Measurement of the indicator 'Retaining Value' in asphalt for circular infrastructure

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ABSTRACT

Aiming to reduce the amount of raw materials extracted from natural sources, the concept of Circular Economy has emerged in the past years. Towards the transition from a traditional linear model to a circular model, many indicators have been developed in order to be able to assess the level of circularity of many industries. Precisely, as the construction industry contributes with the most waste generation, and resource exploitation, being one of the most harmful industries for the environment, research about this is being developed. Having this in mind, the indicator 'Retaining Value' for Circular Economy in asphalt was researched in order to build a framework which can measure both physical and economic values retained in infrastructure projects and find its correlation. This paper explains how the framework was developed and how the indicator is scored. In order to test the framework, a case was analyzed by comparing two different types of asphalts and assessing their performance on the value retention.

Contents

Abbreviations

CE	Circular economy
REV	Retained Economic Value
RPV	Retained Physical Value
RWS	Rijkswaterstaat

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1. Introduction

It is well known that construction sector generates a considerably large amount of waste all over the world; around 50% of the waste generated is mainly produced by the demolition at the end of the life cycle of a project (Akanbi et al., 2018). From the waste generation, materials are the most critical elements that contribute (Esa, Halog, & Rigamonti, 2017) to this large amount of waste production. The traditional model is a linear economy (take – make – consume – dispose), where resources are retrieved from nature, a product is manufactured, then used until the end of its life cycle is reached and then it is disposed where it can be landfilled or incinerated in the best-case scenario in order to produce energy; however, the modern model trends to be a circular economy (take – make – consume – reuse & recycle) which aims to avoid the generation of waste. This model is more sustainable and intents to close loops by reusing or recycling its elements (Akanbi et al., 2018). Figure 1 is the graphic representation of what linear and circular economy is. Moreover, the Dutch Ministry of Infrastructure and Water Management (Rijkswaterstaat) has defined circular economy as "an economic system based on the reusability of products and product components, recycling of materials, and on conservation of natural resources while pursuing the creation of added value in every link to the system" (Potting, Hekkert, Worrell, & Hanemaaijer, 2017).

Foreseeing this trend into the transition towards a circular model, the Dutch government has the intention to implement CE wide scale in their economy. The purpose of this ambitious goal is to be able to turn the Netherlands into a called 'circular hotspot' (Kalmykova, Sadagopan, & Rosado, 2018). But not only the Dutch government has this ambition. Other foundations such as the Ellen MacArthur Foundation, has been researching the development of methodologies to measure the level of implementation of a CE model into the current traditional system. For instance, Ellen MacArthur's Circularity Indicators Project has developed some measurable indicators that allow users and companies to know how they are performing in terms of CE. To make this, the project helps to estimate the level of advancement in the transition towards circularity (Ellen MacArthur Foundation, 2015).

Apart from the level of advancement in the transition towards circularity, and considering the global vision of CE, there is a need to be able to assess the performances of the products and services (Saidani, Yannou, Leroy, & Cluzel, 2017). Although research on the measurement of circularity has been done, it is an aspect that remains in a very early stage (Elia, Gnoni, & Tornese, 2017). There is a growing need for Circular Economy indicators (Saidani, Yannou, Leroy, Cluzel, & Kendall, 2019). As no Circular Economy metric exist, a complex methodology providing the systems thinking is a tool that still needs to be developed (Medkova & Fifield, 2016). Having a systems thinking perspective, where everything is interconnected in space, time and context, many researchers have come up with a lot of indicators that are useful for the measurement of the performance of circularity. These indicators, which can be defined as a means to measure change, are useful for many different aspects. They can help policy makers in their decision making, they can also enable quality standards, compare products in terms of sustainability, and moreover, promote research about them (Cayzer, Griffiths, & Beghetto, 2017). The indicators are also useful to model the impact of the products and services throughout its lifecycle. The challenge is to have the right indicators measured the correct way in order to provide insightful and meaningful results about the endpoints of such life cycle assessments. This in order to be able to have accuracy in the measurement of the level of circularity towards the ambition of the Dutch government to turn industries circular by 2050.

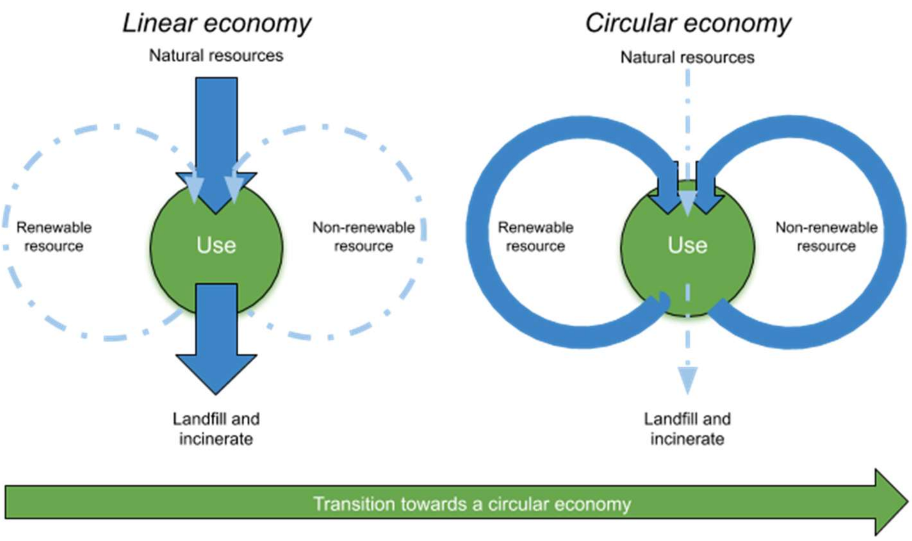

Figure 1- Transition from linear to circular economy (Potting et al., 2017).

Sustainability indicators are classified in three dimensions which are the environmental, the economic and the social aspects (Saidani et al., 2019). However, there are indicators that englobe more than one of these three aspects.

One of these indicators is 'Retaining Value' which is one core element for Circular Economy, as it is all about retaining the optimal value of elements in a physical environment. In this physical environment, 'Retaining Value' can be done at various levels from the strategies (Schut, Crielaard, & Mesman, 2015) which are product reuse, product repair, product remanufacture, and product recycle. These strategies are important as they aim towards the same core elements of what Circular Economy is. Therefore, they are in line to achieve the transition from the linear model to the circular model. Hence, value retention is directly linked with the need for the transition to this new model.

Further explanation of the indicator 'Retaining Value' will be given in part three of this paper.

The scope of this research is the following:

- To provide a framework, that considers both physical and economic aspects, which is able to measure the indicator 'Retaining Value' for Circular Economy. Moreover, to evaluate such framework by applying it to the comparison of two different asphalts as it is the core material to be measured within this research. However, the framework will be adaptable in order to apply it to different kinds of materials in the future.

Considering all this information, the researcher has developed several research questions presented next:

1. How can the indicator "retaining value" be numerically expressed and calculated as an indicator for Circular Economy perspective in the construction industry?
2. What type of framework to include and correlate both physical and economic point of view for the case of recycled material asphalt mixtures considering as options also reusing, repairing and remanufacturing in the different stages of the life cycle of asphalt?

2. Research Strategy

This section contains the plan and strategies followed to develop the research. This is an adaptation of the framework proposed by Wieringa (2014) and can be seen in Figure 2.

This research design consists of different research stages consisting of linear processes, and also iterative processes, finalizing with an application phase which helps to understand the final result that will lead to the possibility of having conclusions out of this research. It is divided into six different parts and further explanation about them is presented next.

Part I consisted of the Research Problem. This part helped to understand the needs and requirements and set goals that align with those of the stakeholders involved. To achieve this, it is necessary to specify the requirements motivated by the stakeholder's interests (Wieringa, 2014).

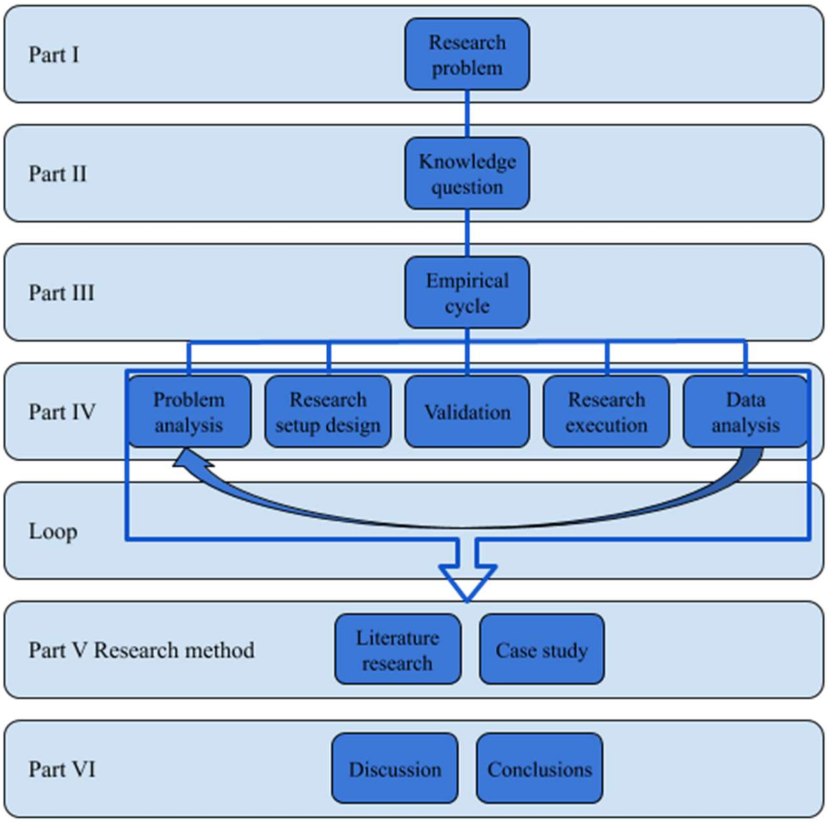

Figure 2 - Research design.

Furthermore, Part II aimed to translate the goals from Part I into knowledge questions. Such questions required relevant data about the world or certain circumstances to be answered, and it has to be answered by conceptual analysis. Therefore, it was necessary to collect and analyze data which helped to in the process of prediction of problems (Wieringa, 2014).

Additionally, this research design was followed by the link of Part III and IV with a feedback loop. This part of the research was formed by five sub-steps (Wieringa, 2014):

a. Problem investigation: this step sets the problem and explains the reason why it is necessary to address that problem.
b. Treatment design: at this point, the design of what can solve the problem is done.
c. Treatment validation: after the design is done, it needs to be proven if the solution will eventually help to solve the problem.
d. Treatment implementation: once the solution is validated, it is now implemented in a real-life situation in which it will give an insight into its effectiveness.
e. Implementation evaluation: finally, once the solution was implemented, it is necessary to perform an evaluation to know how successful the implementation was.

This system is in line to the Systems Engineering framework proposed in the Guideline for Systems Engineering within the Civil Engineering sector by Alsem, et. al. (2013), who claimed that it is an iterative process.

This process has the required loops to improve the accuracy of the method. By having verification and validation the requirements will be transformed into the necessary tool to have a proper measurement (Alsem et al., 2013) in the following Part V of the research design. Part V is the research method. In this part of the research, two types of approaches are performed. Firstly, literature research is conducted in order to scientifically validate the performance of the research, and second, an observational case study.

An observational case study is an approach to a real-world case without performing any direct intervention to it. They are an analytical induction over cases, this means that the research is done in parallel to the case without influencing any of the results in that specific case. The reason to perform an observational case study is due to the impossibility to replicate these types of phenomena in a regular laboratory (Wieringa, 2014).

Steps to consider during an observational case study according to Wieringa (2014) are the following:

1. Case selection
2. Sampling
3. Measurement design
4. Inference design validation
5. Research execution
6. Data analysis
7. Implication for context

Part VI discussed and concluded the outcome. In this part, the performance of the whole research will be analyzed and explained. Moreover, advice on improvements to be done will be given with a follow-up guideline to do them.

3. Literature background

3.1 Value Retention

As it was previously explained, 'Retaining value' is one of the core elements for CE and as Schut et. al. (2015) explained it mainly consists of four strategies; Product reuse, repair, remanufacture and recycle for the achievement of reduction of raw materials exploitation. These strategies are explained next:

- Product reuse: in terms of preserving the same product by giving it the same function it was built for.
- Repair: is about rehabilitating the product – not improving it – and keeping the same function it was built for.
- Remanufacture: is about reconstructing a part of the product in order to be able to continue providing the function it was built for.
- Recycle: probably the most complex among the four strategies. It depends on the material use it is given. Recycling is about reusing the materials in a new lifecycle. However, it depends whether the material can provide the same function (called high-quality reuse or upcycling), or if the material has a limited amount of reuse options into a simpler function (called low-quality reuse or down cycling).

On the other hand, the indicator of 'value retention' also aims to describe the economic value. For instance, demolition and recycling costs are not yet included in the current financial model in construction; the economic value of demolition waste is not enough to cover the costs involved for a high-quality demolition and recycling. The reason for this is mainly due to the design of the elements as they did not consider these aspects of the lifecycle during the design phase. Research on the economic value has already been done but mostly in the manufacturing industry and it has been successful, however, in the infrastructure industry it is not yet very researched (Schut et al., 2015). Therefore, special attention needs to be put for the construction industry in order to have a better link to the value retention in this industry.

Material Economics has researched about the value retention in the Swedish Materials System. Focusing not only in the physical value but also in the economic value and have come up with several questions that consider this very important aspect for Circular Economy (Material Economics, 2018):

1. How much of the material value is retained after one life cycle?
2. What are the core reasons why the material value is lost?
3. Which are the measures to be taken in order to retain more of the value of materials, and from this value how much could be recovered?
4. Which are the business opportunities that derive from this?

The perspective of value is highly important to be able to identify new business opportunities for a more circular economy. Around 75% of the material value is lost during the handling of materials, meaning that only around 25% of the original value is retained. Therefore, the improvement of the handling of materials is an aspect to consider while measuring the 'value retention'. Most of the value loss is the result of the physical loss of materials which downgrades the material quality making it lose properties, materials get contaminated or mixed with other materials. In the construction sector, the amount of recycled materials from demolition which is recycled is very little, and also, losses during construction are very high resulting sometimes to 15 to 20% of material loss from the total amount of materials used (Material Economics, 2018).

Material Economics also mentions how linear the Swedish economy remains. The fact that they only measure the amount of materials collected instead of measuring the amount of collected materials that in reality become secondary material. They still consider and report 'material recycling' when materials are being downgraded. For instance, demolition materials from buildings are being used as fillers in the construction of roads; which means that they do not consider the loss of quality (Material Economics, 2018).

However, not only handling of materials cause loss of value, but many other reasons for value loss can be found throughout the value chain of the elements also throughout their life cycle. Digitalization can be a key tool to make it more efficient the tracking of quality, handing and innovation of materials. The digitalization could lead to a new approach to the demolition process so that in the future, this 'end' life cycle stage could be seen as a 'material bank' instead of only just a source of bulk aggregates. Hence, the preservation of material value is an emerging topic in the industrial innovation agenda (Material Economics, 2018).

Consequently 'Retaining Value' can be defined as a system which helps to maintain a product with the maximum possible value throughout the life cycle of the product and trying to preserve the life cycle for a longer duration. Products might lose value by time, however, with the right treatment, design and Circular Economy strategy, the loss of value can be avoided. A business model which considers economics, environment and profitability is needed for the value retention of elements (Fan, Ripanti, & Tjahjono, 2016).

4. Framework development

It is important to identify first what needs to be measured rather than how to measure it, but now that the indicator is set, the next step is the measurement of it. The intention is to be able to measure the progress of Circular Economy transitions in product chains; and measuring it requires to focus on the process and effects. The process is all the needed steps to make the transition towards Circular Economy, and the effects are the results of those processes in terms of circularity (environment and economy) (Potting et al., 2017). Potting et al. (2017) have set a diagnostic questionnaire (shown in Appendix A) to measure the progress of those process and effects towards the transition to Circular Economy. In this research, only 'Achievements' and 'Effects' are considered as these questions are directly related to the life cycle of the elements to be studied. Referring that it considers from the design phase, going through the production, and use finalizing with the end of life; which are the relevant aspects to consider throughout the life cycle. The first two categories are more related to the stakeholder analysis ('Means' and 'Activities'). However, the challenge relies on the fact that there is a need to compare the multiple factors that are involved in the indicator trying to bring the information into a manageable set which can adequately reflect the effects for the transition to Circular Economy. This means gathering relevant quantitative (for the effects) or semi-quantitative (for the process) data and compiling it into meaningful information for the indicator (Potting et al., 2017).

With the purpose to set a guide to help with the design of frameworks that aim to measure the circularity performance of a product, Saidani et. al. (2017) have discussed and proposed several requirements that these type of frameworks should consider. In their research, they have defined the ideal, desired and required features that such frameworks should have, and it is shown in Figure 3. These different aspects shown hierarchically represented in the Maslow's pyramid of needs, have been adapted in order to show the framework for the development of tools that can measure the circularity performance (Saidani et al., 2017). The top of the pyramid shows the highest level of hierarchy that is the 'connection to sustainable development pillars' which is the main reason why the whole concept of Circular Economy was first developed. On the second level of the pyramid, 'intuitive user interface' meaning that the use of the framework should be easy to be applied by a different type of users. Followed by the third level 'adaptive and flexible', by making the framework consisting of modules which can easily be adapted for a different type of criteria or products but keeping with the same context

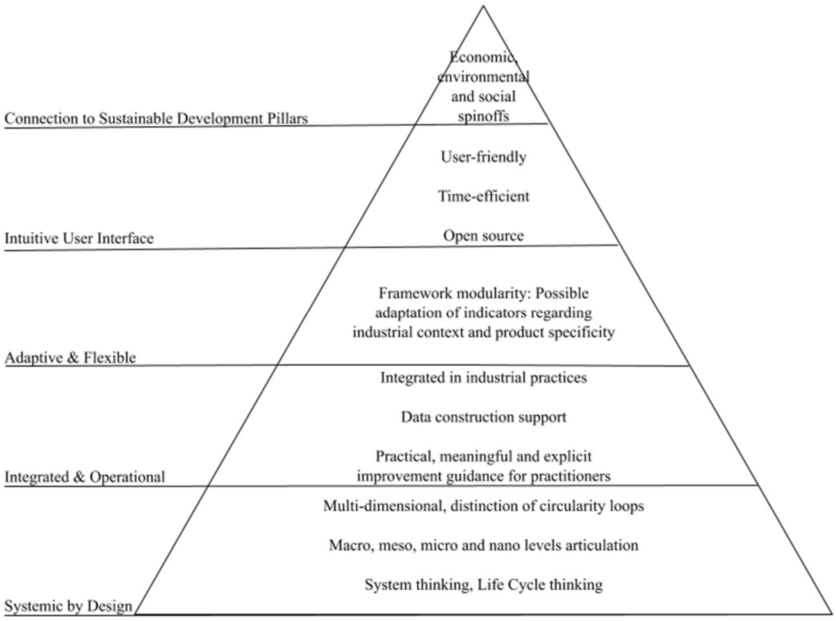

Figure 3 - Proposed hierarchy of desired features to design frameworks, methods, tools, and indicators aiming at measuring product circularity performance (Saidani et al., 2017).

of the measurement by achieving the same results. Next, on the penultimate level, comes 'integrated and operational'. This means that the framework should be developed with the needs of the industry and that the data needed for it should be retrievable from what the industry can provide to make it fully operational. Otherwise, the framework might require from data which is not possible to gather; in this case, the framework would be not useful nor operational for the users.

Finally, on the base of the pyramid 'systemic by design', means that the same framework can be scaled into the different dimensions of the industry and that it considers a system thinking. Therefore, the proposed framework from this thesis will follow this hierarchy of desired features in order to be applicable according to Saidani et. al.

5. Proposed framework

This section explains how the measurement of value retention was designed and it also shows it in order to understand its functionality. Furthermore, a case in which the framework was used is also presented.

5.1 Measurement of value retention

Once explored the core elemental needs to measure the 'value retention' and also after describing and explaining the difference between 'physical value' and 'economic value', in this section the proposed framework to measure both elements is explained.

The proposed framework consists of two separate tools which later on will be compared to result in one single analysis of correlation of both values. On one hand, the first tool will help to calculate the value retention in terms of the physical value. On the other hand, the calculation of the Retained Economic Value (REV) is performed.

5.1.1 Retained Physical Value

To measure the Retained Physical Value (RPV) the first tool was developed. This tool consists of a set of variables that are expressed in questions grouped in a questionnaire that has to be filled in. Each one of the questions has a value depending on the answer that is given, and this results in a final score that has to be computed according to the weighting that the questions will have. Such questionnaire is presented next.

The questionnaire was divided into four different tables. Each one of them was elaborated in order to extract certain information about the project in specific. The first table (Table 1) from this questionnaire aims to explore the current asphalt mixture information. The purpose of this part is to be able to have a baseline into which the level of circularity is compared to. This is how we are able to know how much value is actually retained. Table 1 presents this first part of the questionnaire.

Part two of this tool aims to extract information about the new asphalt mixture. The purpose of this is to understand the amount of materials that are being either reused or recycled within the new mixture. This section is very important in order to be able to know the ratio of each one of the components of the asphalt (stone, sand, gravel and bitumen). The need to know this information is because this helps to track the materials in the new mixture according to its amount. If the ratio of the materials in the mixture is known, it is possible to make a proper traceability of the elements that constitute the mixture and the information that the following parts of the tool extracts can be better allocated.

Table 1 - Current asphalt mixture information. Part 1 of RPV questionnaire.

In order to assess the RPV of asphalt, it is important to know information about the current mixture

Current asphalt mixture information

Location of the project:		
Total volume of materials needed for the project:	(tons)	
Mixture type:		
Life expectancy:	(years)	
Real lifespan reached:	(years)	
Was the life expectancy achieved?	(yes/no)	

	Ratio of aggregates in the mixture (%)
Stone	
Sand	
Gravel	
Bitumen	

Table 2 shows the information required for this section of the questionnaire.

The reason for this is that depending on the method used to process and recycle the materials, the environmental impact can strongly increase or decrease. Therefore, knowing this information will benefit the measurement of the PRV.

Finally, the last part of the measurement of the RPV aims (Table 4) to explore the result of the materials after completing their lifecycle. Such materials can either be downgraded or upgraded. This means that the use result from the material can be increased or decreased in its value. However, depending on the new use it is given to the materials, it can be classified as a different level of downgrading or upgrading. Moreover, it is also important to identify what the market costs of these new materials are. Those costs will help during the calculation of the REV in a further step of the framework.

It is important to point out that in order to build this questionnaire, the questions previously presented in Appendix A were analyzed and translated into specific questions that concern to the required data that the user is able to provide in order to be able to measure the RPV. Therefore, the questionnaire addresses all the necessary information that was presented as to be the core elements to cover for this purpose.

Table 2 - New asphalt mixture information. Part 2 of RPV questionnaire.

To assess the retention of value of the previous asphalt as maintained to the new lifecycle, it is relevant to know information about the new asphalt mixture

New asphalt mixture information

Mixture type:		
Life expectancy:	(years)	

	Ratio of aggregates in the mixture (%)	Amount of primary (raw) material (%)	Amount of circular material: Amount of reused material (%)	Amount of circular material: Amount of recycled material (%)
Stone				
Sand				
Gravel				
Bitumen				

Table 3 - Recycled/Reused materials information. Part 3 of RPV questionnaire.

It is valuable to know the process in which the materials are being transformed to be reused or recycled. Such process can provide information to know the extent of value retention that the material has. Therefore, the following table is also important to be properly filled in.

Recycled/Reused materials information							
	Is the material being downgraded? (yes/no)	Is the material being upgraded? (yes/no)	Is the material maintaining its same value it had before the reprocess? (yes/no)	What type of recycling method was used? i.e. Grinding - sieving - washing	What was the temperature used for the recycling method (ºC)	What type of energy was used in the recycling process? (km)	What is the distance of transportation for the recycled materials? (km)
Stone							
Sand							
Gravel							
Bitumen							

Once the questionnaire is filled in, it is possible to proceed to do the calculation of the elements that will finally give a score to the RPV. To do this, first of all, it is important to mention that every question from Appendix A was given a maximum score of 1. And as it was previously mentioned, the information retrieved from the questionnaire aims to answer each one of those questions. Moreover, each one of the questions has the same value for the final result, therefore it is possible to say that also the final score will have a score which is of maximum 1 as well. This means that if the entire value of the asphalt is retained into the new asphalt layer, the result of this framework will give a score of 1; on the other hand, if no value is retained at all, the final RPV score will be 0. The next section explains how every element was calculated.

5.1.1.1. Calculation of the elements

This section will explain the process in which every question from Appendix A was calculated in order to obtain a score between 0 to 1 with the information retrieved in the questionnaire.

5.1.1.2. CE Design

The point of CE Design consists of four different questions.

1. What is the present lifespan of the asphalt?

Considering that being aware of the lifespan of a project is a fact that contributes to the transition towards a CE by having the lifecycle thinking, if the present lifespan of the current asphalt is known, therefore the score is a 1. On the other hand, if the lifespan is unknown the score would be a 0.

2. Was the lifespan increased compared to the original lifespan?

There might be the possibility in which the lifespan reached could be higher than the lifespan expected. For instance, this can occur when proper maintenance is applied to the current asphalt layer. Hence, when the real lifespan reached is higher or the same than the life expectancy, this question scores a 1. If the lifespan reached is lower than the life expected, then this question would score a 0.

Table 4 - Result from material transformation. Part 4 of RPV questionnaire

Having the correct explanation of downgraded or upgraded material can provide insightful information to have a better classification and understanding of the new lifecycle of circular materials. Therefore, it is needed to know better the new use of the materials to obtain its retained value. Please fill in the following table for that purpose.

	What is the result of the transformation in the downgrading of the material? New use i.e. Asphalt to base	What is the result of the transformation in the upgrading of the material? New use i.e. Base to asphalt top layer	What are the market costs of these recycled materials? €/ton
Stone			
Sand			
Gravel			
Bitumen			

3. Does the design of the new asphalt foresee the use of recycled/reused materials?

In order to have a score of 1 in this question, it is necessary to have any value different to 0 in the amount of reused or recycled materials used in the new mixture information from the second section of the questionnaire in Table 2. In case that this section contains no values, the score to this answer would be 0.

4. Is the asphalt designed for high-grade recycling?

To answer this question Table 3 must be taken into consideration. If the user answers “yes” to the question “Is the material being downgraded”, the sore automatically is 0 to that specific material. In order to have a score different to 0, the user must answer with a yes to any of the questions “Is the material being upgraded?” or “Is the material maintaining its same value it had before the reprocess?”. However, the score is not automatically 1 when the answer is “yes”. Depending on the amount of materials present in the mixture, the 1 is divided into that number of the total amount of materials. For instance, if the mixture consists of 1. stone, 2. sand, 3. filler and 4. bitumen, then the score is ¼ multiplied by the times the answer was “yes” for that question considering the different materials. For example; if stone and sand are both maintaining its original value, or if any of them is being upgraded, then the score would be 2 x ¼ = 0.5.

5.1.1.3. Production

The Production point similar to the CE Design also consists of five different questions presented next with the explanation of how they were scored.

1. Is the overall consumption of materials (primary and secondary materials) decreasing?

In order to answer this question, information from Part 1 (Table 1) and Part 2 (Table 2) of the questionnaire are compared. In this point, the ratios of the materials used in the current asphalt mixture are subtracted by the ratios of the amount of raw materials used in the second asphalt mixture. After that, the difference from all of the materials is summed in order to obtain a value which must be subtracted from 1 to obtain a final score.

2. Are the mixtures with fewer hazardous substances (for human health and ecosystems)?

This point is very similar to the previous question, however, this time only the bitumen and substances are compared between both mixtures. This is performed due to the fact that those are the only hazardous substances that the mixture might have. And also, as the previous point, this difference between both mixtures is subtracted from 1 to obtain a final score to this question.

3. Is the production of this asphalt mixture moving towards lower levels of waste generation?

In order to score this question, the amount of reused or recycled materials in Part II of the questionnaire (Table 2) are summed. Therefore, the amount of waste generation is the subtraction of the total amount of waste (100%) minus the amount of reused and recycled materials from Table 2. When 100% of the materials are circular the final score to this question would be 1, on the other hand, when no materials are being considered to be circular, the score would be 0 as more waste would be generated.

4. Is the company moving to CE revenue models with increased reused/recycled/remanufactured/repaired products and components?

In order to give this question a score, it is necessary to address the total amount of materials used for the current mixture, from the new mixture and also to know the amount of materials that have a circular source in the new mixture. Hence, the score for this question is the ratio of circular materials from all the materials used in the mixture. For example, if the current mixture and the new mixture consist of a total of eight different materials, and the new mixture considers two out of the eight types of material to be circular, then the score to this question will be 0.25. If the complete new mixture consists of circular materials, then the perfect score will be 1.

5. Is the company offering a service rather than a product? (Considering the asphalt life cycle)

This question can only score a 0 or a 1. There is a specific question in the questionnaire in Part II (Table 2) which asks whether the new project has a tendering procedure in which the whole lifecycle of the new mixture is taken into consideration, meaning that if the asphalt for this project is considered as product or a service. Therefore, if the answer is a “yes”, means that the new mixture is considered as a service and then the score is 1. In order to score a 0, the new asphalt mixture should be only considered as a product which means that the lifecycle of it is not considered.

5.1.1.4. Consumption

In the case of the Consumption aspects, there are two questions which help score this part of the framework. Such questions are presented next.

1. Has this CE asphalt mixture a longer lifespan or is going to be used more intensively?

A comparison between lifespans is made in order to score this question. A score of 0 will be given in case the lifespan of the new mixture is the same or shorter than the lifespan of the current mixture. This is done as it is more beneficial if the lifespan is longer in the new mixture. The calculation for this question is the division between the current lifespan over the new lifespan and the result of this is subtracted from 1. This way, if the new lifespan is increased to a longer lifespan, the result of this score will increase as long as the new lifespan increases as well.

2. Is the reuse / recycling / remanufacturing / repairing of asphalt components leading to less waste generation?

The computation for this question is similar to the third question from the Production section of the questions. It is also subtracted the amount of circular materials to a 100% as considered the waste that is being reduced with the circular materials. Therefore, if no materials have a circular source, no waste is reduced; consequently, the new mixture will not reduce the amount of waste generation.

5.1.1.5. Waste

Also, two questions construct the framework in order to measure the value retention for the waste aspects of the framework.

1. Is the volume of landfilled asphalt decreasing?

Having circular materials in the new mixture will benefit by decreasing the amount of materials that are being landfilled. Therefore, as more circular materials are being used, the less amount of waste is generated, then it is possible to score this question if the amount of circular materials in the new mixture is known. Hence, the score is the sum of the ratio of the circular materials. If more circular materials are being used, the score is higher and vice versa. If there are fewer circular materials used, the score is lower.

2. To what extent is high-grade recycling applied?

Part III of the questionnaire (Table 3) aims to explore the information regarding the circular materials. Therefore, this part is used to score this question. In case that the user answers with a “yes” whether the material is being upgraded or maintained with its original value, the question is scored with the ratio of the material that has a circular source. However, if the user answers to those questions with “no” then that specific material scores a 0. The final score for this question is the sum of all the ratios of the materials present in the mixture that has a high-grade recycling or at least maintaining its original value from its previous lifecycle.

5.1.1.6. Circularity

Moving to the circularity aspects of the framework, there are two questions that help measure this important aspect.

1. Is primarily material consumption decreasing (in kg per Functional Unit)?

Similar to the production part, this question tries to explore the decreasing of the use of raw materials. So, in order to score this question, it is necessary to compare the amount of materials used in the current mixture, and the amount of materials needed for the new mixture. The sum this difference in case the material consumption is reduced is quantified and it is divided by a hundred to have a score between 0 and 1.

2. Is primarily material consumption decreasing in the whole asphalt sector (in kg)?

To answer this question, it is necessary to address whether there are materials in the new mixture that consider a circular source. Therefore, if there is a minimum amount of circular materials just higher than 0% in the mixture, the score to this question is 1. If all the materials that constitute the new mixture do not consider a circular source at all, then the question would be scored with a 0.

5.1.1.7. Environment

On the environmental aspects, there is only one question that helps score this section of the framework. This question is presented next together with its the calculation process.

1. Is the cumulative environmental pressure decreasing?

In order to score this question, it is necessary to know whether there are circular materials (such as granular asphalt, reused or recycled stone, sand or filler) in the mixture or not; therefore, it is a question that is either scored with a 0 or a 1 only. In case the new mixture has the presence of circular materials, then the score is 1. On the other hand, if the new mixture has only the presence of raw materials, then the environmental pressure is not reduced and the score to this question would be 0.

5.1.1.8. Economy

Finally, the last element that helps to score the RPV is the economic aspect. This aspect consists of two different questions which are presented next together with the explanation of how they are scored.

1. Is the added value of the product and services increasing with this asphalt mixture?

Regarding the added value, the score to this question is a 0 or 1 as well. As the question is a “yes” or “no” question, then, in case there exist an increase in the added value of the new mixture, the score is a 1. Then, in case there is no increase in the added value the score is a 0.

2. Are employment levels in the product chain increasing with this asphalt mixture?

Table 5 – Required data to calculate the REV.

Apart from the physical value, it is also necessary to assess the retained economic value for circular materials. Please fill in the following information for this objective.

Retained economic value of current asphalt mixture

Net present value (including maintenance costs):		€	
Demolishing costs (including labour costs, machinery, energy, and everything necessary for its correct execution):		€	
Transformation costs (All costs that were needed for the recycling process of the materials):		€	0
	Stone		
	Sand		
	Gravel		
	Bitumen		
Transportation costs (Construction site - recycling plant - construction site):		€	0
	Stone		
	Sand		
	Gravel		
	Bitumen		
Value of the same project calculated with raw materials:		€	

	Market cost of primary material €/ton	Market cost of circular material €/ton
Stone		
Sand		
Gravel		
Bitumen		

Similar to the previous question, this is also a "yes" or "no" question. And also, like the previous question, in case there exist an increase in employment, the score to this question is a 1. On the other hand, if the employment level is maintained the same or decreased, the score is a 0.

5.1.2 Retained Economic Value

Moving on to the Retained Economic Value (REV), it is calculated with the following equation:

$$REV = \frac{VPVM}{(NPV + Tc + tc)}$$

Where:

REV = Retained Economic Value

NPV = Net Present Value

Tc = Transformation costs of the materials

tc = Transportation costs of both pre-transformed and transformed materials

VPVM = Value of the same Project calculated with Virgin Materials (Raw)

This calculation will be done for each one of the components of the asphalt mixture, considering the right allocation of the materials in terms of the amount of it in the mixture. For instance, if the bitumen takes 5% of the total amount of the mixture, then it will also be considered as the same amount of 5% in the calculation. By doing this, it will be ensured that the calculation of each one of the components will not be doubled which could cause a bias in the results.

In order to calculate the REV, the following questionnaire has to be filled in by the user presented in Table 5.

5.2 Case study

To test the proposed framework previously presented, two different asphalts were compared. The information regarding these asphalt mixtures was extracted from the "LCA Background Report Dutch Asphalt Industry. Report for the inclusion of industry-representative asphalt mixtures in the National Environmental Database". These asphalts are AC Surf without PR and AC Surf with 30% PR which have the characteristics presented in Table 6.

Table 6 - Asphalt mixture characteristics (Mos & Beentjes, 2016)

	AC Surf without PR (%)	AC Surf with 30% PR (%)
Crushed Stone Bestone	39	19.8
Crushed Stone Morene	11.6	16.8
Asphalt Granulate	-	29.4
Breaker Sand Bestone	21.5	13.9
Crushed Sand Morene	6.4	11.9
Natural Sand	9.2	-
Weak Filler	4.9	2.7
Bitumen 40/60	5.8	4.6
Own substance	1.6	0.9

With this information, knowledge about the project and research about the costs of materials, the complete framework was properly filled in by adapting the real materials to the proposed framework.

6. Results

The main result of this research is the proposed framework that aims to measure the indicator 'Retaining Value' in asphalt for circular infrastructure. A framework which follows the advice from Saidani et. al. (2017) as it was previously explained. Moreover, in order to validate the framework, it was used in a case in which data from the Asphalt Impulse was used. This framework is presented in Appendix E as it was filled in.

After properly filling in the questionnaire with the information from both asphalts AC Surf without PR and AC Surf with 30% PR, the results for the RPV are the followings presented in Table 7.

Table 7 - Result of Retained Physical Value

	Score in section	Maximum possible score	% from final score
CE Design	0.81	22%	18%
Production	0.49	28%	14%
Consumption	0.46	11%	5%
Waste	0.35	11%	4%
Circularity	0.71	11%	8%
Environment	1.00	6%	6%
Economy	1.00	11%	11%
	RPV=	**100%**	**65%**

It is possible to see how much every aspect affects the final score of the RPV. Appendix B shows the exact scores from every part that are taken into consideration for the calculation of RPV. By having the scores presented this way, it is possible to make it easier to trace back which aspects are those which affect the most on the value retention. Therefore, it is possible to put special attention to those aspects in order to be able to improve those specific aspects when decisions towards the improvement of the value retention need to be done.

Table 8 - Result of Retained Economic Value

Retained economic value of <u>current asphalt</u> mixture		
Net present value (including maintenance costs):	€	$57.97
Demolishing costs (including labour costs, machinery, energy, and everything necessary for its correct execution):	€	12
Transformation costs (All costs that were needed for the recycling process of the materials):	€	81.171396
	Stone	58.35852
	Sand	22.812876
	Filler	0
	Bitumen	0
Transportation costs (Construction site - recycling plant - construction site):	€	13.232
	Stone	1.4
	Sand	11.832
	Filler	0
	Bitumen	0
Value of same project calculated with virgin materials:	€	65.445
	REV=	**43%**

Apart from the RPV, the results from the REV are presented in Table 8. With the information filled in by the user, the information about the materials presented in Appendix C, the proper calculation of the Net Present Value (shown in Appendix D) with an initial investment of €65.45 per ton of AC Surf without PR type of asphalt and a discount rate of 5% considering a maintenance cost of €2.30 per year over the ten years, the result for the REV is 43%.

7. Discussion

Starting from the results of the RPV (65%) it is possible to see that the two main aspects that have helped to achieve a higher score are CE Design and Production. However, those two aspects are also those with the most amount of questions each, four and five respectively which can be seen in Appendix B. This is due to the importance that the early stage of the life cycle of the asphalt has in the transition to a CE model. Nonetheless, Consumption, Waste and Circularity have also a big impact on the optimal final result, but in this case, not much is being done in those aspects which makes the new mix to score low and not have an important impact on the end result. This means that emphasis on those aspects needs to be taken in order to improve the RPV.

It is also important to point out that the aspects concerning the 'Achievements' in the progress towards

CE are the aspects that have received a lower score compared to the aspects concerning the Effects in the progress towards CE. This means that special attention needs to be considered to those that score was lower which again are those that concert no the design phase from the end of the life cycle of the old mixture and the new life cycle from the new mixture. This means that if the new mixture design does not take into consideration circular materials the value retention score will even drop more. However, maintaining 100% of the physical value is also very complex to accomplish due to the possibility of compromising the quality of the new asphalt mixture. Nonetheless, research on new asphalt mixtures that consider a major amount of circular materials is being done to be able to reach a maximal amount of value retention; thus, the avoidance of the use of raw materials.

Regarding the REV (43%), it is still difficult to maintain value in new asphalt mixtures. The reason for this is that the transformation costs for circular materials are still very high due to the lack of both supply and demand for this type of materials in the current market. However, research is being conducted in this aspect to improve the technical aspects that can benefit by lowering prices of circular materials and making a profitable business model out from the need to increase the demand of these type of products that enable the transition towards a CE model in the construction industry. But, notwithstanding this, 43% of REV in AC Surf with 30% PR is a good result as the two asphalt mixtures are similar and the amount of circular materials is not very high.

Since there is a correlation between both RPV and REV, in order to have an improvement on them, the pricing of circular materials needs to decrease to make it more attractive for stakeholders to take them into consideration in their new asphalt mixtures designs. However, in different cases, different correlations might be found as it is dependent on the mixtures that are being compared. Nonetheless, the framework traceability helps to find such correlation by having the final scores divided into the different aspects. Therefore, users of the framework will be able to identify such correlations.

8. Conclusions

First of all, the research questions have been answered with the results of the proposed framework. The indicator ‘Retaining Value’ can now be numerically expressed, and both Physical Value and Economic Value can be correlated. Moreover, the four questions from Material Economics (2018) are considered within the framework. It is now possible to know the amount of retained value, the reasons why the value is lost, traceability to find the reason why the value is lost, and it can also help finding new business opportunities.

Moreover, promoting the analysis of the indicator of Value Retention towards the transition to a CE. It is important to highlight that being aware of how much value can be retained when transitioning from a linear economy to a circular one, can enhance users to understand the need to make this important move. Therefore, special emphasis needs to be made on the design phase of new asphalt mixtures in order to be able to retain the most value possible. Moreover, contractors can also find the benefits of having this transition by being able to understand how this new business model can be adapted to their current model. On the other hand, clients such as the RWS can show their contractors the benefits they can achieve by adopting this new model.

Apart from showing the benefits to both clients and contractors, some things about the framework per se can be concluded. The most important is that this framework proposed in this research is a user-friendly framework as Saidani et. al (2017) suggested that this type of frameworks should be. It followed the suggestions made by these authors in order to be built. Despite the user-friendliness, this framework does not affect the results, and more important this framework methodology to measure the value retention helps to have traceability to the materials and aspects that form the indicator ‘Retaining Value’, and this traceability helps to understand which aspects and materials are affecting the end result. Therefore, users can easily adjust their designs in order to improve the final score and to find a better benefit of the transition towards a circular model.

In addition, giving the possibility to correlate both RPV with REV is an advantage. By knowing that the value can either be physical or economic and assessing both values, users can improve their decision-making process by being aware of the effects of every component of the mixture on the final result. Furthermore, the measurement of the REV and its use on this framework may help stakeholders to understand and find a new business model to make CE more attractive to them and implement it in their normal processes and designs. In addition to this, new stakeholders interested in the development towards the transition to CE may find missing gaps which can be fulfilled by their services to improve the current CE model.

Putting the framework in perspective for the future, there are points in which further research can be developed in order to improve the framework. First of all, to develop different strategies to consider the framework throughout the whole life cycle of the asphalt. Furthermore, trying to implement it and adapt it for different materials or components of infrastructure assets. Possible adaptation to know if it remains consistent and aligned to the future of CE, as it is a term that may continue evolving in the close future. And finally, an improvement on the interface of the design and the results which can facilitate the understanding of them.

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11. Appendices

11.1 Appendix A

Appendix A - Questions for progress towards CE in asphalt (adapted from Potting et. al. (2017))

Achievements	**CE Design**
	What is the present lifespan of the asphalt? Was the lifespan increased compared to the original lifespan? Does the design of the new asphalt foresee the use of recycled materials? Is the asphalt designed for high-grade recycling?
	Production
	Is the overall consumption of materials (primary and secondary materials) decreasing? Are the mixtures with fewer hazardous substances (for human health and ecosystems)? Is the production of this asphalt mixture moving towards lower levels of waste generation? Is the company moving to CE revenue models with increased reused/recycled/remanufactured/repaired products and components? Is the company offering a service rather than a product? (Considering the asphalt life cycle)
	Consumption
	Has this CE asphalt mixture a longer lifespan or is going to be used more intensively? Is the reuse/recycling/remanufacturing/repairing of asphalt components leading to less waste generation?
	Waste
	Is the volume of landfilled asphalt decreasing? To what extent is high-grade recycling applied?
Effects	**Circularity**
	Is primarily material consumption decreasing (in kg per Functional Unit)? Is primarily material consumption decreasing in the whole asphalt sector (in kg)?
	Environment
	Is the cumulative environmental pressure decreasing?
	Economy
	Is the added value of the product and services increasing with this asphalt mixture? Are employment levels in the product chain increasing with this asphalt mixture?

11.2 Appendix B

Appendix B - Results per question for calculation of RPV

Questions for progress towards CE in asphalt			
	CE Design	**Max. possible score**	**Score**
Achievements	What is the present lifespan of the asphalt?	1.00	1.00
	Was the lifespan increased compared to the original lifespan?	1.00	1.00
	Does the design of the new asphalt foresee the use of recycled materials?	1.00	1.00
	Is the asphalt designed for high-grade recycling?	1.00	0.25
	Production		
	Is the overall consumption of materials (primary and secondary materials) decreasing?	1.00	0.59
	Are the mixtures with fewer hazardous substances (for human health and ecosystems)?	1.00	0.02
	Is the production of this asphalt mixture moving towards lower levels of waste generation?	1.00	0.59
	Is the company moving to CE revenue models with increased reused/recycled/remanufactured/repaired products and components?	1.00	0.25
	Is the company offering a service rather than a product? (Considering the asphalt life cycle)	1.00	1.00
	Consumption		
	Has this CE asphalt mixture a longer lifespan or is going to be used more intensively?	1.00	0.33
	Is the reuse/recycling/remanufacturing/repairing of asphalt components leading to less waste generation?	1.00	0.59
	Waste		
	Is the volume of landfilled asphalt decreasing?	1.00	0.41
	To what extent is high-grade recycling applied?	1.00	0.29
Effects	**Circularity**		
	Is primarily material consumption decreasing (in kg per Functional Unit)?	1.00	0.41
	Is primarily material consumption decreasing in the whole asphalt sector (in kg)?	1.00	1.00
	Environment		
	Is the cumulative environmental pressure decreasing?	1.00	1.00
	Economy		
	Is the added value of the product and services increasing with this asphalt mixture?	1.00	1.00
	Are employment levels in the product chain increasing with this asphalt mixture?	1.00	1.00
		18.00	100.00
	Result=	**11.73**	**65.19**

11.3 Appendix C

Appendix C - Pricing list of materials

	Market cost of primary material €/ton	Market cost of circular material €/ton
Stone	83	356
Crushed stone Bestone	41.5	-
Crushed stone Morene	41.5	-
Asphalt granulate	-	356
Sand	151	52
Breaker sand Bestone	70	-
Crushed sand Morene	52	52
Natural sand	29	-
Filler	39	-
Weak filler	39	-
Bitumen	370.5	0
Bitumen 40/60	370.5	-
Own substance	0	-

11.4 Appendix D

Appendix D - NPV calculation

Year	FCA	FC		NPV	Discount rate
0	0.00	65.45	0.00	65.45	5%
1	2.30	62.33	2.19	64.52	
2	2.30	59.36	4.28	63.64	
3	2.30	56.53	6.27	62.81	
4	2.30	53.84	8.17	62.01	
5	2.30	51.28	9.97	61.25	
6	2.30	48.84	11.69	60.53	
7	2.30	46.51	13.33	59.84	
8	2.30	44.30	14.89	59.19	
9	2.30	42.19	16.37	58.56	
10	2.30	40.18	17.79	57.97	

$$NPV = FC\frac{1}{(1+i)^N} + FCA\frac{(1+i)^N - 1}{i(1+i)^N}$$

Where:

FC = Fixed Costs
FCA = Fixed Costs Annually
i = Discount Rate

11.5 Appendix E

Appendix E – Answered framework

In order to assess the retention of value of asphalt, it is important to know information about the current mixture

Current asphalt mixture information

Location of the project:		Rotterdam
Total volume of materials needed for the project:	(tons)	
Mixture type:		AC Surf without PR
Life expectancy:	(years)	10
Real lifespan reached:	(years)	10
Was the life expectancy achieved?	(yes/no)	yes

	Ratio of aggregates in the mixture (%)	
Stone	**50.6**	
	39	Crushed stone Bestone
	11.6	Crushed stone Morene
Sand	**37.1**	
	21.5	Breaker sand Bestone
	6.4	Crushed sand Morene
	9.2	Natural sand
Filler	**4.9**	
	4.9	Weak filler
Bitumen	**7.4**	
	5.8	Bitumen 40/60
	1.6	Own substance

To assess the retention of value of the previous asphalt as maintained to the new lifecycle, it is relevant to know information about the new asphalt mixture

New asphalt mixture information

Mixture type:		AC Surf with 30% PR
Life expectancy:	(years)	15
Does the tendering consider the project a service? (Considering lifecycle of the asphalt)		yes

	Ratio of aggregates in the mixture (%)	Amount of primary (raw) material (%)	Amount of circular material: Amount of reused material (%)	Amount of circular material: Amount of recycled material (%)
Stone	**66**	36.6	0	29.4
Crushed stone Bestone		19.8	0	0
Crushed stone Morene		16.8	0	0
Asphalt granulate		0	0	29.4
Sand	**25.8**	13.9	11.9	0
Breaker sand Bestone		13.9	0	0
Crushed sand Morene		0	11.9	0
Filler	**2.7**	2.7	0	0
Weak filler		2.7	0	0
Bitumen	**5.5**	5.5	0	0
Bitumen 40/60		4.6	0	0
Own substance		0.9	0	0

It is valuable to know the process in which the materials are being transformed to be reused or recycled. Such process can provide information to know the extent of value retention that the material has. Therefore, the following table is also important to be properly filled in.

Recycled/Reused materials information

	Is the material being downgraded? (yes/no)	Is the material being upgraded? (yes/no)	Is the material maintaining its same value it had before the reprocess? (yes/no)	What type of recycling method was used? i.e. Grinding - sieving - washing	What was the temperature used for the recycling method (ºC)	What type of energy was used in the recycling process? (km)	What is the distance of transportation for the recycled materials? (km)
Stone	no	no	yes	Demolition - milling - hot recycling method	135	Fuel	50
Sand	yes	no	no	crushing - grinding	20	Fuel	986
Filler	-	-	-	-	-	-	136
Bitumen	-	-	-	-	-	-	89

Having the correct explanation of downgraded or upgraded material can provide insightful information to have a better classification and understanding of the new lifecycle of circular materials. Therefore, it is needed to know better the new use of the materials to obtain its retained value. Please fill in the following table for that purpose.

	What is the result of the transformation in the downgrading of the material? New use i.e. Asphalt to base	What is the result of the transformation in the upgrading of the material? New use i.e. Base to asphalt top layer	What is the market costs of these recycled materials? €/ton
Stone	-	-	
Sand	Stone to crushed sand	-	
Filler	-	-	
Bitumen	-	-	

Retained economic value of current asphalt mixture		
Net present value (including maintenance costs):	€	$57.97
Demolishing costs (including labour costs, machinery, energy, and everything necessary for its correct execution):	€	12
Transformation costs (All costs that were needed for the recycling process of the materials):	€	81.171396
	Stone	58.35852
	Sand	22.812876
	Filler	0
	Bitumen	0
Transportation costs (Construction site - recycling plant - construction site):	€	13.232
	Stone	1.4
	Sand	11.832
	Filler	0
	Bitumen	0
Value of same project calculated with virgin materials:	€	65.445
	REV=	**43%**

	Market cost of primary material €/ton	Market cost of circular material €/ton
Stone	83	356
Crushed stone Bestone	41.5	-
Crushed stone Morene	41.5	-
Asphalt granulate	-	356
Sand	151	52
Breaker sand Bestone	70	-
Crushed sand Morene	52	52
Natural sand	29	-
Filler	39	-
Weak filler	39	-
Bitumen	370.5	0
Bitumen 40/60	370.5	-
Own substance	0	-