IOP Conference Series: Earth and Environmental Science

PAPER • **OPEN ACCESS**

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To cite this article: R E J van den Bogert and M J Ritzen 2021 *IOP Conf. Ser.: Earth Environ. Sci.* **855** 012004

IOP Conf. Series: Earth and Environmental Science **855** (2021) 012004 doi:10.1088/1755-1315/855/1/012004

Environmental impact evaluation of five circular concrete scenarios

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Abstract. In the Netherlands, the material concrete accounts for 40-60% of the total environmental impact of the Dutch construction industry. Cement accounts for 80-95% of this impact, while not being the main component expressed in mass.

Traditional methods of (re)using and recycling concrete in the construction industry have a high detrimental environmental impact, and are currently not fitting in the transition from a linear economy to a circular economy.

In the Dutch concrete treaty (DCT) (07-2018), the main goals of the 'Green Deal for a sustainable concrete industry' (2011-2015) became tangible. The goals concerning the (re)use of concrete in the DCT are:

1. Lowering CO_2 emissions by 30% relative to CO_2 emissions in 1990, with the ambition to lower CO_2 emissions by 49%, by 2030.
2. 100% high quality reuse of concrete from the demolition stock by 2030.

To achieve these goals, changing traditional use of concrete is necessary. Consequently, there is a demand for initiatives that boost the development of new, circular methods of (re)using concrete, resulting in a lower environmental impact. However, data on the actual environmental impact of these methods is still to be collected. In the European project Urban Innovation Actions (UIA), Super Circular Estate–SUPERLOCAL, this gap of knowledge is addressed, and the actual environmental impact of circular concrete methods is studied. In this project, 10-story high apartment blocks are deconstructed, and circular solutions for material re-use and their environmental impact are researched.

The aim of this study is the analysis and comparison of the actual environmental impact of different methods of how concrete, from the existing building stock, not designed for reuse, can be (re)used in a more circular manner.

This study is designed as a comparative analysis. Based on literature and project-expert consultation, five circular concrete scenarios and a baseline scenario have been formulated. These scenarios are considered promising and feasible methods of (re)using concrete from SUPERLOCAL, in a circular manner. These circular scenarios are compared to the baseline scenario, using 100% new materials and mainstream/traditional methods of pouring concrete on site. The five circular scenarios are:

1. Compartments; extracting whole building components from existing building stock to be reused in new buildings.
2. Slabs; extracting smaller building components that can be used for new buildings.

3. Prefabricated elements (with 100% coarse aggregates from granulated rubble).
4. Pouring concrete on site, with 100% coarse aggregates from granulated rubble, and
5. BRX; pre-manufactured concrete bricks with 100% coarse aggregates from granulated rubble.

Data for the calculations is extracted from literature study, from data gathered through real world executions of several circular concrete scenarios in the project SUPERLOCAL, and using widely accepted data bases on embodied energy and embodied carbon in materials.

The outcome of this study is a process description of each scenario and a calculation of the corresponding environmental impact. The environmental impact is expressed in the amount of embodied energy (MJ/m^3 and MJ/unit) and the amount of embodied carbon (kgCO_2/m^3 and kgCO_2/unit).

Although scenario 1 and 2 score the highest on savings on embodied energy (up to 70%) and embodied carbon (up to 70%) compared to baseline, this cannot be deemed as the most promising scenario currently. The risks during execution are too high and the shortcomings on quality of the existing building stock and current building regulations are too big of an obstacle to overcome to call it a feasible scenario.

The most promising scenarios with the highest feasibility of implementation in the built environment are scenario 3,4 and 5. The risks during execution of these scenarios are low and current building regulation can be met with relative ease. Furthermore, there is significant room for improvements. Optimizing manufacturing processes and material usage has directly significant influence on the environmental impact of these scenarios. The possibilities of end of life re-use scenarios are also significant factors in this.

1. Background

With the signing of the Paris Agreement [1], global warming is now widely acknowledged as a serious problem. Actions that reduce the risk and impact of climate change due to global warming must be taken by every country that has signed the agreement. One of the goals set in the Paris Agreement is reducing the emission of CO_2 drastically. Every sector must contribute to obtain these goals. For the Dutch construction industry these goals are set in the Dutch Concrete Treaty [2].

In the Netherlands, the material concrete accounts for 40-60% of the total environmental impact of the Dutch concrete industry. Cement accounts for 80-95% of this impact, while not being the main component expressed in mass.

Traditional methods of (re)using concrete in the building industry have a high detrimental environmental impact and are not fitting in the transition from a linear economy to a circular economy.

In the Dutch concrete treaty (DCT) [3], the main goals of the 'Green Deal for a sustainable concrete industry' (2011-2015) became tangible. The goals concerning the (re)use of concrete in the DCT are:

1. Lowering CO_2 emissions by 30% relative to CO_2 emissions in 1990, with the ambition to lower CO_2 emissions by 49%, by 2030, and
2. 100% high quality reuse of concrete demolition stock by 2030.

To achieve these goals, changing traditional use of concrete is necessary. Consequently, there is a demand for initiatives that boost the development of new, circular methods of (re)using concrete, resulting in a lower environmental impact. However, data on the actual environmental impact of these methods is still to be collected. In the European project Urban Innovation Actions (UIA), Super Circular Estate–SUPERLOCAL, an urban development project in the Netherlands, this gap of knowledge is addressed and the use of new circular materials and building methods and their social, economic and environmental effects is investigated. In SUPERLOCAL, 10-story high apartment blocks are deconstructed, and circular solutions for material re-use and their environmental impact are researched. Within this project, several demonstrator cases are executed that provide the opportunity to investigate circular concrete building methods and study their actual environmental impact. For example, the realisation of three circular model housing units, using only materials harvested from the 10-story high apartment block [4].

2. Aim

The aim of this study is the analysis and comparison of the actual environmental impact of different methods of how concrete, from the existing building stock, not designed for reuse, can be (re)used in a more circular manner.

3. Methodology

This study is designed as a comparative analysis. Based on literature and project-expert consultation, five circular concrete scenarios and a baseline scenario have been formulated. These circular scenarios are considered promising and feasible methods of (re)using concrete from SUPERLOCAL, in a circular manner. These circular scenarios are compared to the baseline scenario, using 100% new materials and mainstream/traditional methods of pouring concrete on site. The five circular scenarios are:

1. Compartments; extracting whole building components from existing building stock to be reused in new buildings (Figure 1).
2. Slabs; extracting smaller building components that can be used for new buildings (Figure 2).
3. Prefabricated elements (with 100% coarse aggregates from granulated rubble) (Figure 3).
4. Pouring concrete on site, with 100% coarse aggregates from granulated rubble (Figure 4), and
5. BRX; pre-manufactured concrete bricks with 100% coarse aggregates from granulated Rubble (Figure 5).

Figure 1. Complete compartment being hoisted out.

Figure 2. Damaged slabs intended for reuse.

IOP Conf. Series: Earth and Environmental Science **855** (2021) 012004 doi:10.1088/1755-1315/855/1/012004

Figure 3. Placing of prefabricated concrete elements.

Figure 4. On-site pouring of recycled concrete.

Figure 5. premanufactured BRX.

4. Data collection and outcome measures for calculating environmental impact of the scenarios.
Data for the calculations is extracted from literature study, from data gathered through real world executions of several circular concrete scenarios in the project in the project SUPERLOCAL and using widely accepted data bases on embodied energy and embodied carbon in materials [5].

There are several methods to account for the beneficial effects of recycling in an assessment. For each assessment, one must choose the fitting approach, based on the goal and scope of the study. In this study, the Recycled Content Approach (100:0 method) is applied. This method benefits in full of the materials being recycled, but does not account for possible end of life re-use scenarios [6].
In formulating the five circular concrete scenarios, end of life recycling was not included. The exclusion of end of life recycling, keeps the necessary associated assumptions to a minimum and increases the focus on the use of materials and building methods. By excluding the end of life recycling factor, using a recycled content approach is legit, for this approach appoints all the benefits of recycling to the materials being saved and thereby excludes assumptions for possible end of life re-use or recycling for materials and products with a long lifespan, like buildings. This leads to a clear demarcation.

A database containing information that can be used when working from a recycled content approach is the ICE database [5]. The range of the ICE database is cradle-to-gate. This includes: material extraction, material processing, transportation to the factory gate and manufacturing until the product is ready to leave the factory. End of life recycling is outside the range of cradle-to-gate. This makes the ICE database suitable to use in a recycled content approach study. The exception being materials where the demand is higher than the supply of virgin materials (e.g. steel). For these exceptions, adequate adjustments for the embodied energy and embodied carbon must be made.
The outcome of this study is a process description of each scenario and a calculation of the corresponding environmental impact. The environmental impact is expressed in the amount of embodied energy (MJ/m^3 and MJ/unit) and the amount of embodied carbon (kgCO_2/m^3 and kgCO_2/unit).
Because four out of five scenarios had a real world demonstrator, practical knowledge on these scenarios is available. Therefore, the calculated outcome of each scenario is also weighed against points of improvement obtained from this data.Lastly, a recommendation on the most promising scenario with the highest feasibility of implementation in the built environment is made.

5. Scenario description and methodology

5.1 Baseline.
In order to make the comparison between the different scenarios, a volume and a building method is set for the baseline unit as well as a unit for the outcome. The baseline volume is set at 38.07m^3 of concrete. This is the amount of concrete used in one of the housing units of the aforementioned demonstrator case. This unit is also used to calculate the outcome of scenario 1; compartments. The baseline scenario accounts for all the work and materials involved in putting up the baseline unit, using current mainstream methods of pouring concrete on site. This involves:

1. Materials used in and during the construction of the baseline unit.
2. Energy used during the construction of the baseline unit (e.g. transport and general use of energy on the building site), and
3. Labor performed during construction of the baseline unit and scenario specific activities.

The main materials being used are concrete and reinforcement steel (rebar). Because the amount of cement used in the concrete composition has a big influence on the environmental impact, it is of great consequence to pick a concrete composition that is representable for an average concrete composition that is used in the Dutch concrete industry. The same applies for the amount of steel used in the concrete construction. CE Delft has gathered data on this subject in their research on the environmental impact of the use of concrete in the Dutch building industry [7]. This data is used to determine the amounts of materials used in the baseline unit.

Data on the general use of energy during the build of the baseline unit is extracted from a chain analysis of the Dutch concrete industry [8]. When required, a surcharge for transport of materials, gate to building site, is set at 0,0031 MJ/kg and 0,0028kgCO_2/kg. This is based on transportation of the materials by truck; cargo 35 tons, average of 100km supply and discharge route and an average diesel consumption of 0,30L/km.
Labour required for constructing the baseline unit consists of: setting up the formwork, laying the reinforcement steel, pouring the concrete and demoulding. Data on this subject is extracted from a report on the feasibility of circular concrete scenario’s [9].
Scenario specific activity for the baseline scenario is demolishing the existing building stock. Data on this subject is extracted from data gathered during real world execution of the fourth scenario in the project SUPERLOCAL; pouring concrete on site with 100% coarse aggregates from granulated rubble.

5.2 Scenario 1: Compartments; extracting whole building components from existing building stock to be reused in new buildings

For this scenario a real life demonstrator has been executed in the project SUPERLOCAL. This scenario involves sawing out a complete housing unit of an existing high apartment block and re-using it as the structural work for a new dwelling.

The data acquired through this demonstrator is used in the calculation of this scenario. Because this scenario has high fixed costs, it is relevant to research the influence of upscaling. Therefor a sub-scenario is also calculated, were the maximum capacity of the high apartment block of 50 apartments is being used. In the demonstrator case it was unclear what the occupancy rate of the machinery was. Therefor several sub-scenarios concerning the occupancy rate of the machinery have been calculated (100%-75%-50% and 25% occupancy rate).

The scenario specific work and materials included in the calculation for this scenario are as following:

Preparatory work; Improving the carrying capacity of the soil near the high apartment block for the big cranes involved in this scenario, putting up the cranes involved in hoisting out the apartments, stamping the high apartment block to ensure safety while performing the labor, removing the concrete balconies that are attached to the housing unit and designing and manufacturing a hoisting installation specifically for this project.

Work included during construction: Sawing out the housing units, hoisting out the housing units onto a low loader, moving to housing units with the low loader to their new location, hoisting the housing units onto their foundation.

5.3 Scenario 2: Slabs, extracting smaller building components that can be used for new buildings.

No demonstrator has been executed for this scenario. This theoretical scenario researches the effect of reducing the high fixed costs of scenario 1 by hoisting out smaller components (less than 3000kg per building component) instead of entire housing units. Using only one crane and making several high cost items redundant (e.g. specialized hoisting construction) . The high risks involved in hoisting out entire housing units, not designed for this proceeding, will be diminished drastically as well.

The fixed costs for this scenario are still relatively high. Therefore, the same sub-scenarios, including the occupancy rate of machinery scenarios, as for scenario 1 will be calculated.

The scenario specific work and materials included in the calculation for this scenario are similar to scenario 1. Amounts and unnecessary cost items are adjusted accordingly for this scenario.

5.4 Scenario 3: Pouring circular concrete on site, with 100% coarse aggregates from granulated rubble.

For this scenario a real life demonstrator in the project SUPERLOCAL has been executed as well. The foundation and stability walls for the model units in the demonstrator of scenario 1 have been constructed with this circular concrete. This scenario involves, harvesting, depositing and processing the coarse aggregates, mixing the concrete and pouring the concrete. All these proceedings are executed on site. The data acquired through this demonstrator is used in the calculation of this scenario.

The scenario specific material included in the calculation for this scenario is the circular concrete. The composition of this concrete is as following: 1600kg/m^3 coarse granulates, 385kg/m^3 CEM III,B and 97kg/m^3 reinforcement steel.

The scenario specific work included in the calculation for this scenario is as following: Harvesting, depositing and sorting debris for extraction of coarse aggregates, processing the debris to usable aggregates (0-4mm and 4-22mm), setting up the formwork, laying the reinforcement steel, setting up a mobile concrete plant, mixing and pouring the concrete with process control and lastly demoulding.

5.5 Scenario 4 Prefabricated elements, with 100% coarse aggregates from granulated rubble.

No demonstrator has been executed for this scenario in SUPERLOCAL, but information and exchange of experiences of a similar project using coarse aggregates from granulated rubble into prefabricated concrete structural work is available.

IOP Conf. Series: Earth and Environmental Science **855** (2021) 012004 doi:10.1088/1755-1315/855/1/012004

This scenario involves prefabricating concrete elements in a factory, using a concrete composition with 100% coarse aggregates from granulated rubble. Then transporting them to the building site and put them up with the use of a crane.
To determine the amounts of materials used in this scenario, the report of CE_Delft on the environmental impact of the use of concrete in the Dutch building industry is used again, but this time data on the composition of concrete products is used instead of concrete mortar [7]. Data on the coarse aggregates from granulated rubble is extracted from scenario 3 and adjusted accordingly to scenario 4. After testing serval concrete compositions, it is apparent that the sand needed for the concrete mortar can only be replaced by small amounts or not at all with the harvested granulates. Because of the coarse and inconsistent shape of recycled sand grains, the consistency of the mortar becomes unpredictable and will not flow as desired. In a factory process this is not workable, so new sand is used in the calculation of this scenario.
Furthermore a "precast concrete modification factor" from the ICE-Database has been added to this data to account for the work being done and energy used inside the factory gates.
A surcharge for transport of materials, gate to building site, is again based on transportation of the materials by truck and are set similar to baseline values. Lastly the consumption of diesel for the crane is set at an estimate of 75L/unit and labor on site is set at 0,95MJ/m^3 and 5,01kgCO_2/m^3 [9].

5.6 Scenario 5 BRX; pre-manufactured concrete bricks with 100% coarse aggregates from granulated rubble.
For this scenario a real life demonstrator in the project SUPERLOCAL has been executed as well. Several storage units are built using this method. This scenario involves producing stackable concrete blocks, in a dry manufacturing process. This method is developed by Pieter Scheer of Dusseldorp. Assembling of the BRX-system can be done in two ways. One method is to stack the bricks and glue them together using a cement mortar. Another method is to stack the bricks and connect them with steel tensile bars. Although the latter method is a better solution from a circular point of view (deconstruction without decreasing the value of the material is easily accomplished), this calculation is made with the first method because data on the method with tensile bars is not complete.
Specialized machinery is required to produce the concrete blocks. Unfortunately this machinery proved to be so delicate, that the goal of producing the blocks on site (like scenario 3) could not be achieved. Therefore, additional transportation of materials is accounted for in this analysis.
The concrete used in this process is made in the same way as in scenario 3 (pouring on site). The quality of the concrete for the "pouring on site scenario" is set at C20/25. For concrete blocks it is not necessary to have such a high quality. So it is realistic to use a lesser cement consumption for this scenario. The prescribed M10 (10N/mm^2) mortar for gluing the blocks affirms that this is a correct assumption. Cement consumption is set at 250kg/m^3 of concrete (CEM III / B42,5L LH-SR). M10 mortar is set at 42kg/m^3 of concrete. Labor is set at 1.02 hours of labor/m^2 and involves manufacturing the blocks, setting the profiles and gluing the blocks [9].

6. Results
Table 1 shows for each scenario the embodied energy [MJ/unit] and embodied carbon [kgCO_2/unit] and the percentage saved on embodied energy and embodied carbon compared to the baseline scenario. The same information is graphically represented in Figure 6 and 7. The complete calculation, including a more detailed process description can be found in Annex A: Calculation of the environmental impact of five circular concrete scenarios.

Table 1. embodied energy [EE] and embodied carbon [ECO_2] per scenario.

	Embodied Energy [MJ/unit]	Embodied Carbon [$kgCO_2$/unit]	Percentage saved on EE compared to baseline.	Percentage saved on ECO_2 compared to baseline
Baseline	143.088	21.194		
Scenario 1	284.086	27.980	-99%	-32%
Scenario 1b	48.580	14.889	66%	30%
Scenario 2	192.118	43.071	-34%	-103%
Scenario 2b	41.865	6.436	70%	70%
Scenario 3	121.752	13.380	15%	37%
Scenario 4	165.726	20.867	-16%	2%
Scenario 5	51.514	9.713	58%	27%

**Scenario 1b and 2b represent the outcome for upscaling to maximum potential of the scenario*

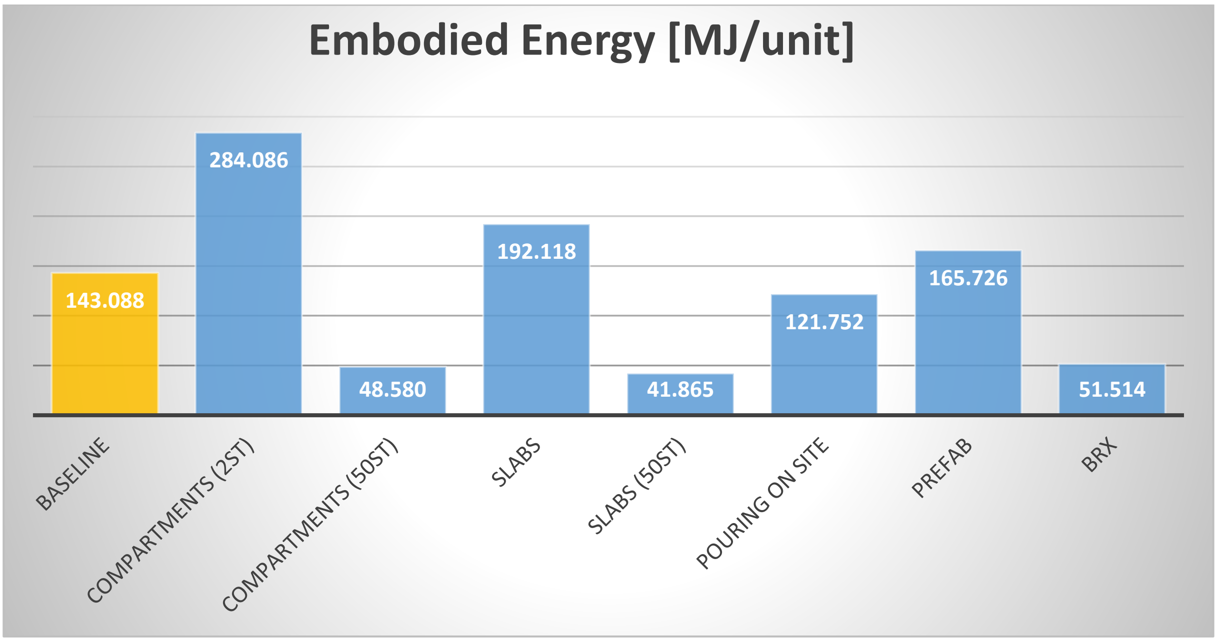

Fig 6. Embodied Energy [MJ/unit] per scenario.

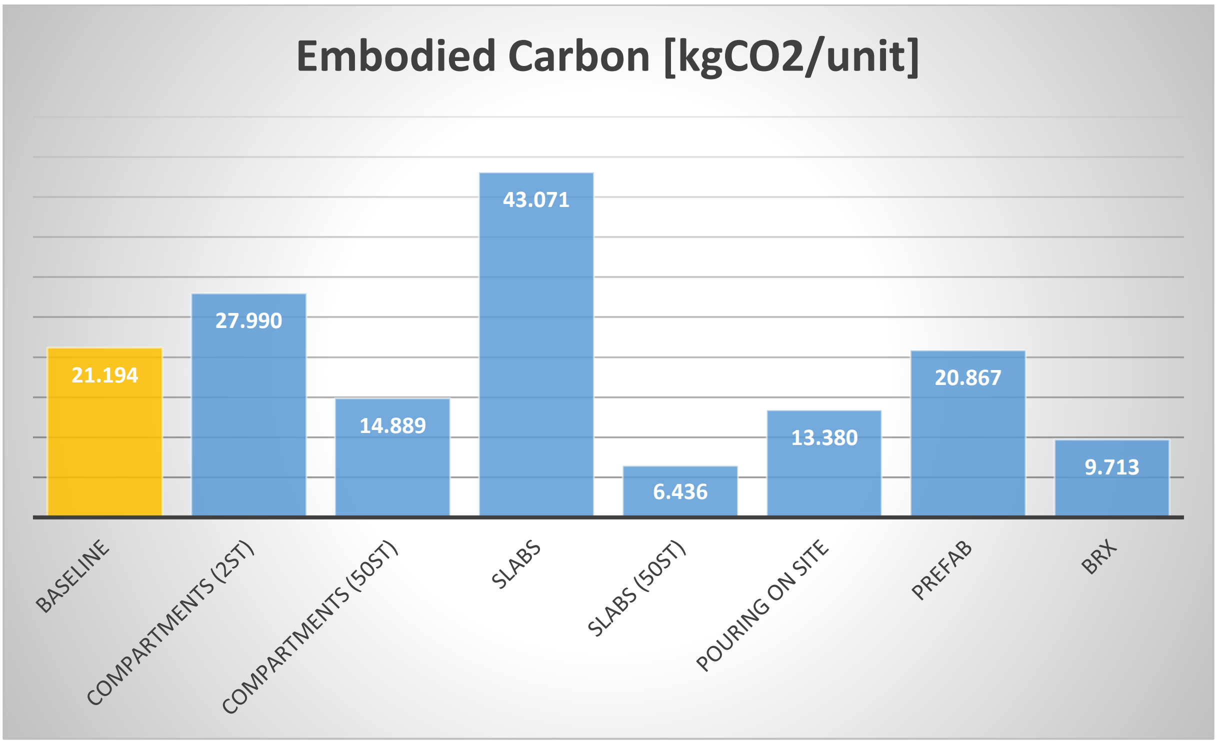

Fig 7. Embodied Carbon [kgCO_2/unit] per scenario.

The baseline scenario leads an embodied energy of 143.088 MJ/unit and 21.194 kgCO_2/unit, while scenario 1 , leads to an embodied energy of 284.086 MJ/unit and 27.980 kgCO_2/unit. This exceeds the baseline scenario by 99% on embodied energy and 32% on embodied carbon. However, upscaling this scenario to the full potential of extracting 50 apartments from 1 apartment building, leads to a saving of 66% on embodied energy and 30% on embodied carbon, compared to the baseline scenario.
Because of uncertainty in the occupancy rate of the machinery used, several sub-scenarios have been calculated (100%-75%-50% and 25% occupancy rate). Table 2 and 3 show the influence of the occupancy rate of the machinery for scenario 1 and scenario 1b.

Table 2. Influence of occupancy rate of machinery used on scenario 1.

Occupancy rate	Embodied Energy [MJ/unit]	Embodied Carbon [kgCO_2/unit]	Percentage saved on EE compared to baseline.	Percentage saved on ECO_2 compared to baseline
100%	284.086	27.980	-99%	-32%
75%	257.168	25.924	-80%	-22%
50%	230.230	23.858	-61%	-13%
25%	203.302	19.727	-42%	7%

IOP Conf. Series: Earth and Environmental Science **855** (2021) 012004 doi:10.1088/1755-1315/855/1/012004

Table 3. Influence of occupancy rate of machinery used on scenario 1b.

Occupancy rate	Embodied Energy [MJ/unit]	Embodied Carbon [$kgCO_2$/unit]	Percentage saved on EE compared to baseline.	Percentage saved on ECO_2 compared to baseline
100%	48.580	14.889	66%	30%
75%	38.816	14.082	73%	34%
50%	29.053	13.275	80%	37%
25%	19.290	12.468	87%	41%

Table 2 and 3 demonstrate that the influence of the occupancy rate of machinery has a significant influence on the outcomes calculated for embodied energy and embodied carbon. The lower the occupancy rate, the higher the savings. The influence of the occupancy rate of scenario 2 is expected to be comparable to scenario 1 and 1b.

Results show that savings op to 70% on embodied energy and embodied carbon can be achieved under ideal circumstances. However, when a scenario involves fabricating new concrete, the results do not demonstrate large savings, ranging from -16% to 58% saving on embodied energy and 2% to 37% savings on embodied carbon compared to the baseline scenario. The reason for this is shown by analyzing the composition of a commonly used concrete mixture a “1,2,4 cement” (C20/25) in table 4.

Table 4. Analysis of a 1,2,4 concrete mixture, using the ICE database

Component	Percentage	Embodied Energy [MJ/kg]	Embodied Carbon [$kgCO_2$/unit]
CEM	14%	0,786	0,136
Sand	29%	0,002	0,001
Aggregates	57%	0,047	0,003
Transport surcharge	57%	0,018	0,001
Total	**100%**	**0,853**	**0,141**

Table 4 demonstrates that while only contributing 14% of the total amount of materials, cement accounts for more than 90% of the embodied energy and embodied carbon. Even if it is possible to use 100% coarse aggregates from granulated rubble, the effects on savings are small. Even more determinative for the outcome is the use of steel reinforcement in the concrete structure. According to the ICE database, the coefficient for using 97kg/m^3 reinforcement steel in a concrete structure will double the embodied energy and greatly increase (>30%) the embodied carbon of the concrete mixture. This conclusion also shows in the results when comparing scenario 3 , which includes 97kg/m^3 reinforcement steel, to scenario 5 , which uses no reinforcement steel. As expected, scenario 5 exceeds savings by > 50% on embodied energy and >30% on embodied carbon compared to scenario 3.

7. Discussion

The aim of this study is the analysis and comparison of the actual environmental impact of different methods of how concrete, from the existing building stock, not designed for reuse, can be (re)used in a more circular manner.

This study demonstrated that savings up to 70% on embodied energy and 70% on embodied carbon could be obtained by upscaling to the maximum capacity of the high apartment block of 50 apartments. Further improvements in savings can be achieved with an optimal occupancy rate of machinery. In scenario's that use new concrete, savings drop drastically, ranging from -16% to 58% saving on embodied energy and 2% to 37% savings on embodied carbon compared to the baseline scenario. This is explained by the disproportionate share on embodied energy and embodied carbon of cement and steel in a concrete mixture.

Although end of life re-use is outside the scope of this study, it should be noted that when making new concrete products, end of life re-use and designing for re-use are important factors to consider, for example based on Design for Disassembly indicators [10]. Preventing the use of new cement will yield significant savings in the second lifecycle of the concrete product.
Scenario 1 and 2 do not suffer from the impact of using new cement and reinforcement steel and therefore appear to be the best circular scenario when scaled up to their maximum potential. The main contributor to the environmental impact for these scenarios, is the use diesel by heavy machinery. Most of the heavy machinery can be seen as a fixed cost in these scenarios. Therefore optimization in occupancy rates of this machinery and upscaling is very effective in these scenarios.
When strictly looking at the savings on embodied energy and embodied carbon compared to the baseline scenario, scenario 1 and 2 score highest. However, there are a lot of practical problems and risks which are not shown in the measured outcome of embodied energy and embodied carbon. Scenarios 1 and 2 are high risk, high reward scenarios. Sawing and hoisting the housing units is a risky undertaking. A single mistake could render the entire housing unit worthless (e.g. cracks or even collapsing on itself during execution of the scenario). Another problem is assessing the quality and durability of the existing building. Especially the quality of the concrete of old buildings varies greatly and is probably not designed for a life span of more than 50 years. Another obstacle for applying these scenario are current building legislations/regulations. The older existing building stock is not up to date to current building legislation. And legislation for building methods like scenario 1 and 2 is not yet available. This means that close cooperation with a willing municipal administration is necessary. All these points require attention and expertise which is not commonly available.
Strengths of this study are the widely availability of data from real world execution of the demonstrators and the usage of a widely accepted database on carbon and energy in materials [5]. Another point of strength is the narrow focus of the study and clear demarcation of the scenarios. Outcomes are hereby not clouded by peripheral issues, but give clear insight on the environmental effect of the circular concrete scenarios.
A limitation of this study is the repeatability of the scenarios. Each new to be realize project and to be harvested building can differ drastically. So for each new project one must assess if that project fits within the set boundaries for this study.

8. Recommendation and conclusion

Several recommendations can be given for lowering the use of (new) cement in concrete. The simplest method is lowering the percentage of (portland cement) clinker in the cement mixture. EU regulations have to be expanded (EN-197-1) to allow this to happen. Another option that is being explored, is extracting reactive (unhydrated) cement from rubble concrete. There can be up to 50% of unhydrated cement in concrete rubble. If this is recoverable as a usable ingredient for new concrete, great savings on embodied energy and embodied carbon in recycled concrete can be made [11]. Promising research for alternative binders in concrete is being done as well. This ranges from adding additives which lower

IOP Conf. Series: Earth and Environmental Science **855** (2021) 012004 doi:10.1088/1755-1315/855/1/012004

the necessary clicker content, to using geopolymer concrete, to reworking fine concrete particles into a cement-like material.

Although scenario 1 and 2 score the highest savings on embodied energy and embodied carbon compared to baseline, these cannot be deemed as the most promising scenarios. The risks during execution are high and the shortcomings on quality of the existing building stock and current building regulations are significant obstacles to enable these scenarios as directly and large scale applicable.

The most promising scenarios with the highest feasibility of implementation in the built environment are scenario 3,4 and 5. The risks during execution of these scenarios are low and current building regulation can be met with relative ease. Furthermore, there is a lot of room for improvements. Optimizing manufacturing processes and material usage has directly significant influence on the environmental impact of these scenarios. The possibilities of end of life re-use scenarios are also significant factors in this.

9. Acknowledgement

The SUPERLOCAL / UIA Super Circular Estate has received funding from the European Fund for regional development in the framework of the Urban Actions Initiative under number UIA02/240. Michiel Ritzen has received funding from the Dutch Organisation for scientific research (NWO) grant number HBOPD.2018.02.025. The authors would like to thank all the partners in the SUPERLOCAL project for their contribution to this research.

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