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## Circular (de)construction in the Superlocal project

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**Abstract.** Worldwide, the concept of the circular economy is gaining momentum. Different strategies are investigated for the construction industry to become circular as it is a major player concerning resource consumption, both energy and material related. One of these strategies focusses on qualitative re-use of building components and building materials. To assess the circularity of different re-use scenarios of building components and materials, we developed and applied a circularity assessment concept in the European Urban Innovation Actions (UIA) project 'Super Circular Estate' (Superlocal). In this project, a 10-floor high 100-apartment building block is deconstructed and its components are re-used in new building objects; 1 pavilion, 4 detached dwellings with different floor areas and 12 terraced dwellings. In the model the environmental impact of different circularity scenarios is expressed in embodied energy, embodied CO<sub>2</sub>, and carbon pricing. Besides the material and energy aspects, other qualities and former social structures are re-used within the project area, boosting the local economy and creating a high-quality and desirable urban environment, resulting in Europe's first super circular housing estate. In the baseline, the existing apartment block consists of 2.3E03 GJ embodied energy and 2.9E03 tons of embodied CO<sub>2</sub>. The investigated pilot dwelling consists of 3.35E02 GJ embodied energy, of which 65% is embodied in re-used materials, and 4.62E01 tons of embodied CO<sub>2</sub>, of which 90% is embodied in re-used materials. This investigation indicates that re-using building components and materials significantly contribute to decreasing building related embodied energy and embodied CO<sub>2</sub>, and should be considered a key step in closing materials loops to make the built environment circular.

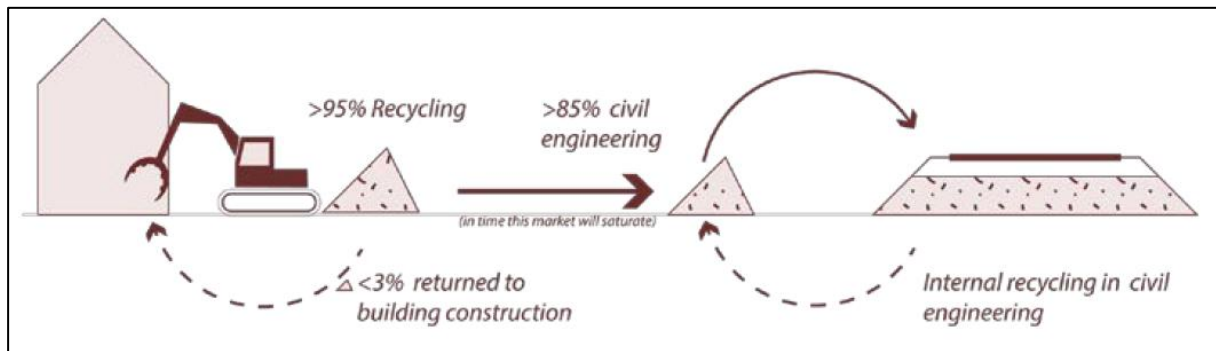
**Keywords:** Circular deconstruction, Re-use of building components, Circularity assessment model



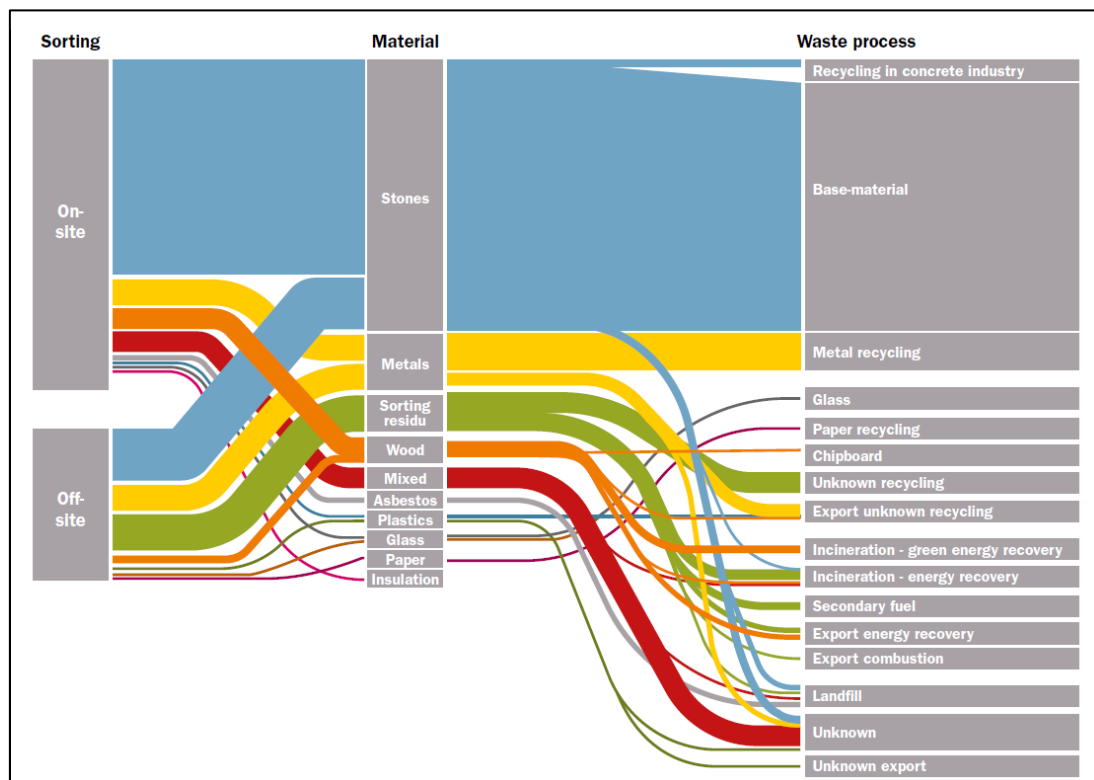
### 1. Introduction

A circular economy consists of an economy without waste, resulting in zero negative environmental, economic and societal impacts [1]. It implies that all energy is based on renewable sources and all materials are permanently able to be recycled or part of the biological cycle. Reflecting this on the built environment results in the definition that a circular built environment is based on 100% life cycle renewable energy, and all materials used within the system boundaries are part of infinite technical or biological cycles with lowest quality loss as possible.

In the Netherlands, the construction sector uses more than half of all the materials used in the Netherlands [2], and collaterally generates more than 25 million tonnes of waste [2]. Of this waste, 85% is downcycled into foundation material; for roads, new residential areas and industrial estates. Only 3% of demolition waste is reused or recycled for the actual construction of new buildings, indicated in Fig. 1 and Fig. 2.



**Figure 1.** Recycling and downcycling in the Dutch construction industry [2].



**Figure 2.** Sankey diagram of flows of demolition materials in the Netherlands [3].

The Dutch construction sector and the Dutch government aim at developing a vision on the high-quality use and re/use of materials in a circular economy [2]. This is expressed in the ambition to have a fully circular economy by 2050 and to have a 50% circular economy in 2030. To realize this ambition, not only new buildings should be designed for complete re-use of building components, also the existing building stock should be considered as a ‘material bank’, with significant potential [3].

In order to improve the rate of change towards circular buildings, research and development projects are initiated by both research and industry. A first key step towards circular buildings and closing material loops is the re-use of building components and materials. A notable example is the Superlocal project which attempts to develop and implement innovative circular building technologies [4]. Going beyond the desire to reduce the environmental impact, a key driver of this project is a large demolition surcharge due to local population decline in the Parkstad region in the South of the Netherlands. The deconstruction of obsolete and outdated buildings results in a significant flow of building components and materials. In the Parkstad region, the aim is the realization of 30,000 dwellings to the level of (nearly) zero energy, the realization of 10,000 gas free buildings, and the subtraction from the market of 10,000 dwellings and 120,000 m<sup>2</sup> retail and utility floor area [5]. This implies that there is a significant potential for re-use and recycling of available construction materials, amongst others from high-rise apartment buildings, such as investigated in the Superlocal project, shown in Fig. 3.



**Figure 3.** High-rise apartment building under investigation in this project.

The strategic objective of the Superlocal project is to contribute to a sustainable, low carbon, resource efficient economy through the management of smart and sustainable shrinkage in the Parkstad region by creating a desirable urban environment and affordable housing opportunities based on breakthrough innovative material re-use solutions and increasing the social acceptance and embracing of circular approaches. Consequently, this will change inhabitant perception and behaviour to be an active agent in the circular built environment in the housing sector and provide as a best example for other parts of Europe through:

1. keeping the value of the buildings, systems, products and social ties by introducing circular economy principles and methodologies into the everyday decision making and management of social housing associations,
2. supporting industry and policy makers with hard-core evidence on circular reconstruction and material harvesting,
3. design, experiment and evaluate 100% reuse and recycle practices in demolition projects for reinforced concrete high-rise buildings (tunnel formwork technology), and
4. increase social acceptance and embracing of circular approaches that consequently changes people's perception and behaviour to be an active agent in the circular built environment.

One of the key challenges of the Super Circular Estate project is to harvest building materials from the apartment building to construct new dwellings. Within the first stage a pilot building (pavilion) was erected to experiment with several demolition techniques. During the second stage, running from 2018 to 2020, four detached dwellings are designed and will be constructed. In a later stage, it will also be investigated or and how twelve terraced single family dwellings can be built based on building components and materials harvested from the apartment building. Doing so, four different re-use/recycling techniques are applied, including:

1. re-using of complete concrete structural apartment blocks in one piece,
2. re-using structural elements such as concrete slabs and concrete walls,
3. recycling concrete waste materials into 'Lego' blocks, and
4. recycling grinded concrete into new concrete via novel technologies such as a 'smartercrusher'.

Academics are involved in the project to assess the circularity of the new dwellings and develop the required knowledge to stimulate innovation in the project. Yet it is unknown how exploiting the re-use potential contributes to circularity with respect to decreasing the environmental impact of newly constructed dwellings in contrast to traditional construction practices. This is further complicated because the circularity assessment methodologies are still to be fully developed. Therefore, in this study, firstly a baseline environmental assessment is presented covering embodied energy, embodied CO<sub>2</sub> and carbon pricing. Secondly, the environmental assessment is conducted for the largest of the four pilot dwellings.

## 2. Methodology

In this project, firstly a baseline environmental impact assessment has been made of the existing apartment building, expressed in embodied energy, embodied CO<sub>2</sub> and carbon pricing based on the concept of re-using and recycling as indicated in Fig. 4. The embodied energy and embodied CO<sub>2</sub> was calculated with the data of the "Inventory of Carbon & Energy" (ICE) database [6]. The carbon pricing is based on the current EU pricing [7]. Secondly, all materials in the apartment building are labeled with a QR code based material passport based on the scheme indicated in Fig. 5. Thirdly, a design has been made for four different pilot dwellings, and of the largest dwelling an environmental impact assessment has been made.



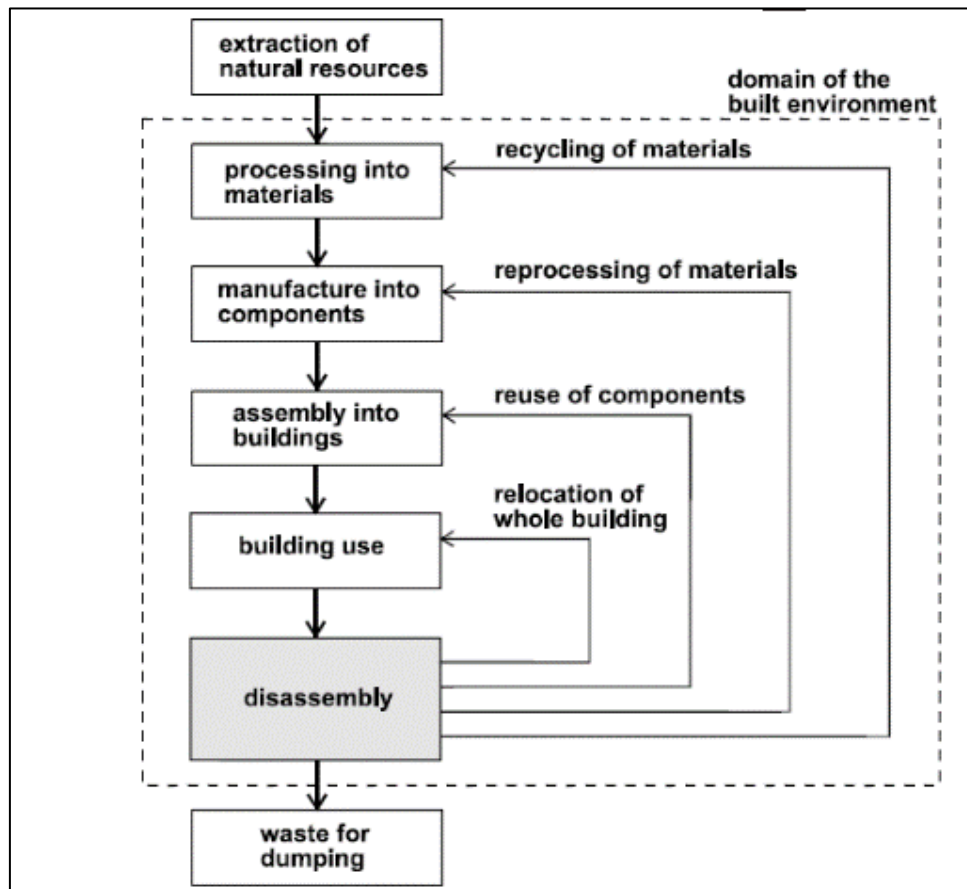


Figure 4. Different process steps in the construction and deconstruction process [8].

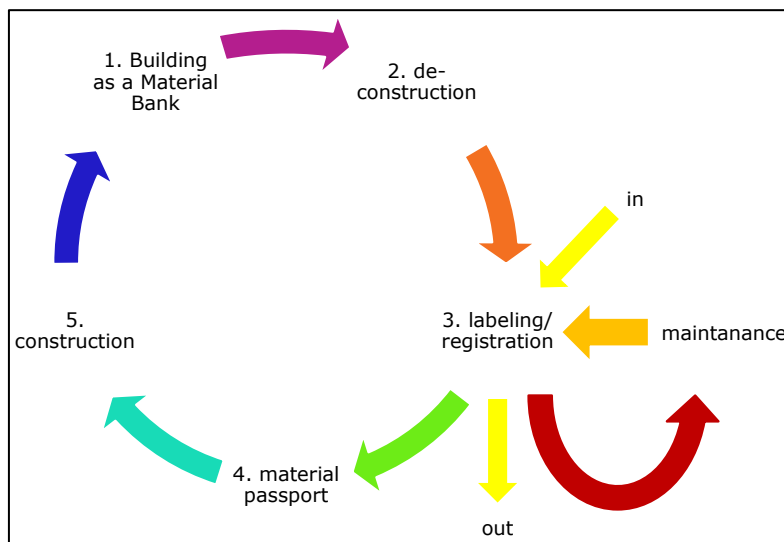


Figure 5. The different process steps including labelling of materials applied in the Superlocal project.

### 3. Results

#### 3.1 Existing apartment building

The existing 10-floor apartment building, indicated in Fig. 3, consists of 100 apartments of approximately 65 m<sup>2</sup>, with a total of 6500 m<sup>2</sup> available floor area. Of this existing building, a material inventory has been made [9]. From this document, a full inventory has been developed indicating the different components, materials, quantity of these materials and related environmental impacts expressed in embodied energy and embodied CO<sub>2</sub>. Table 1 indicates the environmental impact of the 12 main categories. In total, embodied environmental impact of the apartment building are 2.3E04 GJ embodied energy, 2.9E03 tons of embodied CO<sub>2</sub> and reflects 70 k€ with a current carbon pricing of €25/ton CO<sub>2</sub> [7].

**Table 1.** environmental impacts of the 12 main materials in the high-rise apartment building.

material	quantity (ton)	embodied energy (GJ)	embodied CO <sub>2</sub> (ton)	shadowcosts (€)
aluminium	1.03E+01	1.59E+03	8.45E+01	2.11E+03
asbestos	1.81E+02	1.34E+03	2.82E+02	7.05E+03
divers	1.78E+01	2.97E+02	6.23E+00	1.56E+02
ceramique elements	4.40E+01	5.50E+02	3.41E+01	8.52E+02
concrete	1.30E+04	1.33E+04	1.97E+03	4.93E+04
copper	7.45E+00	1.52E+02	9.81E+00	2.45E+02
glass	1.75E+01	4.26E+02	2.56E+01	6.40E+02
masonry	6.38E+01	1.92E+02	1.47E+01	3.67E+02
plastics	1.24E+01	1.00E+03	3.50E+01	8.74E+02
steel	3.26E+02	3.79E+03	3.00E+02	7.50E+03
natural stone	6.05E+01	5.12E+00	2.96E-01	7.40E+00
timber	7.15E+01	6.64E+02	1.00E+02	2.50E+03
<b>total</b>	<b>1.38E+04</b>	<b>2.33E+04</b>	<b>2.87E+03</b>	<b>7.16E+04</b>

#### 3.2 Pilot dwelling

In this study, of the four pilot dwellings, shown in Fig. 9, the largest type of 74 m<sup>2</sup>, shown in Fig. 6, has been selected for further analyses as this is the dwelling type that is most likely to be applied beyond the Superlocal project in the Dutch housing market.



**Figure 6.** Visualization of the four pilot dwellings.

Of this dwelling type, the environmental impacts are 3.35E02 GJ embodied energy, 4.62E01 ton embodied CO<sub>2</sub> and 1.15 k€ shadow costs, based on a carbon pricing of 25€/ton CO<sub>2</sub> [7], indicated in Table 2.

**Table 2.** Environmental impacts of the 12 main materials in the pilot dwelling.

Material	Quantity (ton)	Embodied Energie (GJ)	Embodied CO2 (ton)	Shadowcosts (€)
Aluminium	2.60E-02	4.03E+00	2.14E-01	5.36E+00
Bricks	3.93E+00	1.18E+01	9.44E-01	2.36E+01
Ceramique	1.04E-01	1.97E+00	1.09E-01	2.74E+00
Concrete	1.96E+02	1.73E+02	2.59E+01	6.47E+02
Copper	3.25E-02	1.37E+00	8.46E-02	2.12E+00
Glass	3.38E-01	5.07E+00	2.91E-01	7.27E+00
Insulation	3.44E-01	1.36E+01	5.85E-01	1.46E+01
Paint	5.52E-02	3.25E+00	1.40E-01	3.50E+00
Plaster	6.24E-02	1.12E-01	8.11E-03	2.03E-01
Plastic	3.77E-01	3.10E+01	1.23E+00	3.09E+01
Rubber	9.84E-01	5.02E+01	3.74E-01	9.34E+00
Steel	1.24E+00	2.27E+01	1.78E+00	4.44E+01
Stone	5.00E-03	1.00E-02	5.80E-04	1.45E-02
Timber	1.23E+00	1.70E+01	1.45E+01	3.62E+02
<b>Total</b>	<b>2.05E+02</b>	<b>3.35E+02</b>	<b>4.62E+01</b>	<b>1.15E+03</b>

A key aspect of re-using building components is the energy consumption for deconstruction. In the case of the Superlocal project, the key building component reused consist of tunnel shaped concrete elements which are part of the basic load-bearing structure of the existing apartment building. The exact shape of this element follows from the structural characteristics of the load-bearing structure. This element is considered one of the key building blocks for several reasons, including:

- In this form the tunnel shaped elements reflect the highest level of its re-use potential (re-use of components as indicated in Fig. 4),
- The concrete load-bearing structure has a very low reuse potential when traditionally crushed to concrete granulate,
- The availability of multiple elements which can be extracted from the apartment building provides the opportunities to benefit from replication advantages, and
- As indicated in Table 1 concrete has a high negative environmental impact in terms of embodied energy and CO<sub>2</sub> emission.

Thus, in the four pilot dwellings, tunnel shaped elements encompassing the load bearing structure of complete apartment blocks are removed from the building and re-used. To re-use this element, about 18 MJ per m<sup>1</sup> cutting is needed, resulting in a total of approximately 1.5E02 MJ energy needed for removing the element. From the first pilot it can be derived that removing the tunnel shaped elements is rather complex, labour intensive (and thus expensive) and requires a considerable amount of energy to complete. Further innovation is required to improve the (environmental) efficiency of this process.

#### 4. Conclusion and future research directions

The Superlocal project and this study demonstrate the technical possibility of re-using building components and materials from existing apartment blocks. The application of this solution optimises the material flow as part of the concept of a circular economy and lowers building related environmental impact. The investigated pilot dwelling based on re-used materials has a lower embodied energy of 65% lower embodied CO<sub>2</sub> of 90 % and prevents €1000 in shadow costs. Thus, re-using building components



and materials could significantly contribute to lowering the environmental impact of newly constructed housing, but economic feasibility is challenging. Taking a price increase into account of carbon costs towards 400€/ton CO<sub>2</sub>, the investigated solution would result in a price saving of 16k€ for the dwelling compared to using only new materials, making the proposed solution economically more feasible.

Our research project revealed several opportunities for future research.

Firstly, considering optimal re-use and recycling of materials and construction elements there is the need to define new business models, e.g. based on pre-finance of the demolition of structures, as is already the case for cars and refrigerators. This will make it more attractive to optimally re-use materials as the Superlocal project is financially only viable with additional funding.

Secondly, with respect to newly constructed buildings, it is important to consider during the design stage and re-use how elements of a building can be re-used in multiple cycles instead of the current linear approach. Students and professionals should not be focussing on how to assemble buildings, but how to disassemble them. This should as well be considered in legislation, possibly combined with the EPBD. This circular process should also consider other dimensions on a neighbourhood scale, for example the re-use/recycling of materials as other construction material for example for streets/infrastructure and street furniture and a closed water cycle.

Thirdly, technological innovation is required to efficiently harvest building components and materials from the existing building stock. Harvesting building components and materials turns out to be costly, as a result of inherent complexity and poor experience in the field, and is reflected in a relative high level of energy consumption. Future innovation has the potential to improve the economic and environmental efficiency of harvesting practices.

Finally, the inclusion of society in the transition towards this circular process by raising awareness about the importance of embracing it in daily life practice is essential to achieve a circular built environment.

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