects are designed for a long-term period of time with a specific use so that adaptability and flexibility to other future uses might not be as relevant as in other construction activities. However, future transport usage and mobility needs are factors that should be considered from the project brief and certainly during the design process so that it can be adapted accordingly and avoid unnecessary future demolitions. In this regard, projections of future mobility trends entail a level of uncertainty thus presenting an obstacle to this approach. New technological tools based on data science can help predict future needs in a more accurate manner to help apply the adaptability principle.

Design out of waste addresses the end-of-life stage from the beginning of the project, implementing strategies to enable disassembly for material reuse and recycling. Enabling disassembly entails a kit-of-parts approach in design, where components are assembled through jointing techniques that are easy to disassemble. This type of solutions might compromise the durability of the infrastructure and therefore come in conflict with the design for durability principal. An in-depth analysis is needed at an early stage of the design to determine which circularity approach or solution is more beneficial to the project.

On-site reuse is a circular strategy that infrastructure projects could benefit from. Results of the O'Leary, Osmani and Goodier, (2024) study on rail infrastructure in the UK point out that the benefits are mainly from a construction schedule perspective by avoiding material removal and import whenever possible, but clarify that this solution often presents some difficulties derived from site constraints such as limited access to storage on site or excavated material not being suitable for reuse.

Once in the end-of-life stage, dismantling, sorting and recycling of the different materials can be technically challenging. Challenges regarding material

recovery are associated with the difficulties with separating waste materials (specifically composite products or those bonded with OPC), and lack of specific skill sets. According to Osei-Tutu *et al.*, (2023) the lack of policies, design standards and guidance for effective CDW management has often been cited as impediments to Circular Economy uptake in the construction industry. Focus should be given to the development of building codes centred on deconstructing buildings and standards for reclaiming material.

Whereas Osei-Tutu *et al.*, (2023) attribute the difficulties in implementing circularity within the CDW management to the following: lack of own technology to recover and reuse construction materials by stakeholders, immature recycling technology, lack of producer-based responsibility system in the production of construction materials, insufficient application of the 3R approach by construction practitioners and projects, and immature recycling market.

Material hubs for storage and sorting can help overcome the immature recycling market and incentives for companies to allocate resources to R&D can reduce the lack of current technologies of CDW management. Implementing design for disassembly criteria in the project phase and providing training for the specific skill sets needed for waste sorting can make the application of the 3R approach easier. Finally, incentives for manufacturers to implement extended responsibilities programs and tack-back schemes can engage them in the end-of-life stage and significantly enhance a circular production system.

Reuse of natural products at the end-of-life, moving them from a biological cycle to a technical cycle is also addressed by various authors, though might be less relevant to infrastructure, being projects with a lower use of natural materials.

The barriers and enablers mentioned in this section are summarised in Table 3:

Table 2\_ summary of barriers and enablers associated with project complexity

	Barriers	Enablers
PROJECT COMPLEXITY	Difficulty in designing for future needs due to the uncertainty in future mobility trends	Use of data science for more accurate future mobility trends
	Design solutions for disassembly might come in conflict with durability	System thinking and early stage analysis considering the end-of-life scenario can help prioritise the best strategy (durability or disassembly) for the specific project
	Site constraints limit possibilities for on-site reuse (limited access to storage, excavated material not suitable for reuse, etc)	Site assessment and early construction planning
	Immature recycling technology and recycling market	Material hubs for storage and sorting

Lack of own technology to recover and reuse construction materials by stakeholders.	Incentives to allocate resources for R&D
Insufficient application of the 3R approach by construction practitioners and projects	Implementing design for disassembly criteria and training for the specific skills set needed
Lack of producer-based responsibility system in the production of construction materials	Incentive for manufacturers to implement extended responsibilities programs and take-back schemes

### 2.2.2 Lack of specific knowledge and skills to implement Circular Economy

A model that cannot be assessed and quantified faces difficulties in its implementation. As explained in Hossain *et al.*, (2020) review, research is still ongoing to develop comprehensive assessment that can help streamline the implementation of Circular Economy. As per Coenen *et al.*, (2021) specifically in infrastructure there are limited assessment tools to ascertain the level of circularity.

Quantifiable indicators for circularity (or circularity KPIs) are still relatively unexplored and the lack of available design guidelines as well as practically no academic training prevents from professionals to include these criteria in their designs.

These should address design to material selection and subsequently to the end-of-life for further recovery and reuse. Performance indicators should be based on LCA, MFA and material flow cost accounting and should be integrated in wider comprehensive frameworks that consider LCA, LCC and S-LCA. The difficulty to determine the system boundary can be a barrier to establishing these types of comprehensive frameworks.

According to Kaewunruen *et al.*, (2024) some experts and key stakeholders clearly pointed out that the access to relevant research and education is relatively poor in many counties. Research outcomes, convincing insights and key outputs cannot be accessed by the decision makers such as asset owners or asset managers. This should also be applied to increasing the publications of case studies to establish a solid evidence base for the success of a Circular Economy model.

The barriers and enablers mentioned in this section are summarised in Table 4:

Table 3\_ summary of barriers and enablers associated with the assessment of Circular Economy

Barriers		Enablers
CE ASSESSMENT	Lack of Circular Economy evaluation frameworks	Establishing circularity indicators (KPIs) in design guidelines that consider LCA, LCC, and S-LCA.
	Lack of technical knowledge among project stakeholders	Make the scientific relevant research accessible to the wider public, and specifically to the decision makers of the project. Include Circularity criteria in academic programs

### 2.2.3 Lack of technological enabling tools

BIM is a collaborative working methodology for the creation and management of a construction project by centralising all the project information in a digital information model created by all its agents. This tool has been commercially available for some time and is widely being used in the industry. As per Arup, applying more connected and intelligent technologies like BIM in the built environment further improves information-sharing and transparency. This in turn helps to address inefficiencies in how assets are built and operated, and enhance flexibility, redundancy and resilience (Luebke and Fellow, 2016).

However, currently it does not seem to play a key role in streamlining circularity criteria and its implementation in projects. Some authors argue that additional specific tools are needed to be developed and put on the market to solve the technical challenges previously mentioned.

**Quality assurance:** new technologies, aligned with currently lacking standardised methodologies, should be developed to assess the quality, durability, safety and reliability of reused or recycled materials.

As stated by Hossain *et al.*, (2020) technological limitations in the tracking of recycled materials, quality of recycled products, uncertainty of second or further cycles, etc. would hinder the selection circular materials.

Verifiable traceable product information such as material and project passports as well as implementation of embedded sensors that can attest for the product's quality are some examples of current technologies that can help minimise the uncertainty levels of reused materials. These solutions are currently available in the market but not being used in an extensive market scale yet.

**Material stock:** according to Grossegger, MacAskill and Al-Tabbaa, (2024) the quantification of flows and stock is challenging due to data uncertainties and availableness. In their material flow study, they focus on road construction

highlighting that the lack of well documented waste records and underestimation (or sometimes overestimation) of the design models compared to the actual service life lead to an increase of material output that is not being managed nor introduced in the remanufacturing cycles. As they explain, waste estimations are based on statistics or through demolition functions (based on road service times and provide the likelihood of a road segment failing and receiving maintenance), increasing the level of uncertainties. Therefore, one of the obstacles to reuse of construction and demolition waste can be overcome by creating accurate data sets and developing tools that can streamline the reuse of real-time generated waste.

Luebke and Fellow, (2016) mention artificial intelligence as a tool for waste minimisation relating to the project design process. In addition, Sharing platforms such as FLOOW2, Globechain and HeadBox are helping to address the issues of under-used assets and superfluous capacity – facilitating trust and collaboration on the reuse of materials and assets. While Grossegger, MacAskill and Al-Tabbaa, (2024), point out to remote sensing as being increasingly used for higher data accuracy and to establish material flow analysis as a policy support tool for circular economy and greenhouse gas emission reduction. They also point out to remote sensing as a solution that is increasingly being used to obtain highly accurate data. They also mention the importance of establishing material flow analysis as a tool to support circular economy and greenhouse gas emission reduction policy.

As per Arup, Blockchain technology will provide a transparent ledger of transactions to give all participants real-time information about a material's location, ownership and audit history (REALISING THE VALUE OF CIRCULAR ECONOMY IN REAL ESTATE, 2020) .

**Optimised decision-making:** Uncertainties of the end-of-life scenarios and lack of materials and components information that can guarantee quality and avoid the performance risks prevent Circular Economy from being integrated early in the design stages and decision making. As per Hossain *et al.*, (2020), the use of BIM in early design stage and integration of LCSA for multi-objective optimisation would be an effective workflow to evaluate Circular Economy during the design stage and facilitate decision-making.

According to Grossegger, MacAskill and Al-Tabbaa, (2024), utilising reclaimed materials remains a challenge, as it is unclear if current stock materials can be upgraded for recycling or can only be downcycled. Hence, understanding the relationship between material consumption, climatic changes, and feedback loops is essential for future road material flow analyses, determining potential ways to achieve sustainable road constructions.

Grossegger, MacAskill and Al-Tabbaa, (2024) also suggest that the complex interactions of climatic, material and traffic could be modelled with machine learning and

material consumption, recycling potential and environmental impact could be used as decision assistance.

Singh *et al.*, (2021) states that creating automated cloud-based platform that enables stakeholder engagement with insights from theoretical model will provide significant advancement in implementation strategies.

Parallel research and innovation in Internet of Things, blockchain solutions, and data-driven analyses along with data-driven manufacturing can enhance models that convey the 'business case' for Circular Economy strategies (Singh *et al.*, 2021) .

**Operation & Maintenance:** As per Arup, monitoring and assessment technology is critical to maximise the performance of infrastructure and facilitate repair and prolonging of assets' lives. An example of this is the technology they used to ensure the smooth operation of the Forth Replacement Crossing in Scotland. Arup developed a simple-to-use, fully integrated structural health monitoring system (SHMS) equipped with 1,000 sensors to give advance warning of structural problems and allow targeted inspection and intervention (Luebke and Fellow, 2016).

All these mentioned tools provide accurate data sets to better understand material flow and its relation to climate data that can significantly support new policy and increase enforcement by legislation as well as corporate commitments, which in turn can foster Circular Economy solutions as will be explained in the political-economic-social barriers section.

The barriers and enablers mentioned in this section are summarised in Table 5:

Table 4\_ summary of barriers and enablers associated with the lack of enabling tools

	Barriers	Enablers
LACK OF ENABLING TOOLS	Lack of collaborative working methodologies	Using BIM to streamline circular criteria and its implementation. Integration of LCSA for multi-objective optimisation in early design
	Lack of product information	Information management systems: Material and project passports
	Data uncertainties in quantifications of material flows	Artificial intelligence relating to the project design process for waste minimisation. Use of verifiable material-tracing tools
	Data security	Use of blockchain technologies

## 2.3 Sectoral/social-economic-institutional barriers and enablers

As explained in the classification of barriers section, many of the obstacles to Circular Economy derive from institutional, economic and social or sectoral factors.

In their analysis of methods to enhance circularity within the infrastructure sector, Coenen, Visscher and Volker, (2023) suggest taking a Mission-oriented Innovation System (MIS) framework approach, which is defined as “the network of agents and set of institutions that contribute to the development and diffusion of innovative solutions with the aim to define, pursue and complete a societal mission”, claiming that the transition to Circular Economy requires a comprehensive system change on a relationships, institutions and practices level rather than just technological solutions.

This general conclusion is well demonstrated in the results from a industry-wide survey addressing circularity in the rail infrastructure in the UK that was conducted by O’Leary, Osmani and Goodier, (2024) which ranked the client leadership as a key factor in the implementation of Circular Economy, because of their scale, influence and long-term responsibility for asset ownership, highlighting that they may require support from government to overcome various structural factors. That is, from an industry-wide perspective, interrelationship between stakeholders and government support are considered crucial to adopting circularity.

The following sections will review in detail the institutional-economic-sectoral&social barriers which were considered of high relevance in the reviewed scientific papers:

## 2.4 Sectoral & social barriers and enablers

### 2.4.1 Lack of collaboration among stakeholders

For Circular Economy to be successfully implemented, it should be addressed throughout the whole life cycle stages, from the conceptual stage to the end-of-life, and therefore requires in-depth teamwork between all involved stakeholders.

According to Arup complexity is one of the defining features of the built environment. Built environment assets tend to have long lifecycles in which multiple actors with diverging priorities and incentives interact (Luebke and Fellow, 2016).

To better understand the complexity involved in the relationship between stakeholders, Kaewunruen *et al.*, (2024) highlight two critical aspects to the implementation of Circular Economy.

On the one hand, **influence among stakeholders**: this aspect is critical to understand decision making processes, soft and hard power, obligations and

incentives that could promote circular economy concepts. On the other, the **inter-relationships among stakeholders**: this aspect will help to determine the value chain of circular supply chain network, which identifies the dynamics of who, what, when, how and why for any decision towards circular practices to be made.

Regarding influence among stakeholders, according to Kaewunruen *et al.*, (2024), the implementation of circular economy practices tend to be a top-down inter-relationship rather than bottom-up approach. The communications tend to be direct down from the top layer of value chain network.

That is why key influence is often attributed to the Client or owner and establish a top-down dynamic when it comes to implementing circularity. However, governmental policies and legislation can represent a bottom-up trigger or appeal for competitions and attraction towards circular practices across all value chain.

Clients having a low acceptance of the Circular Economy concept and therefore not being on board is determinant in many cases for disregarding Circular Economy. In this regard, legislation and incentives can help prioritise circularity in the decision making. Making the relevant scientific research accessible to clients can also motivate them to pursue Circular Economy by better understanding the benefits that derive from this model.

Lack of leadership skills, mainly on the client's side, is also identified as a barrier to streamline Circularity. Implementing and integrative process approach with shared responsibilities among all stakeholders can make up for the lack of leadership of a single actor and enhance team engagement. An integrative approach can also contribute to a better and more fluent communication between stakeholders. It is common practice that each stakeholder does not often connect with the other stakeholders outside their own supply chain network due to time constraints.

Regarding the inter-relationship aspect, Hart *et al.*, (2019a) mentions forming longer term relationships and partnerships as a way of developing value chain engagement and resisting short-term blinkers. Additionally, the industry survey performed by Schraven *et al.*, (2019) found that supply chain actors tend to diffuse the responsibility to parties outside of the supply chain.

In Circular Business Models for the Built Environment (Arup, 2020), the case is made that long-term partnerships result in more effective collaboration to common goals and a less adversarial approach to construction. Hart *et al.*, (2019a) also address the aspect of collaboration in its horizontal scale within the supply chain and correlate the lack of consideration of horizontal collaboration to competitive practices, where again knowledge sharing to achieve common goals can may help.

Another underlying cause for the problematic knowledge adoption is the lack of incentives, particularly for market parties, to share Circular Economy knowledge. Cross-project collaboration, such as programmes and strategic partnerships, which can be launched by public clients, would provide incentives to invest in circular solutions and reduce the competitive advantage of withholding Circular Economy knowledge. In turn, this would increase the propensity for cross-project applications of circular solutions (Coenen, Visscher and Volker, 2023).

Multiple stakeholders and long lead times also mean there is rarely continuity of ownership and control (Luebkehan and Fellow, 2016). In this regard, Lack of ownership between client (or owner) and operator was viewed as highly important among the respondents of the O'Leary, Osmani and Goodier, (2024) survey on rail infrastructure in the UK, where rail system is operated by private entities through public concessions. One-fifth of interviewees (3/15) regarded operators as being risk averse or having different priorities, which led to challenges in handover between project delivery and operations. However, one-fifth of interviewees (3/15) said that it should not be a barrier if the client and operator really were one organization (O'Leary, Osmani and Goodier, 2024).

Establishing Circular Economy specific requirements in contracts between owner and operator can also make operators view Circularity as a priority.

On the other hand, maintenance work (and thus material consumption) is gaining importance as the effects of climate change have a direct influence on the performance of transport infrastructure, increasing the frequency and level of distresses that transport infrastructure suffers, which mainly occurs from increments in temperature (Grossegger, MacAskill and Al-Tabbaa, 2024). These factors are usually not taken into consideration by the design team nor the client when separated from the operator. Both should prioritise design for durability solutions to keep future maintenance work to a minimum. Operators, for their part have a responsibility to implement preventive maintenance plans and to use new technology available to predict future failures and prevent them from occurring.

The barriers and enablers mentioned in this section are summarised in Table 6:

Table 5\_ summary of barriers and enablers associated with the lack of collaboration between stakeholders

	Barriers	Enablers
LACK OF COLLABORATION BETWEEN STAKEHOLDERS	Client not on board	Policies and incentives Making the scientific relevant research accessible to the wider public
	Lack of leadership skills	Implementing an integrative process approach with shared responsibilities
	Circular Economy tends to have a top-down inter-relationship	Incentives can promote a bottom-up approach to engage all stakeholders

	Lack of value chain engagement	Forming longer term relationships and partnerships (enhancing collaboration through common goals).
	Lack of continuity of ownership and control	Having the same owner and operator. Contract requirements
	Lack of communication between stakeholders outside their own supply chain network	Implementing an integrative process approach
	Lack of consideration of the whole life cycle: Use phase not considered in project design	Implement design for durability solutions. Implement preventive maintenance plans over corrective ones

### 2.4.2 Cultural acceptance

Lack of general awareness and understanding of Circular Economy concepts among different actors and the public in general prevents from creating a market demand for this type of economy, making it challenging to deliver Circular Economy projects in a linear economy, or of “going it alone” as Hart *et al.*, (2019a) point out. To unlock the circular economy, stakeholders throughout the value chain need education and more awareness to shift their mindset (Luebkeman & Fellow, 2016).

Awareness in Circular Economy is essential to show its economic and environmental benefits to motivate stakeholders to adopt Circular Economy practices. AlJaber, Martinez-Vazquez and Baniotopoulos, (2023) and some authors even argue that the lack of knowledge in Circular Economy concepts, principles and potential benefits among stakeholders is the most important barrier to its implementation. As per AlJaber, Martinez-Vazquez and Baniotopoulos, (2023), The level of awareness among stakeholders significantly influences various aspects such as willingness to adopt Circular Economy, consensus on viewing Circular Economy as part of business ethics, and acknowledgement of Circular Economy benefits. Without this knowledge, stakeholders may overlook the potential economic and environmental gains, missing the opportunity to create more circular and profitable outcomes.

However, cultural shift is not held back only from a lack of knowledge reasons but also from a resistance to change perspective (keeping business as usual), and a short-term vision. This is especially true for transport infrastructure, for which safety is a critical factor thus increasing the resistance to change in this specific sector. Changing the risk-averse mindset requires awareness efforts to be made.

A Circular Economy vision serves as a guiding framework, offering a clear strategic direction with specific objectives and measurable targets. The transition to a Circular Economy requires a strategic framework that outlines specific objectives and measurable targets to guide actions and monitor progress (AlJaber, Martinez-Vazquez and Baniotopoulos, 2023).

Raising awareness entails implementing theories of change to foster resource stewardship, modify consumption habits and acknowledge the added economic value. The leadership of decision-makers is also mentioned as being key to streamline Circular Economy.

The barriers and enablers mentioned in this section are summarised in Table 7:

Table 6\_ summary of barriers and enablers associated with cultural acceptance

Barriers		Enablers
CULTURAL ACCEPTANCE	Lack of understanding of Circular Economy concepts	Raising awareness by applying theories of change, providing training and implementing new policies. Decision makers' leadership
	Resistance to change due to risk aversion	Scientific research. Adequate regulation

### 2.4.3 Lack of symbiosis with other construction activities or industries

The €1.8tn opportunity revealed by the Ellen MacArthur Foundation reaffirms the economic rationale of moving towards a circular economy. Realising and capturing the benefits of this systemic transition requires a cross-industry, cross-performance, and multidisciplinary approach (Ellen MacArthur Foundation, 2016).

Industrial symbiosis promotes circular systems by supporting closed loops and creating networks of waste and by-products from one actor which can be reused for another as a raw material. Industrial symbiosis can play an important role towards materials circularity and efficient resources use. Urban metabolism could contribute to Circular Economy implementation by identifying the most important drivers for resource flows, determining the trends in materials flow, and evaluating the effects of Circular Economy implementation. (Hossain et al., 2020).

As per Arup, many of the same principles and approaches apply to buildings and infrastructure. As with buildings, decisions must be taken early in the design process to ensure circularity is integrated throughout the lifecycle of an infrastructure asset. Coordination and collaboration are essential to achieving this. New relationships may form between industries and stakeholders not normally brought into contact, e.g. designers and demolition companies (Luebkehan & Fellow, 2016).

Cross-industry collaboration and sector networks will provide platforms to exchange information, experiences and best practice. This will help reach mutual agreement on how to progress individual, organisational or joint agendas (Luebkehan & Fellow, 2016).

The barriers and enablers mentioned in this section are summarised in Table 8:

Table 7\_ summary of barriers and enablers associated with the symbiosis with other activities

	Barriers	Enablers
SYMBIOSIS WITH OTHER ACTIVITIES	Lack of coordination and collaboration within the wider construction sector	New relationships between stakeholders that do not normally interact, e.g. designers and demolition companies
	Lack of cross-industries coordination and collaboration	platforms to exchange information, experiences and best practice. Urban metabolism methodological tool.

## 2.5 Economic barriers and enablers

Economic factors play a key role in the deployment of Circular Economy. Moreover, many authors point out to economic frameworks as the “hard” barriers to Circular Economy. It is well acknowledged that Circular Economy provides society with environmental benefits, but these have never been economically quantified.

As companies look for economic profit and, so far, circular economy profitability within the construction industry should be showcased so that it sets a valid business case for implementation.

Financial issues concerning circular solutions relate to various aspects: market challenges, fiscal environment and costing considerations, which will be further detailed in the following sections.

### 2.5.1 Higher upfront investment and lack of Whole life costing approach

The business and investment community is frequently accused of operating with short-term blinkers – capital expenditure is prioritised over operational expenditure, and rapid returns on investment are expected. This tends to favor transactional relationships over long-term collaborations, and works against projects with wider social and environmental objectives but longer financial paybacks (Hart *et al.*, 2019a).

Specifically, when referring to Circular Economy, higher upfront investment is often required and thus presented as one of the main obstacles to Circular Economy uptake. Increased upfront investment is attributed to higher costs in the deployment of design solutions that might be more expensive to execute or require a specific skill set (e.g. design for disassembly), costs of experts and qualified team to be employed on such projects as well as higher market costs of repurposed or recycled materials and costs associated with material testing and certification to ensure quality. Other additional costs are related to the possible increase in time for obtaining permissions or insurance costs associated

with quality and safety uncertainty which also present a concern to clients and engineers.

The high costs associated to reclaimed materials prevent clients from demanding these sustainable materials, as they invariably lead to higher material costs in building construction projects (Genc, 2021). This is seen in suppliers shunning away from such expensive materials, thus affecting the supply and demand of such materials. Similarly, the extra costs accruing from deconstruction prevent building owners and clients from seeking out this sustainable option. (Osei-Tutu *et al.*, 2023).

Increase in awareness and further research on actual study cases to evidence economic benefits from considering a whole life costing could help shift to a long-term thinking and make a clear economic case for Circular Economy implementation. According to AlJaber, Martinez-Vazquez and Baniotopoulos, (2023) Without solid case studies, stakeholders would have limited evidence to demonstrate the feasibility and benefits of adopting Circular Economy principles in building projects. This lack of evidence can make decision makers hesitant to invest in or implement these practices.

Considering whole life costing should be the basis for design optioneering and decision making along with LCSA.

Quantifying the economic, social and environmental benefits of specific circular economy initiatives will help all parties to appreciate its value to their business and sector. This will, in turn, help them to make the case for investment or contractual adjustments to facilitate a broader transition (Luebkehan & Fellow, 2016).

Additionally, adequate financial support mechanisms such as longer-term finance needed for leasing models, can significantly help achieve client engagement.

The barriers and enablers mentioned in this section are summarised in Table 9:

Table 8\_ summary of barriers and enablers associated with the whole life costing approach

	Barriers	Enablers
WHOLE LIFE COSTING APPROACH	Short term thinking	Performing Life-Cycle Cost Assessments
	Cost of upfront investment	Performing Life-Cycle Cost Assessments Long-term financing
	Unclear business case, lack of economic benefits data	further research and study cases showcasing long term economic benefits. Adequate financial support mechanisms such as long-term financing

### 2.5.2 Residual value and second-hand material markets

Using reclaimed or recycled materials presents difficulties on two main levels: the residual value of these materials in terms of their quality and suitability for their intended use, and the increased costs and reduced market availability of these products.

Regarding the quality of reclaimed and recycled materials Grossegger, MacAskill and Al-Tabbaa, (2024) maintain that reclaimed materials are commonly downcycled and used with other secondary materials when referring to road construction. Downcycling due to material quality alleviates material demand. However, the absorption capacity is limited and can only be increased through additional effort. There is a need for closer cooperation between road authorities and construction companies to establish a common understanding of the circular economy concept and which data should and can be collected to quantify circularity.

New technologies to better assess the quality of reclaimed and recycled materials, and introduction of this data in material passports can help manage the risk aversion mindset associated with these products. New regulation requiring a mandatory use of these materials to a minimum amount will increase their market demand and consequently their value.

Regarding costs, low virgin material prices compared to secondary or recycled materials is a high barrier to Circular Economy. Grossegger, MacAskill and Al-Tabbaa, (2024) illustrate this through the example of asphalt mixtures in road projects, explaining that market prices of raw materials are in many cases lower, making reclaimed asphalt reuse hardly economically viable, though being technically feasible. Additionally, Low landfill costs are another factor that discourages recycling and reclaiming materials. Therefore, taxes on the extraction of raw materials and landfilling could be a tool to balance this price difference and make recycled materials a competitive alternative.

According to AlJaber, Martinez-Vazquez and Baniotopoulos, (2023) the lack of consumer awareness about Circular Economy principles affects the demand for purchasing sustainable materials. Changes in regulation and making research more accessible to consumers can increase awareness and engagement with the Circular Economy agenda.

In terms of market and supply chain, various authors mention inadequate market mechanisms for recovery and fragmented supply chains as critical for a Circular Economy to work efficiently, highlighting the importance of fluent communication and a comprehensive approach within the supply chain.

The availability of secondary materials markets is currently limited, entailing unpredictable supply. Limited markets have a direct effect on the demand for reclaimed materials and vice versa. According to AlJaber, Martinez-Vazquez and Baniotopoulos, (2023) point out that the mismatch between supply and demand in reused/recycled materials can lead to inefficiencies and financial burdens.

Joint political and supply chain efforts should be made to increase reclaimed material ratios within performance and legislation limits.

The creation of online platforms and marketplaces for reclaimed materials and deconstruction projects will allow for easier market penetration of reclaimed or recycled materials. Providing a readily available platform could bridge the gap between demand and supply, while overcoming the extra costs of reclaiming materials (Osei-Tutu et al., 2023) .

Considering that recycled building materials are usually downcycled, and that infrastructure projects have high performance requirements that these materials may not meet, a critical reflection seems timely at this point, questioning whether encouraging the use of reclaimed and recycled materials is appropriate for infrastructure projects. Another way of promoting circularity in this type of projects could be from the perspective of improving durability and extending the useful life of materials, in line with the extended period of use of infrastructures. In their position paper on construction products for the European Circular Economy, the European Asphalt Pavement Association (EAPA) determines that the most sustainable strategy for asphalt roads, which support the transport of 81% of passengers and 73% of inland freight, is simply to prolong their service life, preserving the asphalt as long as possible in the road, thereby reducing the need to remove it at all. A pavement preservation strategy involving simple, timely and cost-effective surface treatments to retain the asphalt integrity before later more costly repairs or rebuilds makes economic sense (EAPA Asphalt-A Key Construction Product for the European Circular Economy, n.d.). Added value should be given to the durability of the components instead of seeing them only as potential banks of materials for downcycling. In this respect, an in-depth analysis should be carried out per project to determine the best circular strategy for implementation.

The barriers and enablers mentioned in this section are summarised in Table 10:

Table 9\_ summary of barriers and enablers associated with residual value, supply chain and secondary markets

	Barriers	Enablers
RESIDUAL VALUE AND SECOND HAND MATERIAL MARKETS	Low residual value of secondary materials	Mandatory regulation to introduce a minimum amount of these materials. cooperation between stakeholders to create market demand. New technologies to better assess the quality of these materials, included in material passports. Fiscal suport e.g. tax reduction for CE initiatives

Difficultatly to break into the established markets dominated by industrial materials	cooperation between stakeholders to create market demand. Funding for research and development
fragmented supply chain	platforms and marketplaces for reclaimed materials and deconstruction project could bridge the gap between demand and supply
Low cost of CDW disposal	increasing the cost of landfill disposals
Low cost of virgin materials relative to secondary ones	Taxes on extraction of raw materials.

### 2.5.3 Business model

As per Arup, Circular Economy thinking offers real estate investors a framework for achieving environmental and social goals while at the same time delivering better economic performance (REALISING THE VALUE OF CIRCULAR ECONOMY IN REAL ESTATE, 2020). New circular real estate business models can deliver better returns on a reduced resource footprint.

However, the current there is a general conception that Circular Economy is not profitable and established economic models make it hard to obtain revenue from circular products or services. Specifically, barriers in the implementation of new business models that enhance circularity are the following:

- Unclear business case, and lack of economic revenue data and case studies
- Limited viable business models and lack of business model understanding
- Lack of access to finance

To help create a valid business case, more research and data from study cases should be made available to clients and decision makers. These studies should consider not only direct economic revenues but also the indirect economic benefits/profitability attributed to Circular Economy such as:

- Employment creation,
- Reduction in costs related to public health and environmental aspects,
- Reduction of demand-driven price volatility and supply risk and
- Resource productivity.

However, the crucial first step towards implementing scalable circular economy projects is the development of viable business models that help realise the added value of circular economy business models as stated by Arup (REALISING THE VALUE OF CIRCULAR ECONOMY IN REAL ESTATE, 2020). In order to realise the full opportunity of a circular built environment, these models will have to be implemented at all scales and adress the Circular Economy three main levels: designing out waste and pollution, keeping products and materials in use, regenerating natural systems.

Existing circular business models are into eight categories: Product as a service, Product life extension, Circular Supplies, Waste as a Resource, Resell, Sharing platforms, Remanufacture and Repair.

For the infrastructure sector specifically, some suitable business models area the following:

1. The optimisation of current **design-build-finance-operate-maintain (DBFOM) approaches**, including extended concession periods and optimised resource and recycle plans (Luebkehan & Fellow, 2016).
2. Product (in this case the asset) as a service requires alternative ownership models including **leasing and performance models**. Performance Procurement extends the product-as-a service model, to the asset level. Under product-as-a-service procurement, rather than buying products from suppliers through capital budgets, construction clients and tenants buy subscriptions for services provided by those products through operational budgets. The supplier, now a service provider, retains ownership of the products themselves and is responsible for their maintenance, repair and upgrade. Performance Procurement model has particular relevance in assets where minimal disruption is of utmost importance such as airports or other transport infrastructure (REALISING THE VALUE OF CIRCULAR ECONOMY IN REAL ESTATE, 2020) .
3. Circular Supplies models refer to the **extended responsibilities of manufacturers** and adoption of take-back schemes in which the manufacturers are responsible for retrieving the product at its end-of-life stage and re-introducing it in their manufacturing cycle. This model helps keeping materials within a manufacturing cycle, avoiding waste and extraction of raw materials. This model also facilitates the waste management on site, reducing the client's costs associated with specific sorting technology and skill sets. However, manufacturers are required to invest in designing their products while considering their end-of-life, as well as in new manufacturing technology that reuses secondary materials and in the logistics of material recovery from sites.
4. The **Residual Value model** envisages the creation of tradable futures contracts related to the value of building materials at deconstruction. During construction, clients can sell these futures contracts, which then could be traded while the building is operational, changing in value in response to local real estate and global commodity markets. Transfer of ownership and cash settlement takes place upon deconstruction after which the materials re-enter the market for reuse (REALISING THE VALUE OF CIRCULAR ECONOMY IN REAL ESTATE, 2020) .

Various authors pay special attention to the role of Public-Private-Partnerships (PPP) in the circular business models. According to Hueskes, Verhoest and Block, (2017)

and following the definition of Grimsey and Lewis (2004, p. 2), public-private partnerships are broadly defined as follows:

Public-private partnerships are arrangements whereby private parties participate in, or provide support for, the provision of infrastructure, and a PPP project results in a contract for a private entity to deliver public infrastructure-based services.

Some typical characteristics that distinguish PPPs from traditional public procurements include the use of long-term infrastructure contracts (LTICs), the transfer of certain risks to the private sector, a focus on the specification of project outputs rather than project inputs, and the integration or “bundling” of different functions into a single contract such as design, construction, financing, maintenance and/or operation.

Public-private partnerships are sometimes mentioned as a potential vehicle for achieving sustainability goals. For example, the bundling of various functions into one long-term contract could make it in the interest of private partners to take life-cycle costs into account, since it provides an incentive to think, “beyond the design stage and build in energy-reducing and waste-minimizing features that may cost more initially but result later in lower operating and running costs, and so deliver cost effectiveness over time. Hueskes, Verhoest and Block, (2017).

The barriers and enablers mentioned in this section are summarised in Table 11:

Table 10\_ summary of barriers and enablers associated with circular business models

	Barriers	Enablers
BUSINESS MODELS	Unclear business case, lack of economic benefits data	More accessible research and case studies data to clients and decision makers
	Limited viable business models and lack of business model understanding	adoption of new business models such as optimisation of DBFOM approaches, leasing and performance models, extended manufacturers' responsibilities, residual value model
	Lack of access to finance	Better regulatory financial instruments

## 2.6 Institutional barriers and enablers

### 2.6.1 Legal and institutional framework barriers

As systematically mentioned in previous categories, public institutions play a key role in fostering circularity, even more so in the case of transport infrastructure, as they are public funded.

As per Arup, ensuring that benefits flow to everyone in the value chain also requires changes at system scale: to governance, procurement, financial and delivery mechanisms and incentives (Luebkehan & Fellow, 2016).

However, the current lack of regulatory frameworks and relevant policy to promote Circular Economy across all stages is repeatedly mentioned by several authors. In their scientometric analysis of keywords in relevant articles, Osei-Tutu et al., (2023) identified that “environmental policy” is a current theme in barriers to Circular Economy adoption within the construction industry positing that current environmental policies do not advocate for Circular Economy principles and thus creates a barrier to the successful adoption of Circular Economy into the construction industry.

As-per-today non-flexible or outdated regulations, risk-averse standardization and specifications and lack of institutional incentives currently discourage the implementation of Circular Economy.

Public administration and relevant policy can influence the entire value chain through regulatory and financial instruments and provide a supportive legal framework to foster circularity. They can devise incentives, legislations, enforcements, and penalties that strongly guide the decisions of other key actors or agents (e.g. asset owners, investors, business) to implement circular practices.

As per Coenen, Visscher and Volker, (2023) , institutions have the power to market creation and destabilisation by creating the conditions such that innovative solutions can develop and compete with existing practices through, for example, creating “arenas”, pricing mechanisms, as well as phasing out and destabilizing undesirable markets with respect to the mission.

As per Arup (2020), government intervention may also be necessary to change the way that rail infrastructure (applicable to transport infrastructure in general) projects are funded and procured.

The built environment sector would benefit from strengthening industry targets for waste and reuse, as well as incentives to promote extending product life and remanufacturing. Policy is also needed to help remove barriers, such as altering the definition of waste to facilitate re-use and minimise landfill. This would also help to support new markets for secondary materials, for example, and unlock new revenue streams. Policy can support organisations seeking to train or up-skill their workforce (Luebke and Fellow, 2016) . On the waste definition criteria, EAPA mentions some European countries which have recently established legal mechanisms to change the classification of site-won asphalt (the material to be recycled, in the form of milled asphalt road layers or as slabs ripped up from asphalt pavements, or being asphalt from reject, surplus or failing production) from “waste” to “product” or “by-product” thereby facilitating their re-use (EAPA Asphalt-A Key Construction Product for the European Circular Economy, n.d.).

New policy measures can also help to drive innovation by providing incentives (to develop demonstration projects, for example) and by creating a more secure environment for investors. In addition, policy interventions can accelerate change and promote procurement that favours whole lifecycle approaches (Luebke and Fellow, 2016) .

A way to address the lack of univocality and directionality is to strengthen the coordination between Circular Economy networking activities to avoid multiple Circular Economy operationalizations. Here, ministries and other central government bodies should take a leading role, because of their ability to regulate and allocate resources and their commitment to the Circular Economy mission (Coenen, Visscher and Volker, 2023).

Currently, markets are not incentivized towards Circular Economy although assessment methods to include Circular Economy in procurement are rapidly improving. Circular innovations are often so radically different that they do not meet the current assessment and procurement criteria. This requires public clients to be more open to solutions that have a low technological readiness level. Here, first, clients should provide space in the procurement criteria for more radical innovations and, second, risk should be distributed more fairly between market parties and clients, especially since the benefits of the circular solutions often only become apparent over the long term (Coenen, Visscher and Volker, 2023).

PPP projects might stimulate Circular Economy if the procuring government influences the bid process of the private party by including Circularity requirements and offering incentives to those who will implement circularity.

To understand the obstacles underlaying the lack of this legal framework, some authors offer the following explanations:

(Hart et al., (2019a) correlate this to an absence of global consensus around policy support for Circular Economy while Abdulai et al., (2024) mention the complexity in institutional structures, challenges in local administrative coordination, restricted financing options, lack of transparency, and the absence of region-specific tailored performance monitoring systems.

It therefore seems that the central government and European authority have a role to play in establishing a common legal framework, which each member state would have to tailor to its regional particularities. Institutional structures will have to devise mechanisms to streamline approval of new regulations (based on accurate data sets) in a transparent way. Integration of new business model in public procurement can help overcome the current restricted financing options.

The barriers and enablers mentioned in this section are summarised in Table 12:

Table 11\_ summary of barriers and enablers associated with regulation

Barriers		Enablers
LEGAL AND REGULATORY FRAMEWORKS	Lack of regulatory instruments or pressure and Regulatory obstructions to reuse	<p>Technical Codes and Standardisation for material reuse</p> <p>Establishing mandatory circularity targets such as waste diversion rates, minimum amount of recycled/reused content</p> <p>Altering the legal definition of waste to facilitate reuse</p>
	Lack of Governance	Procurement requirements
	Lack of financial instruments	<p>Financial incentives for R&amp;D, extended producer responsibility and implementation of CE.</p> <p>Pricing mechanisms and phasing out undesirable markets.</p> <p>Taxes on landfilling and extraction of raw material</p>
	absence of global consensus around Circular Economy policy	Common legal framework established by central government and European authority
	Complexity in institutional structures	Legal mechanisms to streamline approval of new regulation in a transparent way
	Challenges in local administrative coordination	Improvement of inner collaboration between public bodies
	Restricted financing options	Integration of new business models in public procurement
	Lack of transparency	Common legal framework established by central government and European authority
	Absence of region-specific tailored performance monitoring systems	Improvement of inner collaboration between public bodies and promoting Public - private collaborations between the administration, research centers and the industry

## 2.7 Summary of the literature's findings

Findings from the literature review confirm that high levels of collaboration and whole-life approach are needed to adopt circularity. The influence and inter-relationship among stakeholders are key for the engagement of the entire value chain and success in the implementation of Circular Economy.

Economic factors are a determinant aspect in the deployment of Circular Economy. Moreover, many authors point out to economic frameworks as the "hard" barriers to Circular Economy. The economic barriers relate to various aspects: lack of a clear business case and profitability, cost considerations (especially the entailed high upfront cost), inadequate fiscal environment and market challenges among others.

Most importantly, as systematically mentioned in most scientific papers, public institutions play a key role in fostering circularity, even more so in the case of transport infrastructure, as they are public funded. As-per-today non-flexible or outdated regulations, risk-averse standardization and specifications and lack of institutional incentives and inadequate financial instruments currently discourage the implementation of Circular Economy.

On the other hand, technical and technological barriers were also addressed in many publications, highlighting the lack of technologies for quality assurance as the most important obstacle related to the risk averse mentality of this sector. The following figure illustrates the mentioned main barriers by level of importance:

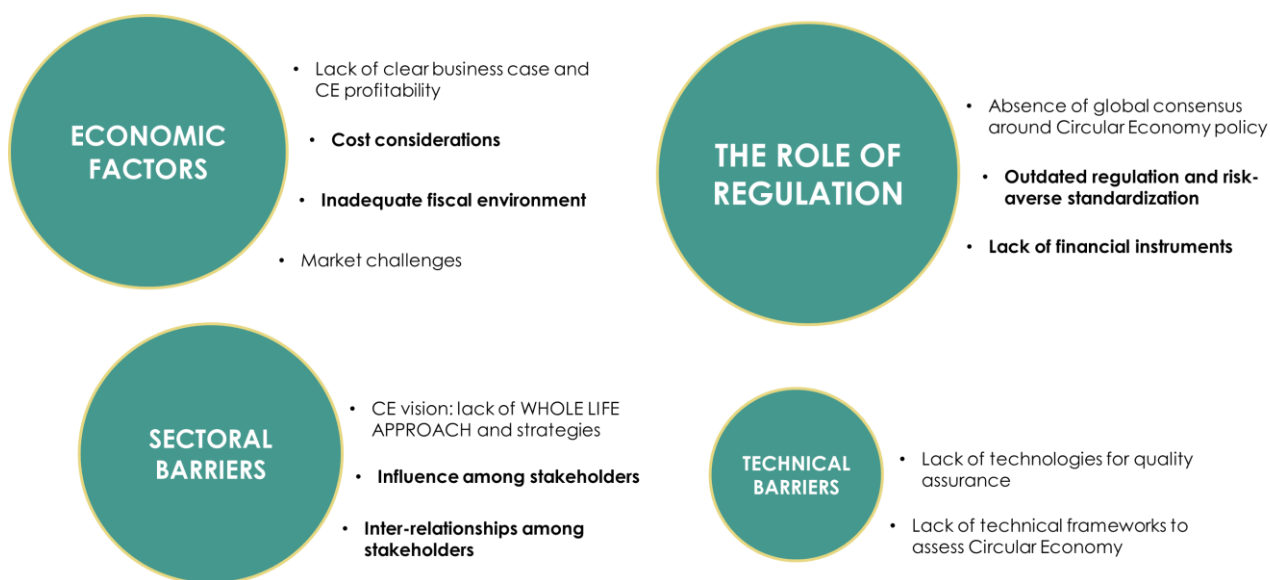


Figure 8\_ Main barriers to the implementation of Circular Economy according to the literature review. Source: Own elaboration.

A summary of all barriers and enablers discussed in previous sections is presented in the Table 13:

Table 12\_Barriers and enablers to Circular Economy based on finding from the literature review

Barriers		Enablers
TECHNICAL AND TECHNOLOGICAL BARRIERS	RISK AVERSION	Engineers not willing to take on the liability
		Guidelines, codes and testing standards
		Different performance requirements prevent direct reuse of material
		In-depth analysis of element requirements
	PROJECT COMPLEXITY	Destructive testing to determine element performance
		New technologies for element testing
		Lack of product information
		Verifiable traceable product information
		Difficulty in designing for future needs due to the uncertainty in future mobility trends
		Use of data science for more accurate future mobility trends
		Design solutions for disassembly might come in conflict with durability
		System thinking and early stage analysis considering the end-of-life scenario can help prioritise the best strategy (durability or disassembly) for the specific project
		Site constraints limit possibilities for on-site reuse (limited access to storage, excavated material not suitable for reuse, etc)
		Site assessment and early construction planning
		Immature recycling technology and recycling market
		Material hubs for storage and sorting
		Lack of own technology to recover and reuse construction materials by stakeholders.
		Incentives to allocate resources for R&D
		Insufficient application of the 3R approach by construction practitioners and projects
		Implementing design for disassembly criteria and training for the specific skills set needed

SECTORAL AND SOCIAL	CE ASSESSMENT	Lack of producer-based responsibility system in the production of construction materials	Incentive for manufacturers to implement extended responsibilities programs and take-back schemes
		Lack of Circular Economy evaluation frameworks	Establishing circularity indicators (KPIs) in design guidelines that consider LCA, LCC, and S-LCA.
		Lack of technical knowledge among project stakeholders	Make the scientific relevant research accessible to the wider public, and specifically to the decision makers of the project. Include Circularity criteria in academic programs
	LACK OF ENABLING TOOLS	Lack of collaborative working methodologies	Using BIM to streamline circular criteria and its implementation. Integration of LCSA for multi-objective optimisation in early design
		Lack of product information	Information management systems: Material and project passports
		Data uncertainties in quantifications of material flows	Artificial intelligence relating to the project design process for waste minimisation. Use of verifiable material-tracing tools
		Data security	Use of blockchain technologies
	LACK OF COLLABORATION BETWEEN STAKEHOLDERS	Client not on board	Policies and incentives Making the scientific relevant research accessible to the wider public
		Lack of leadership skills	Implementing an integrative process approach with shared responsibilities
		Circular Economy tends to have a top-down inter-relationship	Incentives can promote a bottom-up approach to engage all stakeholders

		Lack of value chain engagement	Forming longer term relationships and partnerships (enhancing collaboration through common goals).
		Lack of continuity of ownership and control	Having the same owner and operator. Contract requirements
		Lack of communication between stakeholders outside their own supply chain network	Implementing an integrative process approach
		Lack of consideration of the whole life cycle: Use phase not considered in project design	Implement design for durability solutions. Implement preventive maintenance plans over corrective ones
	CULTURAL ACCEPTANCE	Lack of understanding of Circular Economy concepts	Raising awareness by applying theories of change, providing training and implementing new policies. Decision makers' leadership
		Resistance to change due to risk aversion	Scientific research. Adequate regulation
	SYMBIOSIS WITH OTHER ACTIVITIES	Lack of coordination and collaboration within the wider construction sector	New relationships between stakeholders that do not normally interact, e.g. designers and demolition companies
		Lack of cross-industries coordination and collaboration	platforms to exchange information, experiences and best practice. Urban metabolism methodological tool.
ECONOMIC	LACK OF WHOLE LIFE COSTING APPROACH	Short term thinking	Performing Life-Cycle Cost Assessments
		Cost of upfront investment	Performing Life-Cycle Cost Assessments Long-term financing

		Unclear business case, lack of economic benefits data	further research and study cases showcasing long term economic benefits. Adequate financial support mechanisms such as long-term financing
	RESIDUAL VALUE AND SECOND HAND MATERIAL MARKETS	Low residual value of secondary materials	Mandatory regulation to introduce a minimum amount of these materials. cooperation between stakeholders to create market demand. New technologies to better assess the quality of these materials, included in material passports. Fiscal support e.g. tax reduction for CE initiatives
		Difficulty to break into the established markets dominated by industrial materials	cooperation between stakeholders to create market demand. Funding for research and development
		fragmented supply chain	platforms and marketplaces for reclaimed materials and deconstruction project could bridge the gap between demand and supply
		Low cost of CDW disposal	increasing the cost of landfill disposal
		Low cost of virgin materials relative to secondary ones	Taxes on extraction of raw materials.
	BUSINESS MODELS	Unclear business case, lack of economic benefits data	More accessible research and case studies data to clients and decision makers
		Limited viable business models and lack of business model understanding	adoption of new business models such as optimisation of DBFOM approaches, leasing and performance models, extended manufacturers' responsibilities, residual value model
		Lack of access to finance	Better regulatory financial instruments

REGULATORY	LEGAL AND REGULATORY FRAMEWORKS	Lack of regulatory instruments or pressure and Regulatory obstructions to reuse	Technical Codes and Standardisation for material reuse Establishing mandatory circularity targets such as waste diversion rates, minimum amount of recycled/reused content Altering the legal definition of waste to facilitate reuse
		Lack of Governance	Procurement requirements
		Lack of financial instruments	Financial incentives for R&D, extended producer responsibility and implementation of CE. Pricing mechanisms and phasing out undesirable markets. Taxes on landfilling and extraction of raw material
		Absence of global consensus around Circular Economy policy	Common legal framework established by central government and European authority
		Complexity in institutional structures	Legal mechanisms to streamline approval of new regulation in a transparent way
		Challenges in local administrative coordination	Improvement of inner collaboration between public bodies
		Restricted financing options	Integration of new business models in public procurement
		Lack of transparency	Common legal framework established by central government and European authority
		Absence of region-specific tailored performance monitoring systems	Improvement of inner collaboration between public bodies and promoting Public - private collaborations between the administration, research centres and the industry

### 3 ONLINE QUESTIONNAIRE AND INTERVIEWS

Following the literature review, a questionnaire on motivations, barriers and enablers to circular economy was shared with relevant stakeholders and distributed online to gather wider industry feedback. Based on the responses received, 3 in-depth interviews were conducted with the key stakeholders identified. It is important to highlight that an online questionnaire and interviews approach has a subjective aspect. Whether or not a barrier is recognised, and how often it is recognised depends on the respondent, and not necessarily correlated with its importance. Similarly, stakeholders may consider enablers differently. Therefore, the aim of this approach is not to determine the level of importance of an obstacle or enabler based on the frequency with which it is ranked, but to understand the priorities that each type of stakeholder of value chain stakeholder has in relation to the Circular Economy. The results of the questionnaires and interviews were further analysed against the results of the literature review in the discussion section to determine whether the scientific research is aligned with the industry's perception and to provide a certain level of objectivity to this process.

#### 3.1 Online questionnaire

A self-completed online questionnaire was used to investigate drivers and barriers to the implementation of Circular Economy practice in transport infrastructure projects. It consists of four sections: the first section addresses the respondent's background identify their role in the value chain and their experience with Circular Economy, while the following sections cover motivations, barriers and enablers to overcome them.

Results from the literature review were used to inform the questionnaire, setting out the motivations, barriers and enablers included. These sections of the survey included a core rating question, one or more multiple choice questions on a specific aspect and an open question for the respondents to share their experience or add any aspects that had not been taken into account. A five-point rating scale was used to measure the level of relevance, importance or weight of motivations and barriers, and level of effectiveness of the enablers.

The questionnaire was specifically sent to representatives of the transport infrastructure industry including public entities, concession companies and developers, design team members (engineers) from main European firms and material and product manufacturers among others.

The survey was available for a period of three weeks and resulted in 135 valid responses.

##### 3.1.1 Results

The first section asked for background data of the respondents and their level of experience with Circular Economy.

Most respondents were part of the material and product supply chain (37.50%), numerous responses were also received from other types of entities such as consultants, research institutions and industry associations (30.21%) as well as from design team members or engineers (16.67%). 10.42% of the responses were received from owners (public entity, concession company or real estate developer). 8.33% of responses came from the end-users and only 4.17% from contractors.

In terms of geography, only 65% of respondents indicated their country of residence. Of these responses, around 60% were from Spain and the other remaining 43% from other geographical areas within the EU context, which helped giving a more general picture of the European situation, in addition to the Spanish region. Specifically, the graph below illustrates the responses received by country:

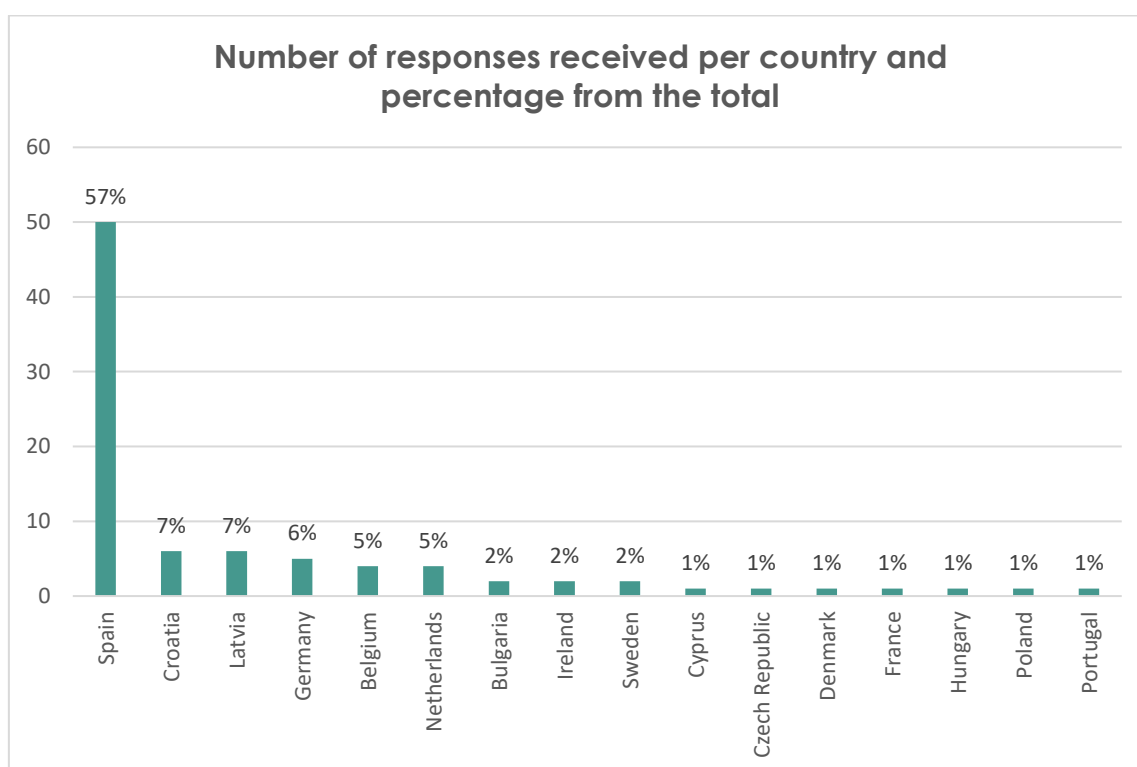


Figure 9\_Survey results: number of responses received by country and percentage from the total of responses received

Please note that 47 respondents did not wish to share their country of residence.

When asked about their level of experience with implementing Circular Economy most respondents reported being familiar with these concepts to a certain extent: 20.83% stated having a basic understanding and no experience, 32.29% confirmed having a fair understanding with little deployment experience and 35.42% claimed to have in-depth knowledge of Circular Economy with some deployment experience. Finally, 2.08% of the respondents admitted no knowledge in this field at all and 9.38% of them reported being experts in this field with extensive deployment experience.

### General questions

The first pair of questions aimed to get a general understanding of the different stakeholders' approach to Circular Economy concepts and whether it is being generally taken into account in the decision-making process. All respondents agreed that not all stakeholders have the same level of understanding when referring to the Circular Economy, providing different reasons for their answers as detailed below:

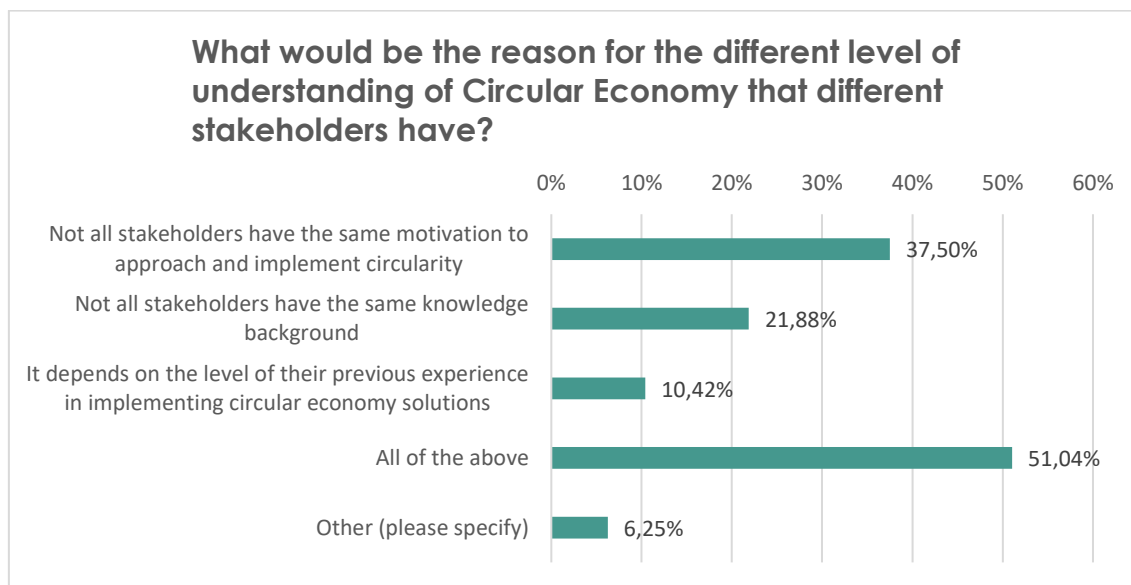


Figure 10\_Survey results: Reasons for knowledge differences in Circular Economy across the value chain

The other reasons given were related to cost considerations, level of available resources to invest in research and development, as well as the different accountability and legal framework to be complied with by stakeholders.

In other words, from a broader industry perspective, the difference in the level of understanding of the Circular Economy along the value chain is a result of a combination of reasons but stems mainly from different motivations to address circularity. To a lesser extent, stakeholders' background and field of expertise influence their knowledge of the Circular Economy, which also correlates with the different responsibilities and legal framework they are obligated to comply with. Their experience and involvement in the deployment of the circular economy might be correlated with the different level of resources each stakeholder has which in turn might influence their level of knowledge in this field.

When asked whether Circular Economy criteria was currently being considered during the decision-making process, 73.96% responded no compared to 26,04% that said yes, which unfortunately confirms that at present Circular Economy is not only not a priority but most of the time is not even considered in construction developments.

For those who answered yes, reference to regional and European legal framework regarding emission reduction was mentioned as the reason to consider the Circular Economy. These legal requirements were mentioned as

hard obligations for the manufacturing supply chain of materials and products, but less stringent, not as well defined or do not present incentives in the contract and procurement requirements nor in the waste management regional targets. Lacking regulation is also mentioned in regard to the permitted use of recycled materials and KPIs of circularity. In other words, manufacturers are the only ones seriously considering circularity strategies because of legal obligations, while the rest of the value chain (which has an important role to play) is not sufficiently motivated by current regulation.

Those who shared their opinion on why it was not being considered pointed out to the client or owner having a “Business as Usual” mindset and not being on board thus not considering Circular Economy from the get go, as well as to economic reasons mentioning that the economic return is not clear and therefore does not incentivise to consider Circular Economy.

Reasons given for not implementing Circular Economy are aligned with the results from the literature review referring to the client as the actor with the highest level of influence and to economic revenue as the main barriers. Whereas the reasons for implementing Circular Economy shed light on the importance that all stakeholders give to the role of regulation, both technical and financial. In this sense, material manufacturers and large companies that are obligated to comply with current green regulation stand out as value chain actors that are currently most involved in driving the Circular Economy agenda.

### Motivations

The first question posed in this section was an open question asking the respondent to indicate his main motivation for implementing Circular Economy solutions. To almost an entire extent, respondents refer to resource stewardship, ESG values and help promote a new way to rethink our production and consumption system. A minor few responses actually referred to specific motivations, mainly indicating compliance with internal goals or legal requirements.

It can be therefore stated that in general terms, stakeholders in the construction sector are aware of the environmental impact that the built environment has on the planet and believe that new ways of doing should be implemented.

However, since in previous questions they stated that Circular Economy was not being contemplated, it can be deduced that environmental values, though being an important first step, are not a hard enough motivation to implement Circular Economy.

The following question asked the respondents to rank a series of motivations by their level of relevance. The results are detailed in Figure 11:

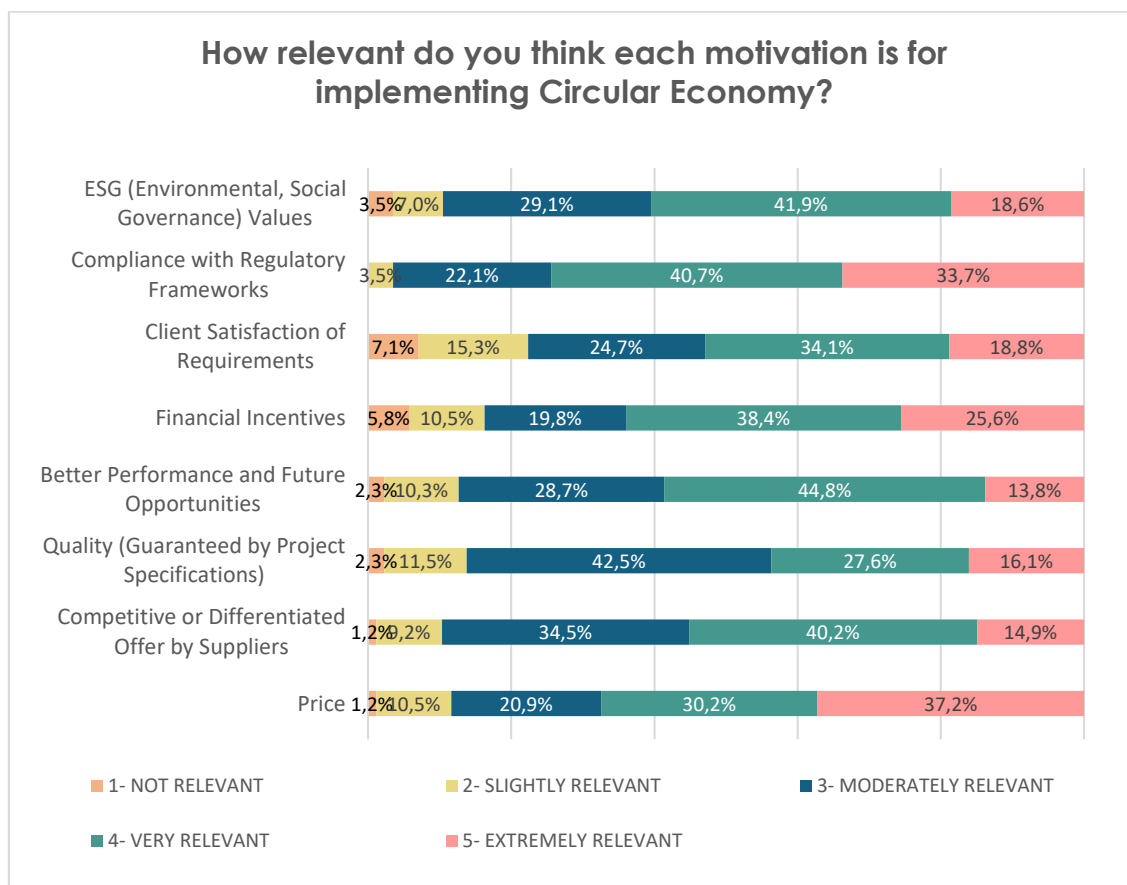


Figure 11\_ Survey results: Leve of relevance of the stated motivations to implement Circular Economy

In line with their answer to the first question, most respondents attribute a high relevance to ESG values and compliance with regulatory frameworks. Economic aspects such as lower price, and financial incentives were considered as extremely relevant motivators. Quality associated with circular solutions was considered a less relevant motivator, however better performance and future opportunities was viewed as more relevant, most likely due to its possible correlation with economic revenue.

From both questions it can be concluded that the motivation among stakeholders to implement Circular Economy derive from a shared mindset of ESG values. However, compliance with regulatory requirements and economic considerations are the actual strong drivers to adopt circular solutions.

### Barriers

The same process was followed in this section of questions, using a first open question for the respondents to indicate the main barrier that they are faced with when trying to deploy Circular Economy.

Most respondents referred to economic barriers, whether it was from a product pricing perspective and higher upfront investment or from the general uncertainty in Circular Economy profitability, as well as lack of adequate regulation (both technical and financial) as the main barriers. The inter-

relationships between stakeholders, ownership models and lack of willingness to share responsibility was also mentioned by many respondents, as well as lack of Circular Economy knowledge within the entire value chain and general conservativeness of the infrastructure sector. Some respondents also pointed out to the lack of quality assurance, little availability of secondary materials markets and technological supporting tools. Again, these responses are aligned with the literature review findings confirming the political-economic-sectoral barriers as being determinant, though attributing a larger weight to the economic aspects.

As a following question, respondents were asked to rank given barriers by their level of importance or difficulty to being overcome:

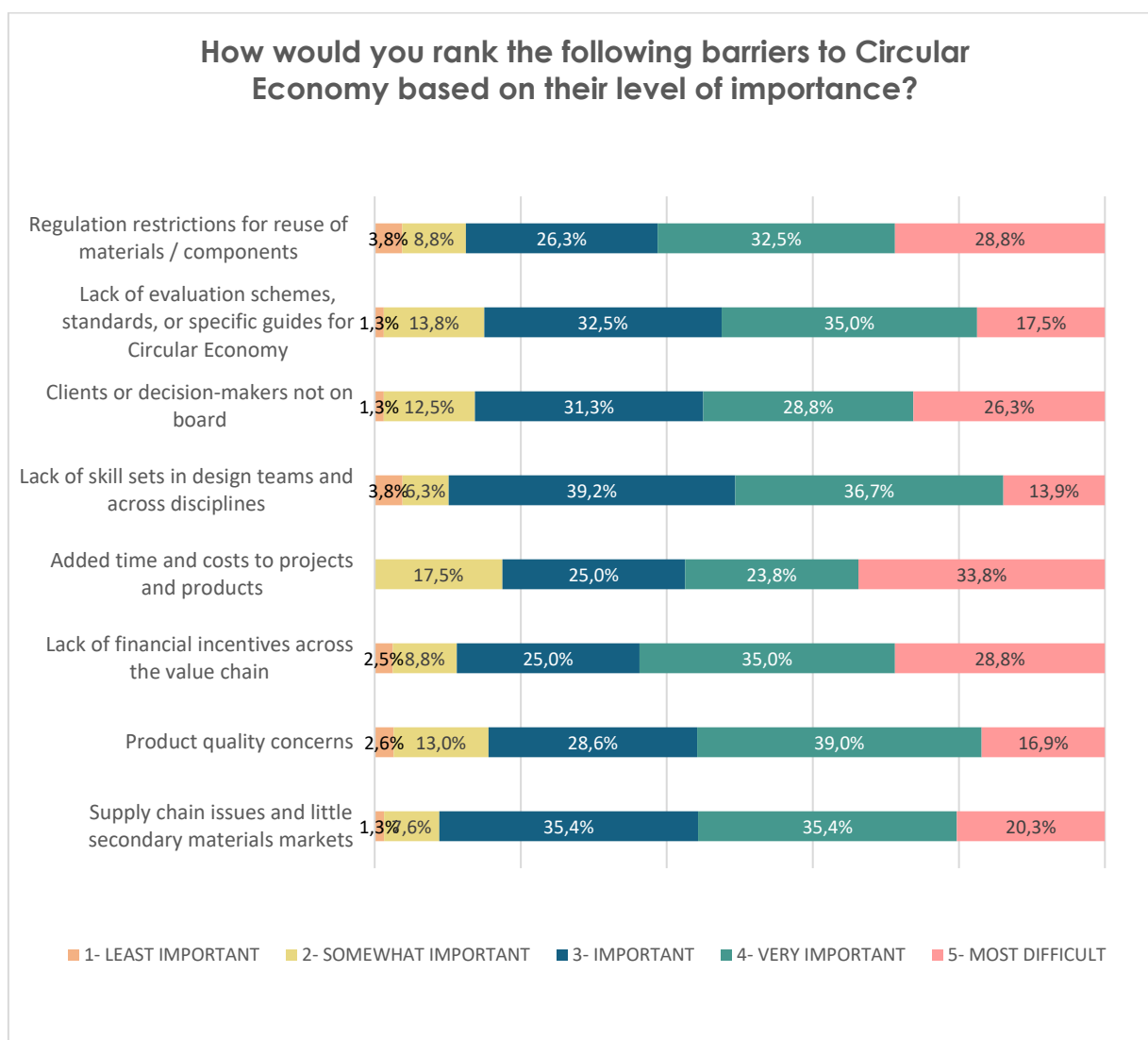


Figure 12\_Survey results: Barriers to Circular Economy based on their level of importance

Same as with the motivations, barriers were ranked in accordance with the answers in the open question, pointing out to the economic difficulties (both in lack of incentives and higher investment) and regulation restrictions as the main barriers. Clients not being on board was also ranked as a difficult barrier to

overcome, showcasing the client's influence on Circular Economy implementation. Supply chain issues and little availability in secondary material markets was also considered a very important barrier, correlating with the associated economic impact.

Product quality concerns was the highest ranked as a “very important” barrier, giving it more relevance in the score question than what was mentioned in the first open question.

From both questions it can be concluded that the barriers to Circular Economy are mainly related to economic impacts and lack of adequate regulation. Client's influence on the value chain has an important role to play when driving the Circular Economy agenda and quality concerns certainly represent a barrier to adopting circular solutions.

Considering that, in some cases, the upfront carbon associated with circular solutions might be higher compared to a conventional linear alternative, it seemed interesting to learn if industry actors share a whole life carbon approach or if they estimate as important other types of benefits related to Circular Economy. Therefore, they were asked whether they would implement a circular solution that entails a higher upfront carbon footprint, and if so, what would be the reason between the provided three options:

- Yes, as it contributes to shift to a new economy model of production and consumption, which would have a positive impact on an economic and social level.
- Yes, upfront carbon might be higher, but when considering the whole life cycle, the solution might be net positive.
- Yes, a higher carbon footprint might imply a negative impact from an emissions point of view but could still have a positive impact in regard to other environmental indicators.

17.5% of the respondents determined that the higher upfront footprint comes in conflict with the Circular Economy objective and therefore they would not implement that specific solution. 32.5% of the respondents chose the second option, understanding that the carbon impact of Circular Economy should be measured considering the whole life cycle, where benefits might show, whereas 18.75% chose the third option looking at the environmental impact from a broader perspective and considering other environmental indicators. 21.25% chose the first option, recognising the value of helping shift to new types of practice. 10% indicated other but specified the same reasons in other words.

### Enablers

Based on the results from the literature review, respondents were asked on the possible enablers for the main barriers identified. The first question addressed was regarding the challenge that circular solutions are not being demanded because they are not offered, and they are not offered due to the lack of demand. The respondents were therefore asked to rank possible solutions to break this cycle based on their potential effectiveness, as detailed below:

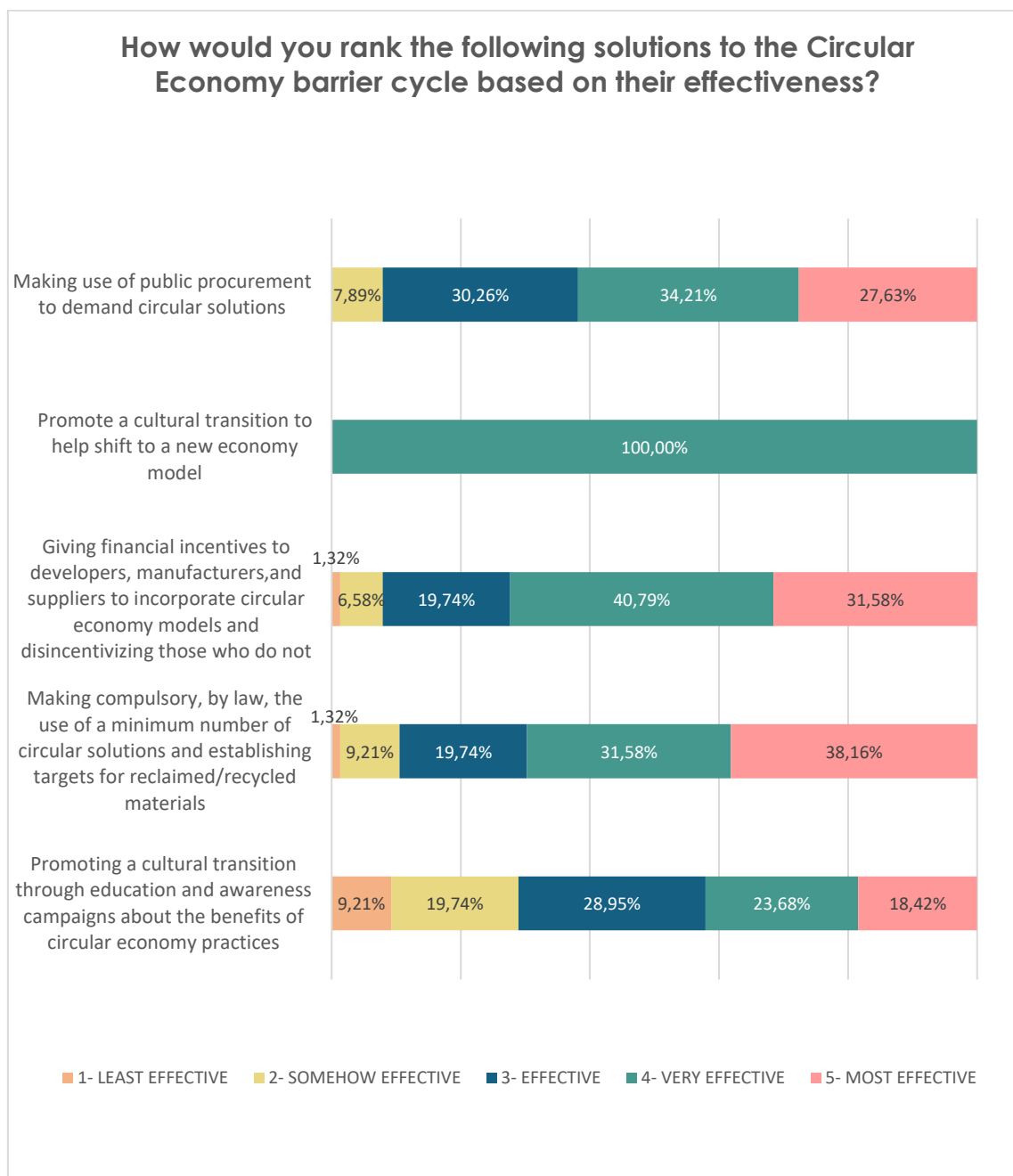


Figure 13\_Survey results: solutions to the Circular Economy barrier cycle based on their effectiveness

The respondents stated that law regulation along with financial incentives is the way to go to drive the Circular Economy agenda and break the current market barrier. Public procurement was also rated as an effective tool, with some opinions affirming that it is the most effective tool used as of today to foster circularity. All respondents agreed that a cultural transition is needed to shift to a new economy model.

When asked whether incentive measures such as financial incentives or tax breaks or mandatory measures defined by law or regulation as well as could be required by clients are preferable in promoting Circular Economy practices 46.05% preferred the incentive measures over 53.95% who preferred the

mandatory ones. These answers can be interpreted as both types of measures are needed to influence the sector and should definitely be supported by regulation.

Finally, a list of broader enablers was given to the respondents to provide feedback on the level of their effectiveness as detailed below:

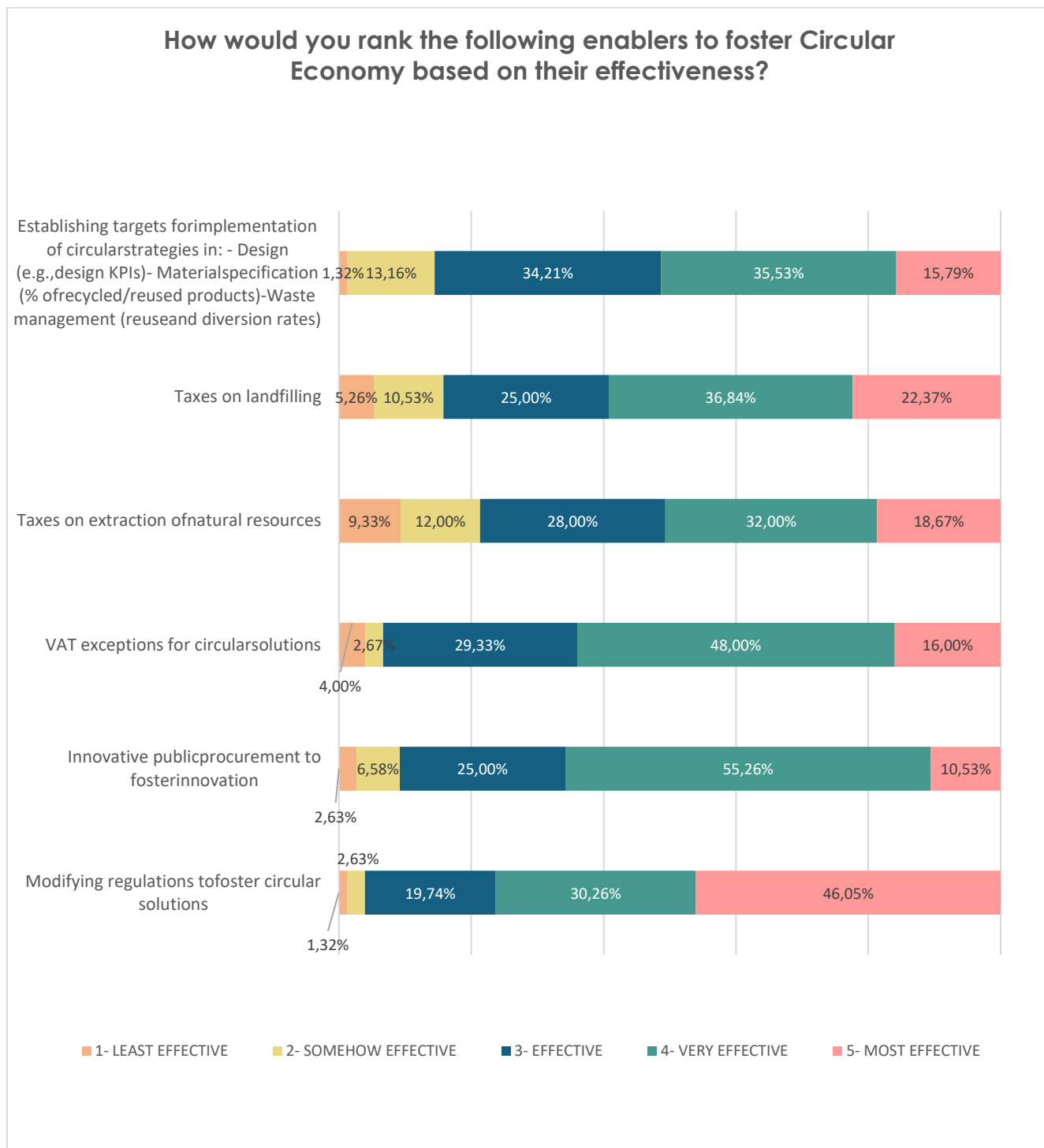


Figure 14\_Survey results: enablers to circular economy based on the level of their effectiveness

In line with previous answers, respondents point out to the institutional role to foster circularity through the modification of regulation and financial tools rating public procurement as most efficient followed by VAT exceptions, but taxes on landfilling and extraction of natural resources was considered effective to a lesser degree.

Establishing circular targets was generally considered effective less effective compared to the other enablers.

### 3.1.2 Discussion

The questionnaire process provided information from a broad industry perspective. Responses were received from a wide range of different types of stakeholders in the sector, with greater representation from the supply chain and less representation from end-users and contractors, and from various geographical areas within the EU context, although most significantly from the Spanish region. Almost all respondents were familiar with the concepts of the Circular Economy and had some level of previous experience in its deployment, thus providing experience-based opinions.

In general terms, the survey results are aligned with the conclusions from the literature review. Industry actors identified institutional-economic-sectoral aspects as more relevant barriers to the implementation of circularity than technical ones.

However, responses provided insight on some important aspects that were not reflected in the literature review, summarised in the following bullet points:

- At present Circular Economy is not only not a priority but most of the time is not even considered in construction developments. When considered, it is mainly due to legal requirements shedding light on the importance that all stakeholders give to the role of regulation, both technical and financial. In this sense, material manufacturers and large companies that are obligated to comply with current green regulation stand out as value chain actors that are currently most involved in driving the Circular Economy agenda.
- When asked about their motivation, almost all respondents referred to resource stewardship, ESG values and help promote a new way to rethink our production and consumption system. However, though being an important first step, environmental values are not a hard enough motivator to implement Circular Economy.
- When asked about their motivations to implement Circular Economy, most respondents attribute a high relevance to ESG values and compliance with regulatory frameworks.
- Respondents related the barriers to Circular Economy to economic impacts and lack of adequate regulation. Client's influence on the value chain has an important role to play when driving the Circular Economy agenda and quality concerns certainly represent a barrier to adopting circular solutions.

- Most respondents understand that the benefits to Circular Economy should be addressed on a broader sense including the social and economic aspects and that the environmental impact include a series of indicators aside from carbon footprint. Specifically, regarding the carbon footprint of Circular Economy, it should be measured considering the whole life cycle.
- Respondents stated that law regulation along with financial incentives is the way to go to drive the Circular Economy agenda and break the current market barrier.
- Both mandatory law and incentive measures are needed to influence the sector and should be supported by regulation.

The following graph summarises the conclusions stated above:

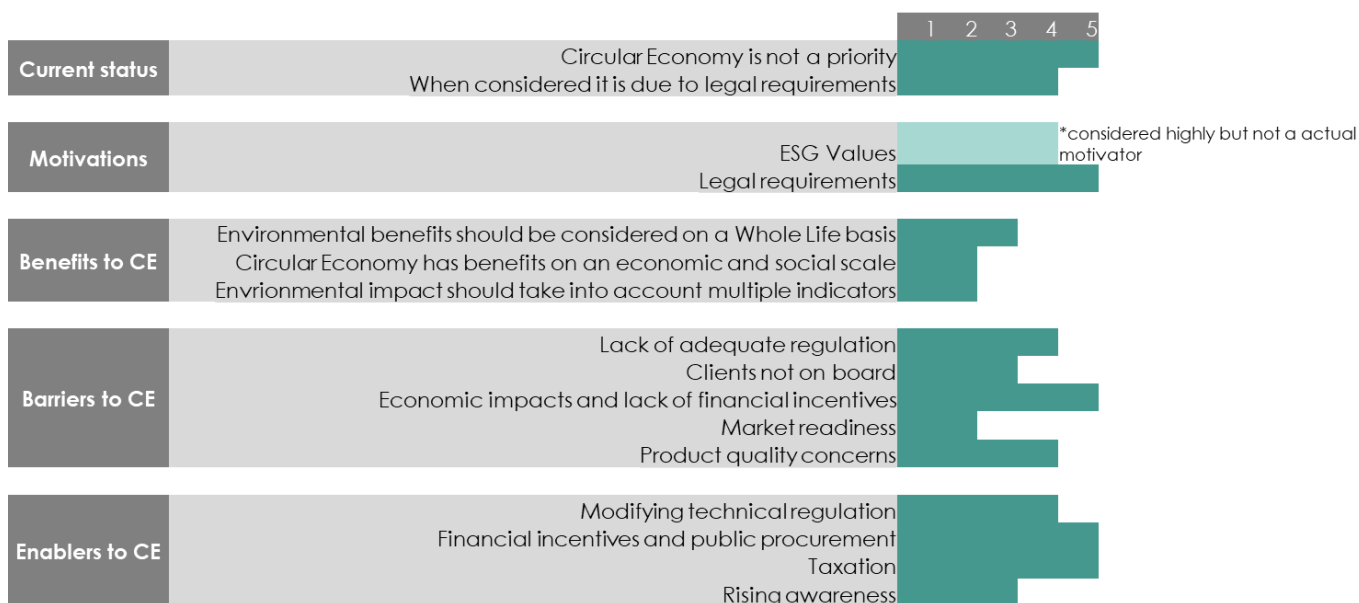


Figure 15\_Conclusions from the online questionnaire. Own elaboration.

### 3.2 Follow-up interviews

To better understand what currently happens in practice, in-depth interviews were undertaken to further explore the current Circular Economy implementation strategies, barriers and enablers as identified in the literature review and rated highly by questionnaire respondents. The interview's structure comprised 5 sections: the first addressed general definition and objectives of Circular Economy and the following focused on the different identified barriers divided by categories including sectoral and social, regulatory, market and supply chain, and circular strategies.

5 Interviews were conducted with key industry stakeholders who provided a viewpoint from an academic context, the R&D department of a major construction company, a certification entity and the technical department of material associations, as detailed below:

- The Head of the R&D Department of Dragados S.A. construction company.
- The Technical Director of ANDECE, National Association of Prefabricated Concrete, Spain.
- An Associate Professor in Structures, UPM, Chairman of the Spanish Mirror Group Eurocode 2, and Chairman of EU funded projects OMICRON EAB and LIAISON.
- The Technical Director of EAPA – European Asphalt Pavement Association
- The CEO of COPRO, certification, inspection and expertise for the road and infrastructure sector

#### Definition and objectives:

The interviewees were first asked about their view on Circular Economy and definition of success in its implementation.

Most of them linked Circular Economy to resource stewardship and being resource efficient, referring to two of the three main pillars of Circular Economy: the removal of pollution and waste, and keeping products and materials in use as long as possible.

Two of the interviewees mentioned that Circular Economy should be addressed at early stages of the project to achieve success in its implementation. One of them highlighted the importance of the design stage to streamline circular strategies while the other emphasised the strategic definition of the project, prior to its kick-off, as a determining phase in which key decisions are made and, therefore, represents the right moment to consider Circular Economy criteria.

One of the interviewees focused the discussion on looking at a structure or built element as a whole and prioritising reuse over material recycling, and another emphasized the value of the existing infrastructure as useful resource or material bank, pushing circularity beyond a secondary lifespan to multiple lifecycles when possible.

A different definition that one of the interviewees gave to Circular Economy was the reuse of a given material or product at the same level and function as it was

designed for the first time. He therefore defined success as when 100% of a material is used in its second life in the same way as it was used in its first life. He mentioned an example of this in a pilot project in which demolished concrete from a highway was reused as concrete aggregates on the same site with the same use to rebuild the highway.

Since both literature review and survey results pointed out to institutional-economic-sectoral factors over technical ones, the interviewees were first faced with this affirmation as an introduction to the issues regarding the implementation of Circular Economy, to confirm whether they agree or not.

According to one of the interviewees, the barrier to a circular economy uptake derives from the following particularities of this sector, specifically referring to infrastructure:

- Being a closed or limited market due that the client is the Government.
- Small profit margins leave little room for exploring unconventional solutions that entail risks and uncertainties.
- Conservativeness.

Therefore, it can be concluded that this interviewee agrees with the affirmation, attributing the obstacles to inter-relationship, economic and social factors. However, he also highlighted the role of technology as a key enabler to the implementation of circular solutions, thus mentioning the importance of current technical barriers.

From the material associations' point of view, one of the interviewees consistently highlighted the lack of a technical framework to assess circularity and the importance in the development of circularity indicators, therefore attributing the Circular Economy barriers to technical aspects. However, the other interviewee, referring specifically to the asphalt industry pointed to regulatory barriers, mainly in terms of the legal definition of waste in the Waste Framework Directive and the lack of end-of-waste criteria, which lead to the classification of site-won asphalt as "waste". This produces extra requirements (e.g for handling, storage, transportation, etc.), testing, administrative procedures and costs. In addition, many countries have technical specifications based on the mix design (instead of performance), which set maximum contents of reused material in the new mixes. In technical terms, the reuse of this specific material, being a common practice, does not represent a current barrier, though there is always room for innovation and further improvement in the recycling and reuse technologies.

The lack of adequate regulation was clearly identified by one of the interviewees as the main barrier to Circular Economy. He further emphasised that without a technical legal framework, professionals and the industry will be reluctant to adopt circular solutions, and therefore developing new technical regulation is a key first step. In this sense, he pointed to a much-needed global consensus on the criteria to assess circularity and the development of common frameworks for CE assessment.

Another interviewee however claimed that the main obstacle stems from the client's expectation that the quality of secondary materials should be as good

as that of new products. In his view, it is impossible to offer the same level of quality in secondary materials and to guarantee the same performance as in new products. There is still a high level of uncertainty in future performance and, even if high levels of control and testing can be carried out, the product will never reach the level of performance it had in its first life. Therefore, both the administration as a regulatory body and the clients must accept this and assume the risks involved. To this end, transparency and communication with client is essential to enable them to make informed decisions. In his experience, when clients are included in the control processes and informed of the risks, they are often open and willing to accept them.

### Sectoral and social barriers:

The first set of questions within the Circular Economy barriers section referred to sectoral issues or inter-relationships among stakeholders, being considered a highly relevant aspect and therefore deserving a detailed discussion.

The interviewees were asked to identify the stakeholder with the highest scale of influence to implement Circular Economy within the value chain and to provide their opinion on the importance of an integrative process in relation to Circular Economy, as well as on the current top-down dynamic tendency when implementing Circular Economy.

Opinions on this question were divided between the interviewees. Some think that this is a matter of shared responsibility while others clearly identify a single stakeholder as responsible for driving the Circular Economy agenda.

One of the interviewees identified that the infrastructure sector strictly follows a top-down dynamic in which the client (Government) has the highest scale of influence to implement Circular Economy. According to him, the Government has the power to create market demand to foster SRM markets and therefore adoption of circular strategies across the entire value chain. However, once the demand is created, industry must take the necessary steps to follow and adapt to this new market, starting with a change in mindset and investment in in-house training, R&D, etc. Leadership across all the industry is also therefore needed.

Another interviewee broadly agreed with this statement. He also attributed the main responsibility to the administration having the power and resources to mobilise the market and even showcase the profitability of a Circular Economy model. He finds it difficult to believe that private actors will invest the time and resources to change their established businesses, even if they are committed to sustainability. That said, he also agrees that efforts have to be made throughout the value chain: customers must be willing to take on the risks, manufacturers of materials and products must make changes and adaptations in their production chain, contractors and site workers must take into account the particularities involved in the application of recycled and reclaimed materials on site and be trained to have the necessary skills.

A third interviewee also argued that leadership should be taken from the Public Administration part, but almost to an entire extent according to him. He claims that the administration has the role and responsibility, as an independent party,

to establish the future development goals through a strategic vision that considers social, economic and environmental factors. From his point of view, it is hard to expect that an individual agent in the value chain, who naturally prioritise his own benefits and ought to comply with specific obligations, to drive the agenda of a holistic approach that is the Circular Economy. He therefore also views the Circular Economy as following a top-down dynamic driven by the administration and finds it hard to believe that bottom-up at an industry level will happen. However, he also mentioned the importance of academic training of professionals in Circular Economy concepts and design strategies, as these actors have the power to prescribe circular solutions at an early stage of a project. In this sense, he thinks that a cultural shift is needed, so that decision makers can factor in other type of criteria related to resource stewardship.

From the supply chain perspective, this responsibility was viewed differently. One interviewee, pointed to forming longer term relationships and partnerships as a way of developing value chain engagement to foster new market demands. He also mentioned that successful study cases can have the power to influence market trends. On the other hand, the second interviewee viewed the transition to Circular Economy as a collective effort among all stakeholders. According to him, there is place for a bottom-up approach in which the industry can lead to changes at a regulatory level. He mentioned as an example a pilot project carried out in France in which private research initiatives showed the technical viability of increasing the content of reused asphalt by 40% without compromising performance, which led to change in regulation. Therefore, in his opinion the industry is responsible for research and innovation, but the administration should have flexible mechanisms to allow this change (for example specifications based on performance instead on material design) and incentivise private initiatives. To that end, he thinks that risks should also be taken collectively, and liability shared among all stakeholders.

### Regulatory barriers:

The lack of a common legal framework or consensus in Circular Economy guidelines was generally stated as key for its implementation, but not by all interviewees.

One of the interviewees considered that there are two key aspects that regulation should address:

- Develop new standards for material and element reuse.
- Certification standards for quality assurance.

Another interviewee strongly emphasised throughout his responses to different questions that the lack of adequate technical regulation is the main barrier to the implementation of Circular Economy within the built environment. The interviewee therefore shared the opinion that the standards should be set for material and element testing to ensure their quality and durability, avoiding potential future risks. But he also thinks that further research is needed to extrapolate the results of a short-term performance testing to a long-term performance guarantee. To bridge the knowledge gap in this field, he additionally mentioned the needed interdisciplinary collaboration between

experts, specifically material experts and engineers or architects to translate theoretical knowledge into the deployment of industry solutions.

The influence that technical regulation has over market demands was showcased by the prefabricated concrete association's experience. This interviewee shared that the demand of prefabricated solutions has increased once deconstruction was contemplated as part of the Spanish concrete structural code review.

A third interviewee mentioned the importance of multiple and repetitive control tests by different stakeholders, and the role of third-party certifications as reliable quality marks. Controls should be carried out regularly by producers, but thorough checks and inspections by an independent third party should also be carried out to ensure compliance. This will be the only way to provide sufficient customer confidence and commitment to the application of such solutions and materials. He also thinks that both regulation as well as client's mentality should allow to adapt to the specific project needs and not exceed in requirements even when not necessary.

On the other hand, one of the interviewees thinks that even though the lack of unified criteria between regions might be perceived as a barrier it is not necessarily true as each geography has a specific economic and market context which should be contemplated in local regulation tailoring it to the regional context. He has identified however regulatory barriers mainly in terms of the legal definition of waste, which might hinder the reuse of materials, as once they are considered waste, the law requires their treatment and certain testing, which discourages their reuse from a logistical and economic point of view. Other barriers identified by him were the outdated and conservative (risk-averse) contracts and the gap between some regulatory requirements and market availability. He gave as an example the EU Taxonomy requirement for a 50% content of reused asphalt which technically is feasible however, considering the scale of infrastructure projects, this amount of reused material might not be available in the market or its transport from far distances may make it less sustainable than using virgin materials.

This interviewee also mentioned examples of successful measures carried out by the administration to foster Circular Economy such as green public procurement systems, which incentivise the implementation of CE strategies and reclaimed/reused materials (requiring materials EPDs).

#### **Market and supply chain barriers:**

The lack of information of the material flow and product information were mentioned as current important barriers for secondary markets. If the sector seeks to reclaim existing elements and use the existing building stock as a material bank, it should be quantified first in order to create a secondary market for its reuse.

In the regard of material reuse in the built environment, this interviewee further elaborated that the existing building stock was not executed for disassembly making it harder to reclaim elements and materials. These actions require

specific skill sets, qualified labour and treatment centres. Additionally, the reuse of the large quantities of materials involved in construction, and even more so in infrastructure, require a more advanced logistic system compared to other industries.

From the supply chain perspective, it was mentioned that the residual value of secondary materials represents the main barrier for their reuse. This interviewee claimed that reclaimed materials are normally downcycled therefore limiting their reuse to elements with lower performance requirements. This however is not the case of asphalt which can be reused after multiple life cycles (in some cases up to 4 or 5 cycles). This interviewee stresses that it has taken a lot of research and many years of experience and performance monitoring to achieve the current levels of circularity in the asphalt sector. The current eagerness to reduce the disposal of certain wastes, for example plastics, has led to numerous investigations about introducing them as a by-product into asphalt. However, it has been identified that some of these waste streams can lead to the release of toxic fumes during the manufacturing and installation process of asphalt, the release of concerning microparticles under the action of traffic, or even compromise the reusability and recyclability of asphalt at the end of its service life. He called for patience and technical rigour when it comes to this kind of innovation to ensure quality, safety and circularity.

A third interviewee re-emphasised that the different quality of secondary materials is something that must be accepted and that this barrier must be overcome by raising awareness and making the use of recycled materials common practice by applying them wherever possible. The more we introduce these solutions, the more they will be shown to meet project requirements and the more they will be accepted. He again spoke of transparency and open communication as key factors in the process, stating that secondary materials must be sold for what they are and not as an easy and equivalent alternative to new materials. In this sense, clients and the entire value chain must be made aware of the economic and technical implications of using recycled and reclaimed materials. The upfront costs are not only associated with the production of materials, but also the transport and handling of these materials on site can represent additional costs. This can be illustrated in the case of concrete with recycled content. When poured in cold weather, this type of concrete can have a reaction to deicing salts that slows down the development of mechanical strength (even if it eventually achieves the same properties, but at a slower rate), leading to delays in the construction schedule and therefore economic repercussions. When it is prescribed in a project, the contractor should take this factor into account and plan ahead for its use in the warm season.

### Circular strategies:

One of the interviewees believes that further research is needed, specifically in regard to materials and their durability and / or adaptability to future needs. When asked whether design for durability should be prioritised over design for disassembly this interviewee answered that both strategies should be combined in an integrated solution that is designed for durability to avoid maintenance and

repair but should be able to be disassembled at the same time to allow adaptability and avoid unnecessary demolitions and waste generation.

In this regard, another interviewee shared an interesting reflection on the concept of lifespan. In his opinion, products and projects should be designed for the time for which they are intended and, if they last too long they could become obsolete and useless, especially considering the high level of uncertainty of future needs. He favours adaptable solutions and efficient maintenance to striving to produce durable products that are not fit for purpose and may have a greater impact on its production. According to him we shouldn't "over-produce" in quality and lifespan. He cites the example of metal road guardrails. These elements, if they receive an impact, are completely destroyed and, therefore, there is no need to try to produce corrosion-resistant railings that are more durable over time when, in fact, they can be removed and maintained regularly and easily.

When referring to future adaptability, a third interviewee highlighted the uncertainties of future demands therefore limiting the lifespan period of a transport infrastructure to 50 -100 years (depending on the type of infrastructure). However, materials used in infrastructure projects should comply with the established infrastructure lifespan, implementing design for durability to the furthest extent possible to avoid maintenance and repair works.

Uncertainties also arise from the lack of information of new developed materials, as their performance on the long term has not been monitored yet.

From the supply chain perspective it was explained by one interviewee that in technological terms, design solutions that can be easily disassembled are already available in the market but might be disregarded due to cost considerations. The other interviewee paid particular attention to preventive maintenance as a key factor to increase sustainability and adapt to future needs, attributing this responsibility to the road owner. He considers that a different approach should be taken towards existing infrastructure, considering it as source of a valuable raw material rather than a future waste or secondary resource for downcycling.

In regard to enabling tools, two of the interviewees think that BIM sets an effective collaborative framework but if not introduced with the relevant information, circularity will not be streamlined. Information from Digital Material Passports should be therefore integrated in BIM.

### 3.3 Discussion

The five interviewees provided perspectives from different contexts: academia, the R&D department of a large construction company, the technical department of two different material associations and a material inspection and certification entity. Most agreed on the objective of the Circular Economy, which is to achieve efficiency in the use of resources and to maximise their useful life, with one interviewee arguing that lifespan should be determined by the intended use and not maximized without justified reason.

In terms of the main barriers, most interviewees pointed to the lack of adequate regulation mainly from a technical point of view as well as legal framework to define Circular Economy. Other interviewees attributed obstacles to inter-relationship between stakeholders, economic and social factors, related to the particularities of the infrastructure sector being conservative with small profit margins and public funded, as well as to the general risk-averse mentality and the tendency to demand higher quality than necessary.

When asked about leadership and who should drive the Circular Economy agenda, 3 of the 5 interviewees attributed this role to public administration, identifying a clear top-down dynamic when referring to the implementation of the Circular Economy. They see public bodies as an independent party with the necessary power to drive market change, with a special role to play in infrastructure projects being the client//owner in most cases. The other two interviewees recognised that a bottom-up approach where the industry pushes changes is possible and pointed to private research initiatives as well as the formation of long-term relationships and partnerships as a way of develop value chain engagement to foster new market demands.

In this respect, while attributing greater responsibility to a single stakeholder, all agreed that a general change in the industry mindset is needed, and that the implementation of the Circular Economy depends on the joint efforts of all stakeholders in the value chain. Leadership needs to be taken at all levels, as everyone has a role to play in market demand: clients driving this agenda as a project requirement, engineers and architects as responsible for applied design solutions, material manufacturers and the supply chain as suppliers of materials and solutions to the market, and contractors as responsible for implementation.

Some enablers mentioned in the literature review, which mainly refer to Circular Economy business models such as the leasing model or producer's extended responsibilities, were not perceived by industry actors as applicable to the infrastructure sector due to its particularities, mainly in terms of scale, long lifespan and fragmented value chain. Therefore, there is a need for further research and development of certain technologies to create circular business models that can apply to this specific sector. Lack of confidence in the application of recycled materials, as they are perceived to be of lower value, hinders the creation of markets for secondary materials. One interviewee argued that a change of mindset is needed to avoid demanding higher quality than necessary. Regular

and multiple quality checks, both by producers and by an independent third party, can help to provide a level of confidence in these materials that should be used wherever possible to establish their application as common practice.

In terms of supporting tools, further research is needed, and all interviewees mentioned the importance of relevant data being integrated into collaborative tools, e.g information from Digital Product Passports integrated into BIM.

Interesting insights were provided on circular strategies and its main principles of durability versus adaptability. There are many uncertainties regarding the future requirements of infrastructure projects, as well as the performance of new materials that are currently being developed. In this sense, aiming to increase the lifetime of an infrastructure project to more than 100 years seems ambitious and, on the other hand, designing for adaptability or flexibility is not an easy task due to the uncertainties mentioned above. The conclusion suggested by the interviewees is that a combined design solution should be applied, ensuring durability as far as possible to avoid unnecessary maintenance work, but combined with design solutions that allow for dismantling and adaptability to expand or reduce the infrastructure according to future needs. In this sense, each case should be evaluated individually to consider what is actually needed for the project and avoid over-producing in quality and lifespan if not necessary.

The following graph summarises the conclusions drawn from the interviews:

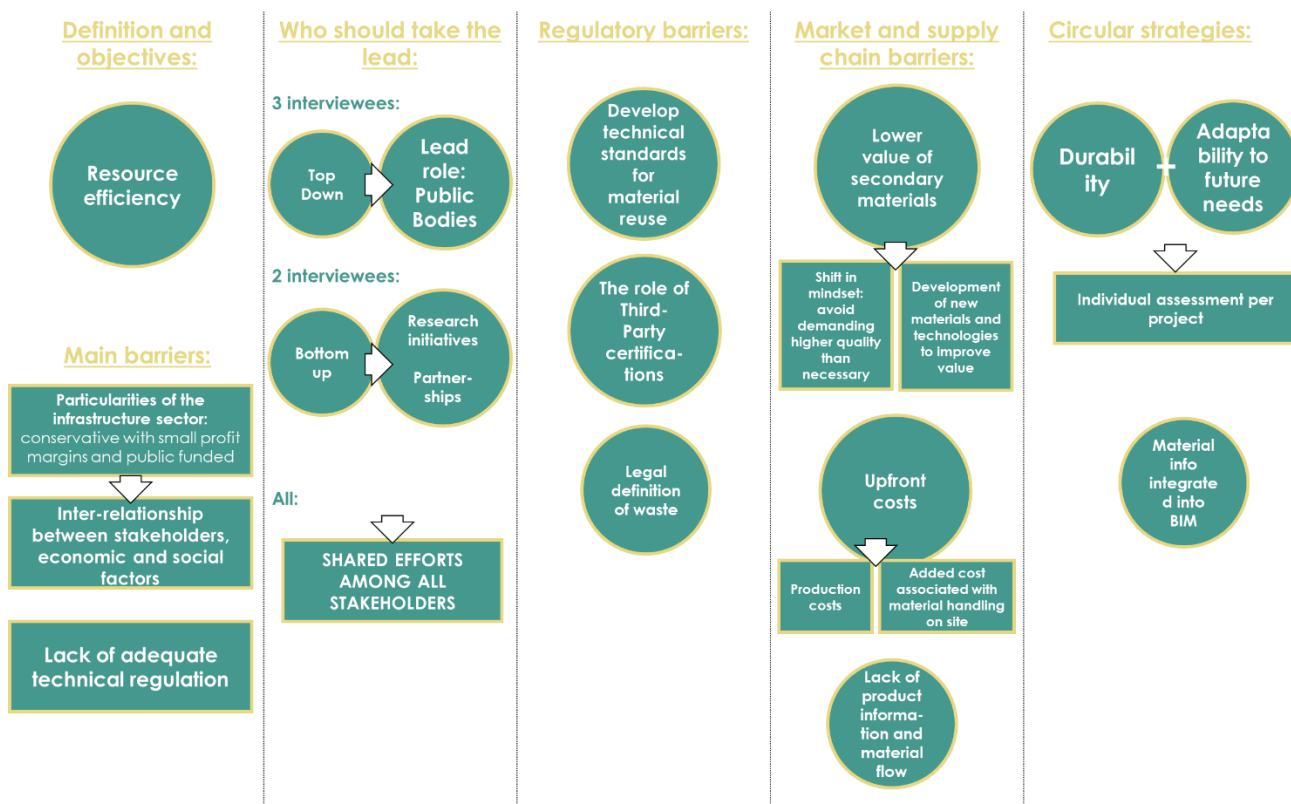


Figure 16\_ Conclusions from the follow-up interviews. Own elaboration

## 4 FINAL DISCUSSION AND CONCLUSIONS

As detailed throughout this report, this study aimed to identify the barriers and enablers to the adoption of Circular Economy in the transport infrastructure sector. This study is based on (i) a critical literature review of key documentations such as articles, standards, industry reports and white papers; and (ii) a consultation process that includes an online questionnaire and interviews with key relevant stakeholders.

The literature review provided a scientific rigorous and analytical framework to establish the drivers, barriers and enablers to the implementation of Circular Economy, whereas the consultation process provided a perspective on what currently happens in practice.

In general terms, results from the survey and in-depth interviews were aligned with the conclusions from the literature review. Industry actors identified institutional-economic-sectoral aspects as more relevant barriers to the implementation of circularity than technical ones.

However, responses both from the survey and interviews provided information on some important aspects that were not reflected in the literature review. Even though the literature search included publications tailored to the infrastructure sector, most papers addressed the implementation of Circular Economy in construction in general. The consultation process gave a specific picture on the difficulties that the infrastructure sector specifically faces, in relation to its conservativeness, having small profit margins and being public funded.

The most important aspect to highlight is the greater relevance that industry actors attribute to role of the Public Administration. Generally speaking, regulation is viewed as the most efficient measure to enable and drive circularity. The administration is perceived as an independent party with the necessary power to drive market changes through financial instruments and technical regulations. From a technical point of view, new regulations on reuse of materials and use of materials with higher recycled content, as well as standards on materials testing and performance and quality assurance certifications can influence the current risk aversion mindset of this industry and will facilitate decision-makers to adopt circular solutions in their designs. In this respect, both survey respondents and interviewees mentioned the need for a global consensus on Circular Economy criteria and assessment.

Even though the consultation process revealed that the industry generally perceives Circular Economy as following a top-down dynamic, there is a consensus on the high levels of collaboration among stakeholders and whole-life approach that are needed to adopt circularity. In that sense, the inter-relationship among stakeholders is a key aspect to address in order to overcome the fragmented value chain barrier that exists in the construction sector and most agree that it is a matter of shared responsibility concluding that efforts should be made at all levels.

Many authors point out to economic frameworks as the “hard” barriers to Circular Economy. The economic barriers relate to various aspects: lack of a clear business case and profitability, cost considerations (especially the entailed high upfront cost), inadequate fiscal environment and market challenges among others. Survey respondents and interviewees shed light on this topic explaining that the higher upfront costs are a determinant factor, not only from the material production perspective but also from the technical implications throughout the construction process, from specific expertise of the design team to the implications on site regarding material handling on site, technical implications and required skill sets. In that sense, they highlighted the importance of financial incentives to help both producers to adapt their production chain and decision makers to take on the implications and risks involved, as well as the entire value chain from designers to contractors so as not to lose profit.

Some enablers mentioned in the literature review, which mainly refer to Circular Economy business models such as the leasing model or producer's extended responsibilities, were not perceived by industry actors as applicable to the infrastructure sector due to its particularities, mainly in terms of scale, long lifespan and fragmented value chain. Therefore, there is a need for further research and development of certain technologies to create circular business models that can apply to this specific sector.

Product quality concerns and the discussion on durability and adaptability to future needs raised the question of the high levels of uncertainty involving both: the future requirements for the project as well as the future performance of new materials that are currently being developed and implemented. Time is needed to monitor performance and develop new technologies to test materials or predict future demands. In this respect, it seems relevant to mention a reflection provided by one of the interviewees. According to him, both the administration and the industry should accept the fact that there are risks to implementing secondary materials, and their performance level will never be the same as when first designed, the question or requirement should rather focus on whether these are good enough to meet the project needs rather than demanding for the highest standards of quality.

The following graph qualitatively summarises the importance level given to each of the main barriers and enablers identified by the survey respondents, interviewees and according to the literature review:

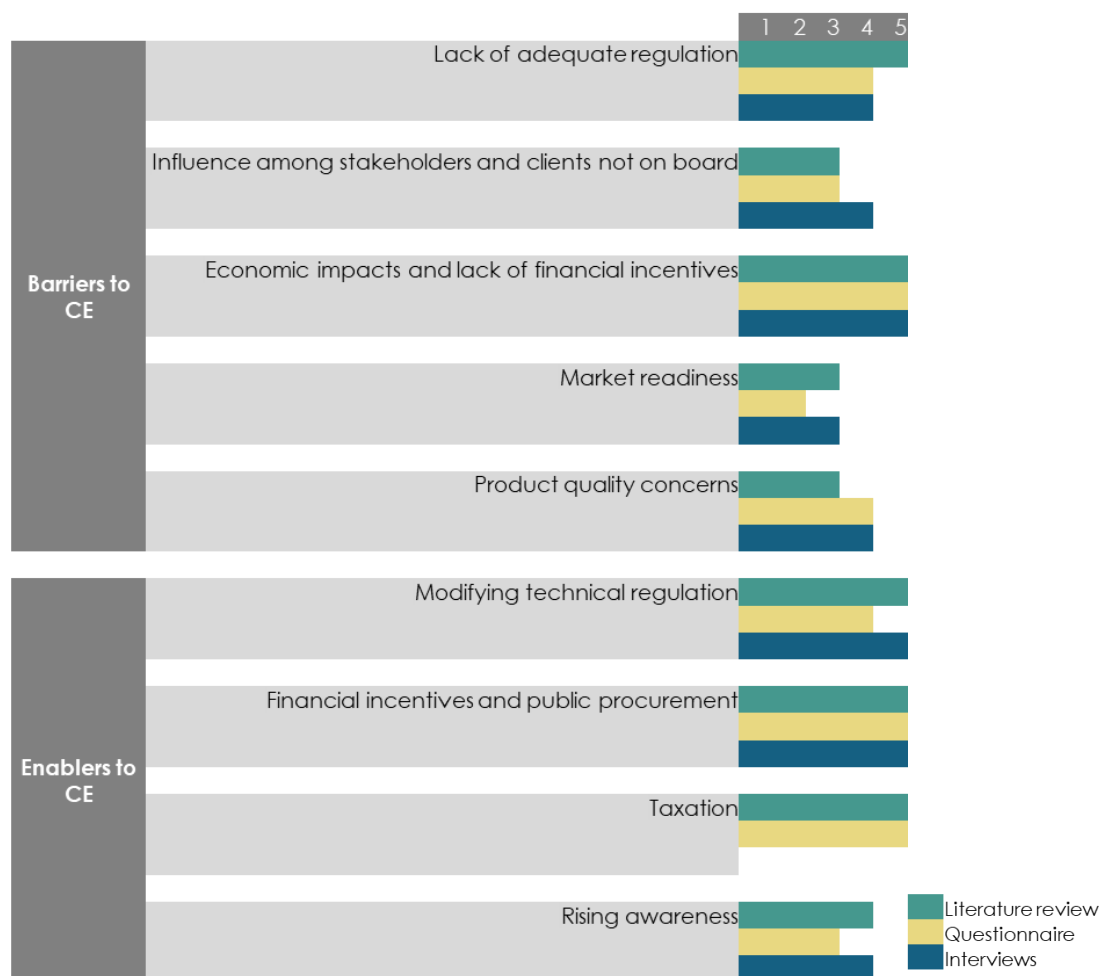


Figure 17\_Summary of qualitative level of importance that was given to the main barriers and enablers to Circular Economy by the interviewees, questionnaire respondents and according to the literature review. Own elaboration.

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## 7 appendix A: Survey questions

### SURVEY ON BARRIERS AND INCENTIVES TO CIRCULAR ECONOMY AMONG STAKEHOLDERS

#### General questions

1. What type of stakeholder are you?
  - Owner (public entity, concessionary company or real estate developer)
  - Designer (engineer or architect)
  - Contractor
  - Material and product supplier
  - End user

2. What would you say is your background level in Circular Economy?

1 None	2 Basic understanding and no experience	3 Fair understanding and little experience	4 Deep understanding and some experience	5 Expert with board experience

3. When referring to circular economy, do you think that all the stakeholders involved across the construction value chain have the same level of understanding?
  - Yes
  - No

If not, what would be the reason?

Option 1. Not all stakeholders have the same motivation to approach and implement circularity

Option 2. Not all stakeholders have the same knowledge background

Option 3. It depends on the level of their previous experience in implementing circular economy solutions

Option 4. Other

4. Based on your experience, are circular economy criteria currently considered during the decision-making process?
  - Yes
  - No

If so, who is taking circular economy into account and what type of strategies are being considered? Please, give one or two examples.

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### Motivation

5. Please indicate your main motivation for implementing Circular Economy solutions

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6. The following table contains a list of current motivations that different stakeholders of the construction sector supply chain might have for implementing a circular economy model.

Please indicate how relevant do you think they are or what weight will they have in decision making? (Being: 1- lowest and 5 – highest relevance or weight)

CURRENT MOTIVATION		1	2	3	4	5
Values	ESG (Environmental Social Governance) values					
Requirements	Compliance with regulation frameworks					
	Client satisfaction or requirements					
	User demands					
Financial factors	Limited budget					
	Profits					
	Financial incentives					
	Lowest economic offer					
	Maintenance costs					
	Added value: the implemented circular strategy implies better performance, future opportunities, better return on investment, etc.					
Considerations regarding products and suppliers	Quality (guaranteed by project specifications)					
	Compliance with the guarantee period					
	Price					
	Competitive or differentiated offer by suppliers					
	Performance differentiation compared to other products/ materials					
Others	Other (specify)					

## Barriers

7. Please indicate the main barrier that you have found (or think that you would find) when implementing Circular Economy solutions

8. The following table contains a list of current barriers. Please rank them based on your understanding and experience (Being 1.: Least important barrier and 5.: very difficult barrier to overcome).

BARRIER		1	2	3	4	5
Policy and regulation	Regulation restrictions for material reuse					
	Lack of available evaluation schemes and standards or specific guides for the deployment of Circular Economy					
Integrative process	Lack of an integrative process approach between all stakeholders to help streamline Circular Economy throughout the project phases					
	Clients / decision makers not on board					
	Lack of skill sets in the design teams and across disciplines					
	Lack of qualified labour					
Financial factors	Organisations are unwilling to take on the liability involved / Unclear responsibility distribution					
	Added time to project or costs to products and construction methods					
	Lack of financial incentives across value chain					
	Difficulties to predict future needs / uncertainties on the long term					
Considerations regarding products and suppliers	Product quality					
	Performance risks					
	Difficulties in certifying construction products					
	Supply chain & no/little second-hand market for construction sector materials					
	Difficulties and implications to integrate circularity in the production processes					
Others	Other (specify)					

9. As you might know, environmental impact is measured through different indicators, one of which is carbon footprint, but there are many others to consider such as ozone depletion potential (ODP), acidification potential (AP), Eutrophication potential (EP), water deprivation potential and so forth.

In the construction sector, circular strategies do not always lead to a lower carbon footprint. Do you consider that implementing circular solutions despite an overall higher carbon footprint is positive?

- Yes
- No

If yes, why?

Option 1. It contributes to shift to a new economy model of production and consumption, which would have a positive impact on an economic and social level.

Option 2. Upfront carbon might be higher, but when considering the whole life cycle, the solution might be net positive.

Option 3. A higher carbon footprint might imply a negative impact from an emissions point of view but could still have a positive impact in regard to other environmental indicators).

Option 4. Other

### Questions on potential solutions

10. The circular market seems to be in a vicious cycle. Circular solutions are not demanded because they are not offered. And they are not offered due to the lack of demand. How would you break this cycle? (Please rank the following solutions based on their possible effectiveness)

	1	2	3	4	5
Promote a cultural transition to help shift to a new economy model					
Making use of public procurement (demanding circular solutions)					
Giving financial incentives to developers, manufacturers and suppliers to incorporate these solutions and disincentivize those who do not incorporate circular economy models in their operation					
Making compulsory, by law, the use of a minimum number of circular solutions and establishing targets for reclaimed/reused materials					
Other (specify)					

11. What are you more in favour of or think would be more useful?

- Incentive measures
- Mandatory measures (defined by law/regulation) / required by the client

12. Some measures to promote circular economy solutions are listed below, Taxes and financial incentives for example can become a good incentive for circular solutions. How effective are the following in your opinion?

	1	2	3	4	5
Establishing targets for implementation of Circular Strategies in: -The design (design KPI), -Material specification (% of recycled / reused products) -Waste management (reuse and diversion rates)					
Taxes on landfilling					
Taxes on extraction of natural resources					
VAT exceptions for circular solutions					
Others (specify)					

13. Everybody agrees that a minimum market for circular solutions is necessary to foster innovation, thus creating new products and reducing costs. Measures to break the vicious cycle previously mentioned can help create this minimum market. What other measures do you consider that are necessary?

	1	2	3	4	5
Innovative Public Procurement to foster innovation					
Modifying regulation to foster circular solutions					
Others (specify)					

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<https://www.circuitproject.eu/>

In case you would like to contribute further to this project and want us to contact you for a detailed interview, please share your contact details with us.

- Name:
- Company:
- Email address:
- Phone number:

## 8 appendix B: Interview questions

### INTERVIEW ON BARRIERS AND INCENTIVES TO CIRCULAR ECONOMY AMONG STAKEHOLDERS

Thank you for agreeing to participate in this interview. Our goal is to dive deeper into the barriers that are preventing the shift to a Circular Economy model, focusing specifically on transport infrastructure.

As a starting point, let's discuss general **Definition and Objectives**:

1. What is, in your point of view, the definition of a circular project?
2. Have you been involved in any projects which implemented Circular Economy strategies? How many? To what extent was Circular Economy implemented? Was it successful? Why do you consider it was/it was not successful?

Let's move on to **BARRIERS**. Current Circular Economy implementation barriers relate to many different aspects. At a larger-scale these can be classified as technical/technological barriers on the one hand and political-economic-sectoral/social on the other. Which would you say have a higher influence or are more determinant?

Let's start with the political-economic-sectoral/social factors:

#### SECTORAL - Inter-relationships among stakeholders

3. In your opinion, how important is following an integrative process (where all the stakeholders involved from the beginning) for achieving the circularity goals?

Do you think that implementation of Circular Economy practices tends to be a top-down inter-relationship rather than a bottom-up approach? (that is, the client has the highest scale and influence and communications tend to be direct down from the top layer of the value chain network?)

To implement circular economy, is it enough to have it in the contract or a continuous leadership is needed?

4. When referring to infrastructure projects, do you consider that there is a lack of ownership between developer and operator which in turn prevents from Circular Economy to be implemented? (operators are often regarded as being risk averse or having different priorities, which lead to challenges in handover between project delivery and operations).

#### SOCIAL - Cultural awareness & behaviour change

5. Would you say that safety, being a critical nature in infrastructure, increases the resistance to change in this specific sector? (although all performance tests are satisfactory)

6. What efforts would you say are needed to change the risk-averse mindset? (e.g. insurance companies taking on the liability, standardised methodologies for quality assurance testing, better knowledge sharing etc.)

#### **ECONOMIC - Whole life costing:**

7. Short-term thinking and focus on capital expenditure are usually prioritised over long-term thinking. Do you think that higher upfront costs are the main barrier for implementation of circular strategies? What other lifecycle costs are associated with circularity and may represent an obstacle to its implementation? (e.g. costs of removing contaminated components for materials reuse, preventive maintenance costs, etc.) Please elaborate and share your experience
8. What sort of economic benefits can be drawn from long-term thinking? What would help shift to a long-term mindset and to base decision making on total (whole life) costing rather than capital expenditure?
9. The economic benefits of reusable and recycled materials are reliant on the deconstruction approach, transportation costs and demand for used or recycled materials. What is your view on this?
10. What business case and type of business models should be established for CE implementation?

#### **ECONOMIC - Business model – economic influence**

Circular business model provides a pathway to achieve social, economic, and environmental sustainability by closing the resource loops.

Existing circular business models are into nine categories including Product as a Service, Sharing Platforms or Waste as Resource, Can you think of any business models that would apply to transport infrastructure? What are the pro/cons for implementing them?

Some economic benefits/profitability attributed to CE implementation in construction are:

- (1) employment creation,
- (2) reduction in costs related to public health and environmental aspects,
- (3) reduction of demand-driven price volatility and supply risk and
- (4) resource productivity.

Which of the above mentioned would you say have the highest importance or would lead to higher profitability?

#### **SECTORAL – ECONOMIC Supply chain, waste management and secondary markets**

11. What would you say are the market's bottlenecks preventing the implementation of circularity within the supply chain? (e.g. lack of financial support, fragmented supply chains, etc.)
12. Do you think that a lack of strategic vision is a current barrier, and would you say that collaborative platform and/or frameworks to distribute the responsibility help foster circularity within the material flow and resolve the fragmented supply chains barrier? What are the stakeholder's responsibilities in the material chains and flows?
13. What would help raise the value of second-hand materials? And the demand for secondary materials markets? Would regulatory measures and taxation help support these new market needs?

#### **POLITICAL – Regulation / Policy**

14. How strongly do you think Circular Economy is influenced by the governmental policies and legislation? Should it be more?
15. What type of changes in regulation are required to foster circularity? E.g. standardisation and certification schemes for quality assurance, financial incentives/public procurement models, local administrative coordination, more transparency.
16. Do you consider that PPP (Private Public Partnership) procurement approach would help hinder circularity and what type of strategies could help make this approach more effective? (e.g. Adopting relational contracts to deal with negotiation time, mechanisms to mitigate issues pertinent to traditional PPP projects, an information platform to share and update data in a real-time manner).
17. Should procurement requirements be established in transport infrastructure contracts by the public administration?

The other main barriers to Circular Economy are related to **technical and technological aspects**:

18. Circular Economy is usually addressed only at the End-of-Life stage. Do you agree / disagree with this approach? Please rank the following lifecycle stages on their importance in Circular Economy implementation: project brief, design, manufacture and supply, construction, O&M, End-of-Life.
19. Product life extension require a framework to assess and ensure quality. What type of measures do you think are needed to hinder this framework? (standardise methodologies and technological innovation)

#### **Circular Economy Strategies:**

20. Circular design is based on the following main principals: design for durability, design for flexibility, extend product life, design out of waste. Specifically for transport infrastructures, what is your opinion on the

mentioned strategies? Are these feasible in this type of projects? which represent a future opportunity, and which are extremely challenging?

Another main technical/technological barrier identified is the lack of **Enabling tools & the role of Digitalization**

Do you think that despite having integrated processes tools available such as BIM, digital tools are still a obstacle to support implementation of circularity? Would you say that other additional tools are needed? (e.g. Blockchain, information management systems such as material and project passports, embedded sensors that can attest for the product's quality, material flow tracking tools, artificial intelligence relating to the project design process for waste minimisation)

### **C&DWM**

How can Design out of waste be promoted? What type of technical solutions in your experience should be implemented? The limitations include a lack of guidelines for adaptability and reusability of materials at the design stage, difficulties related to waste transportation, a lack of standardised practices for demolitions, and a limited market for recycled products.

Do you consider that on-site reuse has benefits over off-site reuse? Can you name a few difficulties that might arise from on-site reuse (limited access to storage on-site, excavated material not being suitable for reuse, etc.)

Would you say that transport infrastructure waste reuse in other types of construction activities (such as buildings) is a better solution than backfilling?