From Waste to Resource

How abandoned materials can be utilized to prevent the increasing amount of waste products within the built environment

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Abstract

30% of the world's waste is generated within the built environment. In order to reduce this, materials that are seen as waste could be reused within architecture and create new ways of designing for example by symbiosis between industries or implementing a circular economy. However, it is important to look critically at the additional process that is necessary to create new products from waste as some processes require a lot of energy that could potentially do more harm than good. Nevertheless, to reduce waste itself, the current process of producing materials should be tackled by reducing waste generation itself rather than using the waste that was generated. In the end it is important to look at the different possibilities per project and new ways of designing by using what is at hand rather than using more primary materials.

Key words – Waste, Waste flow, R-strategy, Circular Economy, Life Cycle Assessment, Industrial symbiosis.

Content

1. Introduction

Each year, between 7 and 10 billion tons of waste is produced globally from which currently only 31% is recycled (Zeller et al., 2019). This means that still 70% of the yearly produced waste is landfilled or incinerated, which causes rapid loss of valuable resources. According to Carpentier (z.d.), up to 30% of the world's waste is produced in the built environment (Bao, 2023). As the built environment is the leading producer of waste, this might be an interesting sector to look at when trying to reduce the amount of generated waste. In order to preserve natural resources and reduction of waste and pollution, a transition is taking place from a linear economy, where waste is considered within a dead-end scenario, towards a circular economy (CE), where waste is considered valuable. According to Ho et al (2024), 'CE focuses on resource conservation and supporting more effective use of natural materials while demonstrating economic benefits makes a persuasive case for adoption in practice.'.

The R-ladder is an extensive scheme that is categorised into different subgroups that seeks to explain the various ways in which a product can be reused as a whole, deconstructed as material, etc. (Morseletto, 2020). The principle originated with the 3R "reduce, reuse and recycle" and expanded into the 10R's "recovery, recycle, repurpose, remanufacture, refurbish, repair, reuse, reduce, rethink and refuse" (Potting et al., 2017). The different R-strategies can be ordered by their level of circularity, which is shown by their place on the R-ladder in figure 1.

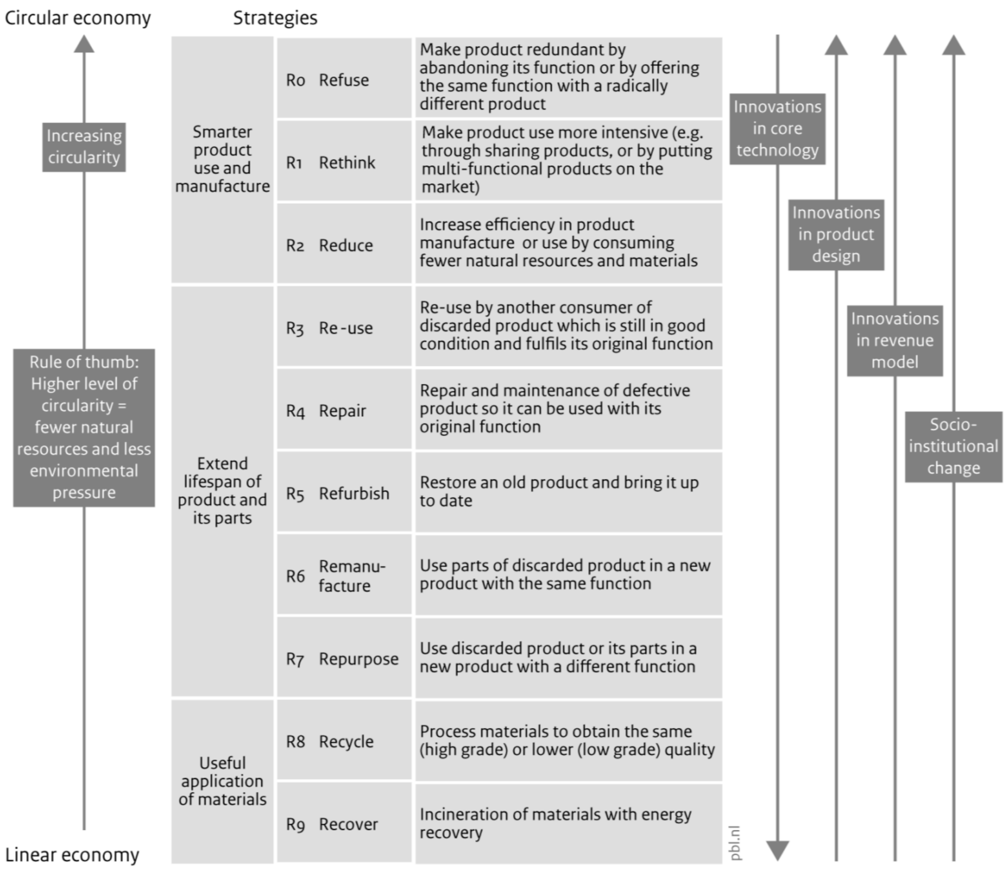

Figure 1 – R ladder from Potting et al. (2017).

The higher their position on the R-ladder, the more circular the option to use. The first three strategies “refuse, rethink, reduce” indicate ways of using a product in a smarter way. With these strategies, the aim is to reduce product use in general. This can be done by making a product unnecessary or by making products multipurpose in order to reduce the amount of products. R3 until R7, “reuse, refurbish, remanufacture, repurpose”, make sure the life span of the product gets extended by recycling the individual materials of a product. By making some alterations to (part of) a product, a new product is created. Lastly, products can have a useful application in another form (“recycle, recover”). Within these strategies, more change in the product is needed which is linked to less environmental benefits as a lot of energy is needed for these practices. Thus, the higher on the R-ladder, the more circular economy will be and the more environmental benefits will occur. While the primary resources are becoming scarce, using waste as a resource is an important next step that should be taken. Or as Hebel et al. (2014) says: ‘The future city makes no distinction between waste and supply.’. This principle is applicable at various scales, including the built environment.

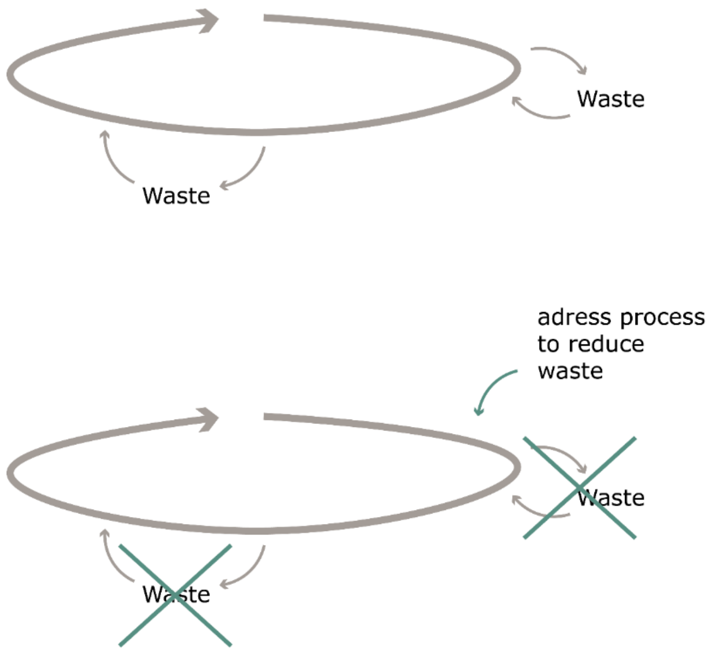

Figure 2. Diagrams of the current circular process and the future circular process. Own work

In the previous generations, not a lot of thought was given to repurposing and reusing parts of buildings, which is why during renovation of buildings, a lot of waste is generated and R-strategies lower on the R-ladder have to be used in order to still be able to use the waste. To make this visible, the top cycle in figure 2 shows the current circular process of a material, with along the way some waste that is discarded. In the future, the intention is to address the problem at its origin and prevent the generation of waste itself. More attention will be given to using demountable parts in order to make it easier to reuse the products within the building stock. Nevertheless, the current building stock that needs renovation or demolishing cannot be recycled the most beneficial way yet, which is why this paper researches the ability of effectively using the R-ladder on the waste flows in order to reduce the waste generation within renovation of a site. The main question in this paper is:

How can designing with waste reduce the generated waste within the built environment?

To answer this question, first the concept of waste and waste flows are explained as well as the way they work. Different scales in which waste flows can be used are introduced and discussed within an industrial symbiosis framework. Additionally, some different case studies are discussed which shows various ways in which creative reuse promotes the use of waste materials into 'new' material in order to be used within architecture.

2. Waste streams

There are different ways in which waste can be understood: 'eliminated or discarded as no longer useful or required after the completion of a process', 'not used', 'any substance discarded after primary use, or is worthless, defective and of no use.'. Within this paper, waste will be seen as a material that is discarded by a party because they do not need it anymore.

Waste streams are flows of specific waste products through recovery, recycling or disposal. An example of a waste stream is shown in figure 3. This diagram shows the flows of demolition materials in The Netherlands. Of the demolition waste, 85% is downcycled into foundation material and only 3% is recycled for the actual construction of new buildings (Ritzen et al., 2019). As the Dutch government has an ambition to become a circular economy in 2050, the current building stock should be considered as a material bank with potential. Therefor demolition waste should be used for more than foundation products only.

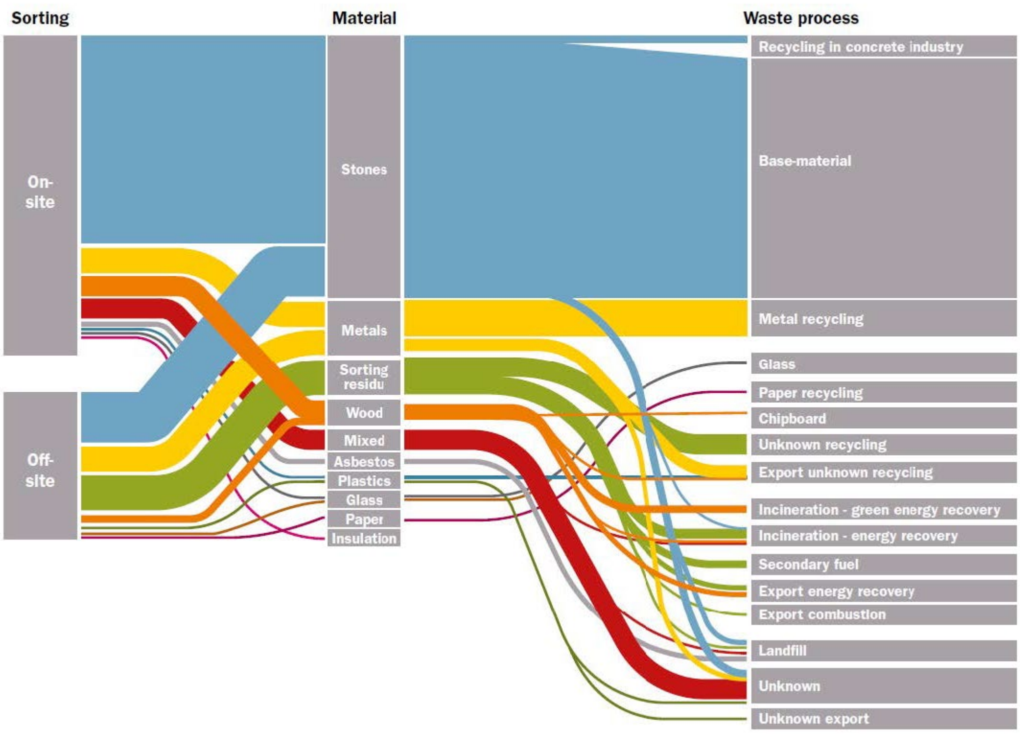

Figure 3. Diagram of demolition flows of a variation of materials in The Netherlands. Ritzen et al., 2019.

In order to reduce the global environmental pressure from waste, waste management principles have been introduced at large scales. In Europe, laws have been implemented in order to increase reuse, recycling and energy recovery (Zeller et al., 2019). However, the result of generalisation of countries or regions makes the outcome inefficient as 'results from Life Cycle Assessments (...) show strong dependency on local specificities of the waste management systems.'. Whereas waste streams show the amount of waste generated, a Life Cyle Assessment (LCA) is a tool that quantifies environmental impacts of this waste. This is an important distinction as not all products entail the same environmental impact. Additionally the investigation can be done at different scales, from whole countries to specific sites. This method shows whether products are reused (and in what way) or landfilled ((Laurent et al., 2014)). The LCA show different kinds of waste, each requiring its own waste treatment technology. While organic waste can be recycled, composted, treated or landfilled, mixed waste has fewer options. On a larger scale, a region with a lot of farming and a different region that produces a lot of steel are very different, and according to Laurent et al. (2014) cannot be generalised in the Life Cycle Assessment and thus cannot be generalised in the waste management systems. This is the same for different countries; one country may export mainly vegetables, while another country produces steel that is used worldwide. These countries will not be able to comply with the same regulations, which is why waste management principles should take into account different industries within a region or country.

Like in LCA's, waste streams depend on their effective size. The waste streams of one industry may be beneficial to another industry in which it might be possible to create an industrial symbiosis by waste exchange (P. C. Chen & Ma, 2015). The symbiosis can be implemented at different scales with each their own advantages and disadvantages. Currently, industrial symbioses is mostly done at a scale smaller than cities, but new studies are done on circular economy at city scale or larger. According to Zeller et al. (2019), there are some factors that influence cities in circular economy. Proximity, scale and the ability to shape urban planning and policy are seen as important factors in order to make the circular economy work. Looking at the proximity within CE, reduced transport, packaging and distribution losses can be the result of a smaller CE (Sanyé-Mengual et al., 2015). On the other hand, Sterr and Ott (2004) state that 'the right size is the minimal size in which outputs can be retransformed into desired input, thereby adequately closing material loops' meaning that a larger distance can have its advantages if that means that material loops are closed by that and enough products are gathered. In their research, metals came out as the only material that cannot always be recycled within the regional boundaries, while 'the market needs to be sufficiently large to sustain specialized industries'.

Subsequently, the question of scale arises. The scale of the CE depends on the type of waste. Some waste products need a larger boundary than the other. Chen et al. (2012) state that 'waste oil, metal, plastics, paper, and waste electrical and electronic equipment are circulated in large regions, whereas organic waste, mixed waste and demolition waste are suitable for local recycling and recovery'. In addition, the density of the material and the costs of transportation or treatment determine the most efficient scale. For example, glass and metals have a high market value with low density and low cost of transportation, which means that the most convenient scale would be a larger one. On the other hand, products with a lower market value and a high density with high transportation costs would require a smaller scale (X. Chen et al., 2014). Furthermore, smaller CE boundaries create a smaller variety of waste flows. However, not every company needs a wide variety of products in order to carry on its business. In figure 3 a summary is shown that explains the advantages and disadvantages of a bigger or smaller scale of the use of waste symbiosis.

Big scale	Small scale
Low cost of transportation	High cost of transportation
Low density of material	High density of material
High market value	Low market value
Waste oil, metal, plastics, paper, and waste electrical and electronic equipment	Organic wastes, mixed waste and demolition wastes
A bigger CE can close the material loops	Reduced transport, packaging and distribution losses
Unspecific material (bigger variety)	Specific material (smaller variety)
Sufficient amount of waste	Little amount of waste

Table 1. Conclusion on big and small scale CE. Own work

To illustrate that waste symbiosis is possible on different scales, two different case studies are discussed in this paper. Ho et al. (2024) present the case of the Australian state of Victoria where they want to transition to a circular economy. As data shows, 52% of glass waste ends up unsuitable for recycling, ending up in a landfill (State Government of Victoria, 2013). By participation of multiple stakeholders within the state, a project was set up (Climate Action; Responsible Consumption and Production) to make concrete for roads by reutilising glass. The glass gets crushed and replaces the sand needed in the creation of concrete. By implementing this concept, new life is brought to old glass which can replace about 80% of virgin sand in the future. In this case study done by CYP D&C at the Metro Tunnel Project, the government was helped by the concrete industry using the glass waste, and the concrete industry was provided with a product that they needed within their process that they otherwise had to get as a primary resource somewhere else. Furthermore, as a lot of sand is needed to produce concrete, a lot of glass waste is needed. Therefore a bigger scale could be more beneficial than a smaller scale.

On a smaller scale however, CE can be applied in a different way. For example, a study by Zabaniotou et al. (2015) on a pyrolysis-biochar system shows the CE created in a small scale symbiosis between an olive farm and an olive mill. The olive mill was not only used to produce olive oil, but also to produce the energy to power the milling process by pyrolysis and use the biochar as soil amendment. Biochar is the co-product that is produced along the production of olive oil during pyrolysis which can be used to improve the soil fertility at the olive farm. Within the project, the closeness of the two parts is crucial as this reduces the logistical and transportational costs. The fuels extracted from the olive mill can fulfil the energy needs of the mill and produce an energy surplus that can account for an extra income when sold to the grid.

3. Application of waste

More and more creative applications are invented to reuse products to reduce the generated amount of waste, which is translated into creative reuse. ‘Creative reuse is when the addition of creativity is added to an already manufactured item and brings a new function.’ (Scrap Creative Reuse, 2021). According to Hebel et al. (2014), the most obvious and direct way to process waste products into building construction elements is densification of waste products. As waste products are often gathered in low density bulk, after compressing they require much less space and are more easy to handle. These compressed blocks, could be made into pellets to use as an energy source for heating systems. Aside from their fuel capacity, this means the lowest R-strategy is used, namely recovery. Besides fuel, compressed waste can also be used to create structures, insulation or facades element or even all of them combined.

In Germany for example, a temporary structure had been created from discarded cardboard to house start-up companies. As yearly 16 million tons of paper and cardboard waste is generated in Germany, PHZ2 had thought of it as an enormous potential for the building sector. For the project, they repurposed cardboard and created densified bales with metal straps to hold it all together (figure 4). Each bale has an extremely high compressive strength, has a weight of 500 kg per unit, and can be used to build up to a height of 30 metres. The thickness of the building blocks make for a great sound and thermal insulation. To top the cardboard bales, the roof was covered with a cement board deck, which made the building resist the rainfall enough to prevent rain damage. Approximately 550 bales of paper waste were used, which in total reduced the amount of waste by about 275.000 kg. However, the building was not protected against fire because of its temporary function and in April 2011, the structure caught fire and was destroyed.

Figure 4. Papierhouse on the World Heritage Zollverein by Anja Bäcker (2010).

In 2010, 30 billion of used carton drink packages were recycled (Environment Energyleader, 2011). These products could be a great source for building products while they contain a combination of paper and aluminium. Once shredded in small pieces and heated while in a mould to form sheets, they offer advantages in contrast to iron or fibre cement sheets, because they are non-corrosive, light and require a low production cost. From this, Tuff Roof was created, which are waterproof, fireproof, low heat absorption and flexible panels that can be used as roof elements and look like corrugated sheets, currently often made from steel or plastic (figure 5). As these panels need some form of processing, this could be categorised as recycling of waste products. This reconfiguration of waste is still at the low end of the R-ladder, but nevertheless reduces a lot of waste without the need of incineration. On the other side the process of making these panels require a lot of energy and cause not that great working conditions. Furthermore the manufacturer is located in India so a lot of transportation is necessary as well.

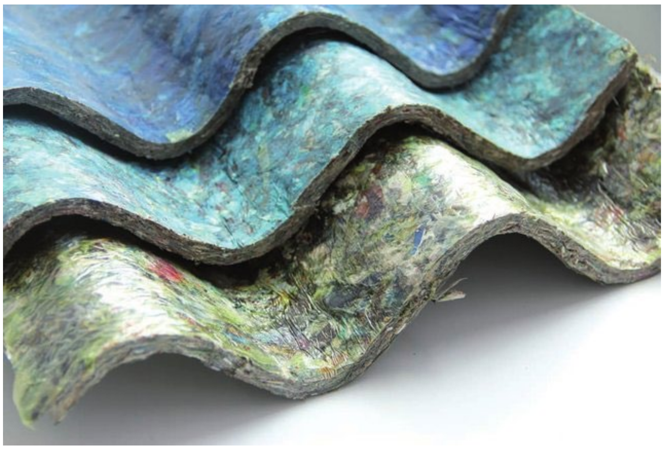

Figure 5. Tuff Roof panels are produced 100% out of discarded Tetra Pack and other drinking cartons of similar materialization. By Felix Heisel.

Another application of waste is StoneCycling. At lot of processing is needed within the production of recycled stone, but by doing this, the product will re-enter the same environment as it came from in contrast to downgrading the product during downcycling. Hebel et al. (2014) state that the annual demolition waste in the Netherlands is 15 million tons, while the demand of building product is 10 times higher. Tom van Soest has created StoneCycling, now called WasteBasedBricks (Front, z.d.), by transforming building rubble into different functions and properties. In order to create new 'baked goods', the rubble is mixed and baked into new stone-like products that are fireproof, waterproof and can mainly be used for finishing tiles. One square metre of brickwork contains 91 kg of waste as at least 60% is made with waste. In Amsterdam, the interior of an office has been created with WasteBasedBrick and has saved 77.250 kg of waste by using it within the interior (figure 6). However, like Tuff roof, the process to create WasteBasedBricks requires a lot of energy, which could be something to take into consideration when designing with the intention to reduce waste, because emissions can also be seen as some form of waste.

Figure 6. Adyen in Amsterdam by TANK / Teo Krijgsman.

4. Discussion

In the paper, different circular economies have been discussed at different scales. These scales are dependent on different factors and characteristics of the waste according to the streams. As previously discussed targets can be made for whole countries or even continents. However, these targets generalise many elements which makes the outcomes distorting.

While most of the papers look into the bigger scales to implement a circular economy, sites with a more specific need of products also need a more specific circular economy, which can mostly be found at a smaller scale. To get a wider knowledge, more research could be done into smaller scale circular economy. On the other hand, maybe the same intention as with the large scale circular economy could be implemented at a smaller scale.

The three case studies show different ways to build from waste. While compressing cardboard and paper does not require any further processing, the Tuff Roof and WasteBasedBrick require a lot of processing which might also need more energy for the machines. In addition, the extra modifications and additional use of energy could be seen as another waste product. This could be important to keep in mind and maybe important to include that within the calculations for the LCA.

Furthermore, the ways of creative reuse that are currently created are applicable at the current way of designing. However in the future, different ways of building might be invented and implemented, which is why the reuse of materials has to be evolving all the time.

5. Conclusion

To conclude, various approaches of reuse could be implemented at different scales. For example at a building scale within its own site, or on the other side a whole country could implement symbiosis of material at a bigger scale that requires and contains less specific materials. Additionally, different scenarios require different approaches from the R-ladder because some R-strategies simply do not comply in some situations as the products and buildings that have been built in the past did not take into account the idea of reusing the materials in a later stadium. It is therefor important to look at what is possible per project and maybe later on, when buildings that were built with demountability factor included within the design, R-strategies higher on the R-ladder could be implemented. The solution to reducing the amount of generated waste is on the one side using waste products for new material, but on the other side tackle the problem of waste production at an earlier stage, by adjusting material production and keeping the reuse element (for the future) in mind while designing new things.

6. Bibliography

Bao, Z. (2023). Developing circularity of construction waste for a sustainable built environment in emerging economies: New insights from China. *Developments in the Built Environment*, *13*(September 2022), 100107. https://doi.org/10.1016/j.dibe.2022.100107

Carpentier, H. (z.d.). *Circular Economy in the built environment waste hierarchy: Why recycling is the last resort*. Geraadpleegd 8 oktober 2024, van https://worldgbc.org/article/waste-hierarchy-cbre/

Chen, P. C., & Ma, H. W. (2015). Using an Industrial Waste Account to Facilitate National Level Industrial Symbioses by Uncovering the Waste Exchange Potential. *Journal of Industrial Ecology*, *19*(6), 950–962. https://doi.org/10.1111/jiec.12236

Chen, X., Fujita, T., Hayashi, Y., Kato, H., & Geng, Y. (2014). Determining optimal resource recycling boundary at regional level: A case study on Tokyo Metropolitan Area in Japan. *European Journal of Operational Research*, *233*(2), 337–348. https://doi.org/10.1016/j.ejor.2013.01.054

Environment Energyleader. (2011, april 22). Tetra Pak "to Double Carton Recycling". *Environment Energyleader*. https://environmentenergyleader.com/stories/tetra-pak-to-double-carton-recycling,40338?

Front. (z.d.). *WasteBasedBricks - How It's Made*. Geraadpleegd 17 januari 2025, van https://www.front-materials.com/how-its-made/wastebasedbricks/

Hebel, D. E., Wisniewska, M. H., & Heisel, F. (2014). *Building From Waste: Recovered Materials in Architecture and Construction*. Birkhäuser. https://doi.org/10.1515/9783038213758

Ho, O., Iyer-Raniga, U., Sadykova, C., Balasooriya, M., Sylva, K., Dissanayaka, M., Sukwanchai, K., Pal, I., Bhatia, A., Jain, D., & Sivapalan, S. (2024). A conceptual model for integrating circular economy in the built environment: An analysis of literature and local-based case studies. *Journal of Cleaner Production*, *449*(June 2023), 141516. https://doi.org/10.1016/j.jclepro.2024.141516

Laurent, A., Bakas, I., Clavreul, J., Bernstad, A., Niero, M., Gentil, E., Hauschild, M. Z., & Christensen, T. H. (2014). Review of LCA studies of solid waste management systems - Part I: Lessons learned and perspectives. *Waste Management*, *34*(3), 573–588. https://doi.org/10.1016/j.wasman.2013.10.045

Morseletto, P. (2020). Targets for a circular economy. *Resources, Conservation and Recycling*, *153*(November 2019), 104553. https://doi.org/10.1016/j.resconrec.2019.104553

Potting, J., Hekkert, M., Worrell, E., & Hanemaaijer, A. (2017). CIRCULAR ECONOMY : MEASURING INNOVATION IN THE Policy Report. *Planbureau voor de Leefomgeving*, *January*.

Ritzen, M., Oorschot, J. Van, Cammans, M., Segers, M., Wieland, T., Scheer, P., Creugers, B., & Abujidi, N. (2019). Circular (de)construction in the Superlocal project. *IOP Conference Series: Earth and Environmental Science*, *225*(1). https://doi.org/10.1088/1755-1315/225/1/012048

Scrap Creative Reuse. (2021). *Creative Reuse*. https://scrapcreativereuse.org/What-Is-Creative-Reuse

State Government of Victoria. (2013). *Market summary – recycled glass*. 12.

Zabaniotou, A., Rovas, D., Libutti, A., & Monteleone, M. (2015). Boosting circular economy and closing the loop in agriculture: Case study of a small-scale

pyrolysis-biochar based system integrated in an olive farm in symbiosis with an olive mill. *Environmental Development*, *14*, 22–36. https://doi.org/10.1016/j.envdev.2014.12.002
Zeller, V., Towa, E., Degrez, M., & Achten, W. M. J. (2019). Urban waste flows and their potential for a circular economy model at city-region level. *Waste Management*, *83*, 83–94. https://doi.org/10.1016/j.wasman.2018.10.034