# URBAN MINING AS TOOL TO STIMULATE COMPONENT REUSE IN ARCHITECTURE

Dominik Lukkes
Faculty of Architecture & the Built Environment, Delft University of Technology
Julianalaan 134, 2628BL Delft

## *ABSTRACT (150 WORDS MAX)*

*In recent years, the reuse of building components has gained more attention within the built environment due to the global transition towards a circular economy. However, there is a gap between the availability of used building components and the actual application of these components in new building projects. Urban mining is a process that engages in recovering used components from buildings. The process of urban mining consists of making an inventory, harvesting and distributing. In these phases, many challenges are encountered that make it difficult for the reuse of components to be financially or environmentally preferred compared to conventional materials and techniques. Information on buildings and the components they are comprised of is important in determining the added value of reusing building components. New initiatives such as design for disassembly, design for reuse and material passports are paving the way for urban mining to make an impact in component reuse.*

***KEYWORDS:*** *Urban mining, Component reuse, Architecture, Circular economy Reusability*

## 1. INTRODUCTION

The world is facing a number of large-scale challenges, such as the changing climate and its effects, the increasing world population and the depletion of fossil fuels and raw materials (Luscuere et. al., 2018). The bizarre fact that China has used more cement in the past 3 years than the United States has in the entire 20th century (Eurostat, 2016), is simply mind-blowing. If we zoom in on the Netherlands, and Amsterdam specifically, we see similar challenges. According to the ministry of infrastructure and the environment (MIE) and the ministry of economic affairs (MEA), the construction industry is estimated to account for 50% of total raw materials used, 40% of total energy consumption, and 30% of total water consumption in the Netherlands (MIE & MEA, 2016). To make the situation a little worse, we also see an abundance of vacant offices in the city of Amsterdam: roughly 462.387 $m^2$ (which equals to about 7,9% of the total amount of offices in Amsterdam) is standing empty (Cushman and Wakefield, 2017). These buildings usually sit empty for a couple of years, until the decision is made to demolish them. According to the government, approximately 40% of waste in the Netherlands involves construction and demolition waste (MIE & MEA, 2016).

We also see developments that present a more positive prospect. Following the ideas of the circular economy, the built environment is in transition. An example of this is the reuse of used building materials. Research has shown that in the past few years a lot of companies have invested money in online material marketplaces, where used materials and building components are being sold. The idea behind the online marketplace is that it becomes easier for architects and builders to start reusing these materials and components. However, this same research has shown that in 2017, only 200.000 euros of circular building material was sold. In a sector in which around 6 billion euros in sales are made annually, this amount is still very little (Slager & Jansen, 2018). In fact, it comes down to less than 0,01%. So, despite the transition towards a circular economy, it becomes clear that there is a gap between the availability of used building components and the actual application of these components in building projects.

## 1.1 Cities and buildings as mines

The philosophy of urban mining is to see urban areas, such as cities and buildings, as potential material mines. Instead of constantly creating building materials out of newly mined raw materials, urban mining focusses on the recovery of materials and energy from products of the urban catabolism (Baccini & Brunner, 2012). So instead of demolishing buildings and destroying the materials and components these buildings comprise of, they are harvested for reuse. Reusing building elements and recycling materials is something of all times and has been done since the classical period (Addis, 2006).

## 1.2 Component reuse

To avoid any misunderstandings in terms of terminology, a distinction is made between material reuse and component reuse. This paper focusses on component reuse, where a component is defined as "a part of a building that predominantly consists of two or more different materials." The reason for choosing this definition is because buildings consist of components such as doors, windows, walls, floors etc. that are connected to each other. These components in their turn are predominantly comprised of more than one material. A door, for example, can be made out of wood mainly but is likely to have a metal handle as well. But a copper pipe that is used for plumbing basically is a component made out of one material. In urban mining, there is no clear distinction between recovering pure materials from buildings or recovering components that consist of more than one material.

## 1.3 Closing the gap

This paper addresses the relation between urban mining and component reuse, as it seems as if these two processes are treated as separated and independent. Furthermore, the question of how the process of urban mining can play a role in closing the gap between the availability and application of used building components and how it can stimulate this will be discussed. Therefore, the following research question has been formulated: *"How can the process of urban mining enhance the reuse of building components?"* This paper is intended to inform architects, designers, builders and all engaging in reusing materials on the current state of the art.

## 1.4 Methods

The research comprises of three parts: the phenomenon of urban mining, the reuse of building components and the relation between these two subjects. Several types of research have been conducted, including literature review, conducting interviews and case study analysis. An additional source of information has been important. Together with fellow students, research was conducted prior to this one, as part of a visiting professorship at the Faculty of Architecture and the Built Environment of the TU Delft. The research focusses on the potential for urban upcycling in Amstel 3 and has been translated into a booklet called Upcycle Amstel. Amstel 3 is an area in the South-West of Amsterdam and will undergo a large-scale transition in the next 20 years, with an emphasis on the circular economy. A large part of the currently vacant office buildings will be transformed into apartment buildings or will be demolished. The booklet addresses the possibilities for a circular transformation of these buildings, with a focus on material upcycling. Although the booklet does not specifically focus on urban mining, this subject has been very important in creating the base for the rest of its content. It has also formed the starting point for this research paper. Therefore, quite some information discussed in this paper has been derived from the booklet. The stakeholder interviews that were conducted for the booklet, in particular, have provided valuable insights for the chapters on urban mining in this research paper.

1. Literature review

By means of a literature review, the current state of the art on urban mining and the reuse of components will be explained. What is urban mining? How did it start? What are challenges and opportunities when engaging in urban mining? What types of building components are suitable for urban mining and reuse purposes?

2. Interviews

To find out who is actually engaging in urban mining, stakeholder interviews have been conducted. Who are these stakeholders and what drives them? How do they engage in urban mining? Architects, builders, demolition companies, developers, consultants, and researchers have been interviewed to gather knowledge on the different perspectives and create an overview of how these stakeholders are connected.

3. Case study analysis

Lastly, case study research on existing architectural projects was conducted to find out more about the connection between urban mining and the reuse of components. What types of components are commonly reused in building projects and why?

# 2. URBAN MINING

It is clear that the transition towards a circular economy has an impact on the built environment. With the attention moving from limited and fixed stocks of raw materials to the increasing anthropogenic stocks, the base for the concept of urban mining has been created (Stallone, 2011; Bonifazi & Cossu, 2013). Urban mining originally focused on electrical and electronic waste (WEEE), because the concentrations of elements coming from natural ores in anthropogenic stocks are often comparable or even higher than in natural stocks (Cossu & William, 2015). Aside from the fact that these elements are depleting, they are also depleting rather rapidly. Figure 1 (appendix) graphically shows how long it will take before metals and other raw materials, such as gas, oil, and coal, will be depleted. For some of these materials, this will be before the end of the century. Although it should be noted that this is a projection of a worst-case scenario, it clearly shows that we are in fact running out of raw materials and fossil fuels and something needs to be done.

As explained before, the construction industry in the Netherlands is estimated to account for the use of 50% of these raw materials (MIE and MEA, 2016), including, but not limited to, wood, iron, sand and other minerals needed to make concrete for example. Therefore, we cannot only look at metals and rare elements when talking about urban mining as we used to. The concept of urban mining needs to be applied to the built environment as well. In this paper, the definition of urban mining as defined by Cossu & Williams will be adopted, although slightly amended. It reads as follows: [Urban mining is] "the process of reclaiming components from any kind of anthropogenic stocks, including buildings, infrastructure, industries, and products (in and out of use)" (2015).

The process of urban mining can be divided into three different phases, which are all related to and dependent on each other. The first phase is the phase of inventorying, the second phase is the phase of harvesting and the last phase is the phase of distributing.

## 2.1 Inventorying

Inventories are made to determine the availability and reusability of components in buildings. Making in an inventory means getting an overview of the number of components that can be harvested from a certain building, what their quality and value is, and how they are connected for example. There are two known methods. The first method focusses on creating estimations of material quantities based on key figures and formulas. Depending on the parameters, the quantities of the different types of materials can be determined. This method can be applied fairly easy if the right information is available (Dekker et al., 2018). In reality, however, this information is often lacking (Wu et al., 2014). Knowing the precise context of a building component and how it is assembled for example is significant for determining the ease of extraction and whether it can be reused. An important factor to keep in mind is the fact that buildings tend to be maintained for quite long periods and are frequently adapted. This may cause their original structure and composition to be changed. Extensive research is therefore needed to find out what resources one might find in a building (Koutamanis et al., 2018).

The second method is more precise and hands-on. It requires a thorough inspection of the building, including measuring, counting and evaluating the components that might prove interesting for reuse purposes. In addition, knowledge of building materials, component assembly, and construction techniques is required. Gathering this information is often difficult, making this method more labor-intensive and time-consuming (Dekker et al., 2018).

There is not a specific job title (yet) for those who engage in making inventories, but stakeholders from different fields of work are involved. We can divide the different stakeholders based on the two methods of making an inventory. Consultancy and research firms are sometimes hired by municipalities and other governmental institutions to estimate material inventories for an entire area. Therefore, they prefer the first method. In some cases, this involves creating timelines of what projects will take place during a certain period in a certain region. These construction projects, transformation projects, and demolition projects are then all connected to see if matches in supply and demand can be made. (Dekker et al., 2018).

The second group mainly consists of architects, designers, demolition companies and so-called material scouts (Hinte et al., 2007). These stakeholders prefer the on-site method, mainly because they are looking for specific materials or building components. For these stakeholders, it is important to know in what state the building components are, how they are assembled and connected to other components, what their measurements are, and in what quantities they are available. These stakeholders are interested in reusing the components for construction projects or simply in selling them after they have been recovered (Dekker et al., 2018).

## 2.2 Harvesting

Harvesting involves the recovering of components from buildings and typically starts after the inventory has been made. Instead of demolishing a building entirely, the reusable components are (carefully) removed and separated. Recovering these components requires knowledge on the assembly and disassembly of components. Harvesting the materials can be done in different ways. Some harvesting jobs require heavy machinery, but others can be done by hand with tools. Building components like windows, doors, cabinets, installations, ducts, furniture, cables, and lighting etc. can be harvested by people without the need for heavy machinery. However, if heavy (structural) elements need to be recovered, machines are necessary for lifting, turning and placing. In this case, professional companies such as demolition companies are often hired to do the job (Dekker et al., 2018).

In the Netherlands, 90% of the total construction and demolition waste is concrete, brick or asphalt. The remaining 10% contains plastics, wood, and metals (Vereniging Afvalbedrijven, 2015). When translating this to building component level, this 90% would presumably consist of concrete from columns, walls, floors, and other structural elements, as well as brick from facades and asphalt from roofs and roads for example. The components that are usually subject to harvesting, such as windows, doors, flooring, walls, ceilings, façade cladding, plumbing fixtures, wiring etc. (Dekker et al., 2018) together, would count for the resting 10% waste.

Stakeholders that are involved in harvesting are demolition companies mostly. An increasing amount of demolition companies has started to take this role of disassembling instead of demolition more seriously, mainly because of financial benefits (Dekker et al., 2018. In some situations, it turned out that harvesting a building was financially more interesting than demolishing a building after calculating what the value of the harvested components would be (Rau & Oberhuber, 2016).

## 2.3 Distributing

Bringing the harvested components to their destination is a logistical process. In some cases, the components might be needed on a construction site on short notice. In other cases, they might not have a place to go yet. In both situations, a temporary storage place is usually required. There are three ways to handle the distribution of a harvest: the first option is to bring the harvested components to a storage place. This can be a location nearby the harvest location or nearby the location where they are known to be reused, but it can also be somewhere else. Bringing the harvest directly to the site where they will be reused is usually preferable because reducing the need for transportation additionally saves on $CO_2$-emissions and costs. However, this is not always possible (Dekker et. al., 2018).

The second option is to distribute the harvested components to a manufacturer who will re-sell them. A window manufacturer, for example, buys the harvested windows, takes out the glass, repairs or refurbishes the frames and sells them again. In some cases, this can be done easily, resulting in an almost new product. These manufacturers usually have existing distribution networks for their new products, so it is fairly easy for these stakeholders to integrate the harvested components into these systems. Because this can save a lot of costs, it seems an interesting option (Dekker et al., 2018).

If the harvested components do not have a destination at the time of harvesting, the last option is to send them off to marketplaces where they can be stored until sold to anyone interested. Usually, demolition companies that have started to engage in urban mining are doing this (Dekker et al., 2018). At these (online) marketplaces, harvests are made available through collaborations between these demolition companies (Insert, 2018). The distribution of components coming from these marketplaces is sometimes arranged by the demolition company that has taken on the harvest job, by hired transportation services or by the clients themselves (Dekker et al., 2018).

# 3. Reuse

The main reason why we are reusing materials and goods is to reduce our society's impact on the environment (Berge, 2001). The Ellen Macarthur Foundation defines reuse as "the use of a product again for the same purpose in its original form or with little enhancement or change" (2013). However, according to Addis, it is possible to distinguish different forms of reuse: reuse of a whole building or some of its parts in its same location; the reuse of components that have been removed from one building and are then refurbished or reconditioned for use in a different building; the use of recycled materials, for example, in what are known as recycled-content building products (2006). This paper considers the term 'reuse' as a general term that entails various forms of reusing a building component. To give an example: a building component can be reused one to one, as the Ellen Macarthur Foundation describes it. However, a building component can also be reused after a slight modification has been made. This is called refurbishing. Although the component is not exactly the same way it was before, a part of it is still being reused.

In discussions on what is actually a good form of reuse from an environmental perspective, many different terms are often used, including, but not limited to, prolonging, upcycling, recycling, downcycling, refurbishing, remanufacturing, reconditioning and cascading. What distinguishes these terms? What is good? Or are they all examples of a 'less bad' approach (Luscuere, 2018)? To prevent any misunderstanding in this paper, the meaning of these terms will be defined.

## 3.1 Definitions

The definitions used in this paper are predominantly coming from the Ellen Macarthur Foundation. The reason for this is that their ideas concerning the circular economy have been adopted and copied by many institutions and researchers globally. It is important to note that the circular economy is not only about circularizing material streams. Therefore, we should not limit our approach to materials only. Circularity of energy, water, and air should be considered as well (Luscuere, 2018). However, since we are only addressing the component and material cycles in this research, we will limit our definitions to those as defined by the Ellen Macarthur Foundation. It should be noted that this list, although presented by the Ellen Macarthur Foundation, is not a direct translation of their well-known butterfly scheme (figure 2).

1. Prolonging

Before removing a building, a component or even a material, the possibility of prolonging its life should be considered first. In the case of components, they should be kept in use for as long as possible (Ellen Macarthur Foundation, 2013). Maintaining the materials and building components is a way to achieve this.

2. Upcycling

Upcycling is "the process of converting materials into new materials of higher quality and increased functionality" (Ellen Macarthur Foundation, 2013). An example of this is the growth of algae out of $CO_2$ and using them for the production of new materials (Dekker et al., 2018), where $CO_2$ should not be seen as a climate change propelling waste product, as people tend to see it (Luscuere et. al., 2018), but as a resource.

3. Recycling

Recycling is "the process of recovering materials for the original purpose or for other purposes, excluding energy recovery" (Ellen Macarthur Foundation, 2013). Using steel scrap to produce new steel is an example of recycling (Dorsthorst et al., 2000).

4. Downcycling

Downcycling is "the process of converting materials into new materials of lesser quality and reduced functionality" (Ellen Macarthur Foundation, 2013). Shredding used jeans to make insulation out of it is an example of downcycling (Dekker et al., 2018).

5. Refurbishing

Refurbishing is "the process of returning a product to good working condition by replacing or repairing major components that are faulty or close to failure and making 'cosmetic' changes to update the appearance of a product, such as cleaning, changing the fabric, painting or refinishing" (Ellen Macarthur Foundation, 2013).

6. Remanufacturing

Remanufacturing is "the process of disassembly and recovery at the subassembly or component level. Functioning, reusable parts are taken out of a used product and rebuilt into a new one. This process includes quality assurance and potential enhancements or changes to the components" (Ellen Macarthur Foundation, 2013).

7. Cascading

Cascading is "putting materials and components into different uses after end-of-life across different value streams and extracting, over time, stored energy and material 'coherence'. Along the cascade, this material order declines" (Ellen Macarthur Foundation, 2013).

## 3.2 Good or less bad?

Now that we have an overview of the different options on how to reuse harvested building components, we can evaluate them on their environmental impact. In other words: what is good and what is less bad?

According to the technical cycles proposed by the Ellen Macarthur Foundation in figure 2 (appendix), the preferred first step in handling products, such as materials or components, is to maintain them and therewith prolong their lifecycle. If maintaining is not possible, reuse one on one is the next best option. After reuse comes refurbish or remanufacture and if that is also not possible, recycling is the last option (2013).

Brewer and Mooney have created a comparable hierarchy, see figure 3 (appendix). Theirs, however, is more directly focused on the building, whereas the first step would be to relocate the whole building. If that is not possible, the components should be reused. After that follows the reprocessing of materials and the last step would be to recycle the materials coming from the components (2008).

The Delft Ladder, see figure 4 (appendix), is a 10-step hierarchy developed by Dorsthorst et al., that also starts at building scale instead of product scale. Their first step is to prevent a building from becoming unused. If that is not possible, renovation might be needed to make the building usable again. Next in line is element reuse. This requires the building to be dismantled into elements and components. After element reuse comes material reuse, which entails recycling, upcycling and downcycling. The last steps are to incinerate the materials for energy recovery and landfilling (2000).

Comparing the different approaches clarifies that (after prolonging) reusing buildings, components or materials one on one is often the preferred way to go. If this is not possible, other ways of processing are possible.

## 3.3 State of the art

By means of case study research, the current state of the art has been examined. The building projects, of which most were completed in recent years, have been analyzed predominantly on the types of building components that were reused and how they were reused. The outcomes have been combined and narrowed down to component groups. There are two projects that form an exception. These projects did not reuse used building components, but they designed the buildings so that they will be in the future. The so-called approach of design for disassembly.

1. Floors and walls:
    a. On two projects in Linkoping, concrete floors and walls were harvested from unused buildings, that had not been designed and built to be disassembled back in the day. Therefore, a lot of sawing and cutting was required to remove the components from each other. According to the contractors, there were no technical or structural difficulties in deconstructing and reassembling the elements. It also turned out that the environmental impact of the project was less due to reusing these elements, compared to using conventional materials and techniques (Addis, 2006).
    b. A project in Copenhagen reused cutouts from a brick wall. Because the bricks were glued to each other with mortar, they could not be separated without breaking the bricks. The decision was made to cut out square elements out of the brick wall and reuse the elements instead. The elements were connected to a concrete panel and used in a new facade (Lendager Group, 2018).
    c. Another project in Copenhagen created a test-building, based on the approach of design for disassembly. Special steel connections were developed to assemble and disassemble concrete walls and floors so that they could be taken apart easily when needed (Vandkunsten, Lendager Group and 3XN architects, 2018).

2. Beam and columns:
    a. On a project in South London, structural steel beams and columns were reused in a cost-neutral way. The steel was inspected thoroughly, sandblasted, coated with zinc and painted (Addis, 2006). Another project used steel profiles coming from an old factory nearby. The steel beams that were used for the structure of the new building, were extracted from an old textile machine (Superuse Studios, 2009).
    b. A recent project in Eindhoven involved a pavilion building. This project was also focused on design for disassembly, using only borrowed products. All building components used in the building would be returned to the original owner. This required special measures to assure that no component would be damaged at constructing and disassembling the building. All the wooden beams and columns where connected by means of tension straps (Bureau SLA, 2017).
3. Windows and doors:
    a. In a few examples window frames were reused one on one to create partition walls. In these cases, the design of the partition wall was influenced by the measurements of the frames. In some cases, the windows came from old buildings that were to be disassembled and demolished. The quality of the glass inside these frames was not high enough to meet energy efficiency requirements. Therefore, these window frames could not be used in the facades of the buildings in which they were reused (Superuse Studios; Circl, 2017). In other cases, plexiglass, that had been ordered mistakenly by a different client, was reused (Encore Hereux, 2015).
    b. In other cases, the glass was reused to serve as a second skin. This type of reuse required a new system to mount the glass panels on to the facade (Wessel van Geffen Architecten, 2017; Cepezed, 2018).
    c. Doors are fairly easy to reuse one on one. In a particular example, the doors were used as facade cladding on a pavilion building (Circular Pavilion). However, in another example, the reuse of doors was difficult and did not prove to be financially interesting. This was due to the size of the demand, that was too large to be taken from one building. Therefore, extra time went into searching for extra doors from other sources, leading to higher costs (Addis, 2006).
4. Insulation:
    a. Insulation types such as stone wool, EPS and PS can often be amended fairly easy to fit the dimensions required by their new use. Especially rigid forms of insulation make it easy to be cut into pieces with the desired measurements (Wessel van Geffen Architecten, 2017; Superuse Studios),
    b. In a specific case, old jeans were shredded into small pieces and used as ceiling insulation (Circl, 2017).

It should be noted that these examples of reuse are not the only possible ones. Other types of components can be (and are) reused as well, such as, for example, installations, lighting fixtures, and plumbing fixtures. However, they are not applied as frequently in reuse projects as the ones just described. In addition, the components used in this research can be found in almost any building. This research paper is simply too short to elaborate on all forms of component reuse.

# 4. INFLUENTIAL ASPECTS

Based on the same case studies, interviews and literature review, three influential aspects, that were frequently encountered during reuse projects, have been established. Being aware of these influences, either positive or negative, can be helpful in making decisions when engaging in reusing building components.

## 4.1 Reusability

In general, it is difficult to reuse buildings, components, and materials, because almost all buildings today have not been constructed and designed to be reused later. When these buildings are now demolished, the result is a mixed construction waste, which nowadays often ends up as road base layer. (Dorsthorst et al. 2000). Therefore, expertise is required to appraise the status of the building including its structure, the facade, and all other parts. This information is needed to decide if it is sensible to reuse any parts of the building (Addis, 2006). There are many more factors that influence the reusability of components, either directly or indirectly, such as, for example, transportation, value, usefulness after being removed and possibilities for refurbishment (Addis, 2006; Dekker et. al. 2018).

### 4.2 Availability and demand

Another challenge is getting the right information. It seems that there is no clear overview of what components are actually available and in what quantities. This makes it hard to find what one is looking for. If the particular component has been found, often only a little information is available on that component (Slager & Jansen, 2018). This has a great influence on the demand for used building components. It is expected that the demand should come from building owners, developers, clients, architects, designers and contractors (Addis, 2006).

### 4.3 Financial benefits vs environmental benefits

Although almost every building is dismantlable with current techniques, the question is if it will be economically profitable. Another question is if it reduces the impact on the environment, compared to using conventional techniques and methods (Dorsthorst et al. 2000). It should be taken into account that the ecological gain of reusing can be greater of materials where the production process has a large $CO_2$-emission (such as steel) than for materials based on renewable materials (such as sustainable wood). For this reason, for example, it can be ecologically justified to transport steel from a greater distance than wood (Dekker et. al. 2018). However, this does not mean that this is also the cheapest option.

## CONCLUSION

It has become clear that preventing buildings and building components from ending up at the landfill is important in the transition towards a circular economy. In terms of reuse, the general opinion on reusing seems to be, that one on one reuse is most preferable in terms of environmental impact. However, it is not guaranteed that this is always the fact. Many factors, such as the process of recovery, the transportation of the recovered building components and the handling thereof, should be considered when calculating the environmental benefits compared to conventional standards.

If the process of urban mining is to stimulate component reuse, special attention needs to go out to the phases of inventory, harvest, and distribution, whereby the information on buildings and their components acquired in the inventory phase is key. In addition, it must be clear to those who want to engage in reusing components what the possibilities are, what the consequences can be and what the challenges are.

The fact that many buildings have not been built to be disassembled, and therefore to be reused, is an important given as well. This makes it hard sometimes to recover building components. However, many forms of reuse are possible with the techniques available today. To make it easier for building components to be recovered and reused in the future, it should be considered when designing a building, that upgrades or adjustments might need to be made to that building in the future. Having a building that consists of easily removable building components will make this possible. This is called design for disassembly or design for reuse and is something that has started to gain more interest among architects and builders.

## DISCUSSION

Although intended at first, due to a lack of time this research did not include case studies on specific projects where the process of urban mining was implemented. Therefore, the information on the different urban mining phases provided by different stakeholders should be considered as indications of how these phases can look, rather than considering them as given facts. The information allowed for a relation to be established between urban mining and component reuse. It seems that, if we want to allow the process of urban mining to influence and stimulate the reuse of building components, information on these components is vital. To get a better idea of how the process of urban mining can be amended, more information is needed on, for example, the exact harvest methods, how this method influenced the component, how transportation was organized etc. It is clear that still a lot can be learned on this phenomenon.

For now, the challenge lies in finetuning the process of urban mining and in finding ways of creating coherent overviews on the availability of building components, where they are located, in what quantities, what their quality is and maybe even on how they could be reused. Perhaps some sort of catalog can be created, comprised of all different types of building components and how to reuse them. At least this would give designers and builders an idea of what to do with these components, as knowledge on component reuse is one of the obstructing problems right now.

There are companies that have started introducing material passports for building materials and components. These passports are given to all building materials and components that are used in new construction projects and contain the types of information as stated before. This is supposed to make it easier to locate and evaluate the materials when a building is up for demolition and therewith stimulate reuse. In combination with design principles such as design for disassembly and design for reuse, smart designs can be created that are prepared for future changes. Integrating these new design approaches with state of the art urban mining techniques, might create new interesting forms of architecture.

# REFERENCES


Addis, B. (2006). *Building with reclaimed components and materials. A design handbook for reuse and recycling.* London: Earthscan.

Baccini, P. & Brunner, P.H. (2012). *Metabolism of the Anthroposphere – Analysis, Evaluation, Design*. Cambridge: The MIT Press, Massachusetts Institute of Technology.

Berge, B. (2001). *The Ecology of Building Materials*. Oxford: Architectural Press

Bonnafazi, G. & Cossu, R. (2013). The urban mining concept. *Waste Management* 33, 497-498.

Brewer, G. & Mooney, J. (2008). A best practice policy for recycling and reuse in building. *Engineering Sustainability* 191, 173-180

Bureau SLA (2017). *Peoples Pavilion*. Retrieved from https://www.bureausla.nl/project/peoples-pavilion/ on December 16th 2018.

Cepezed (2018). *The Green House.* Retrieved from: https://www.cepezed.nl/projects/226-the-green-house on December 13th 2018.

Cheng et. al. (2018). Quantifying potential anthropogenic resources of buildings through hot spot analysis. *Resources, Conservation & Recycling* 133, 10-20.

Circl (2017). *The making of Circl*. (article that was published in September 2017 on the occasion of the opening of Circl).

Cossu, R., & Williams I. D. (2015). Urban mining: Concepts, terminology, challenges. *Waste Management* 45, 1-3.

Cushman & Wakefield (2017). *Kantorenleegstand daalt naar laagste niveau in 10 jaar.*

Dekker, E., Gao, Q., Lukkes, D., Markus, F. & Bohle, M. (2018). Upcycle Amstel. Delft: TU Delft Faculty of Architecture and the Built Environment.

Dorsthorst, B. J. H., Kowalczyk, T., Hendriks, C. F. & Kristinsson, J. (2000*) From grave to cradle: reincarnation of building materials* (From: Conference Proceedings of Sustainable Building 2000, Maastricht, Holland)

Eurostat (2016). *Waste statistics, statistics explained*.

Ellen Macarthur Foundation (2013). *Towards the circular economy. Economic and business rationale for an accelerated transition.*

Encore Hereux (2015) *Pavillion Circulaire*. Retrieved from http://encoreheureux.org/projets/pavillon-circulaire/?lang=en on December 14th 2018.

Geldermans, B. (2014). *A contextual and spatial approach towards resource cycles*. Delft University of Technology, Faculty of Architecture, Department of Architectural Engineering + Technology, Chair of Climate Design & Sustainability. (From: World Sustainable Building Conference 28-30 October 2014, Barcelona, Spain)

Heinrich, M. (2017). *Material flows of the German building sector.* (From: International HISER Conference on Advances in Recycling and Management of Construction and Demolition Waste 21-23 June 2017, Delft University of Technology, Delft, The Netherlands)

Hinte, E. van, Peeren, C. & Jongert, J. (2007). *Superuse - Constructing new architecture by shortcutting material flows.* Rotterdam: 010 Publishers.

Insert (2018) *Over Insert.* Retrieved from https://www.insert.nl/over-ons/ on December 16th 2018

Koutamanis, A., van Reijn, B. & van Bueren, E. (2018). Urban mining and buildings: A review of possibilities and limitations. *Resources, Conservation & Recycling* 138, 32-39.

Krook, J., Eklund, M., Carlsson, A., Frändegård P. & Svensson N. (2010). *Urban mining. Prospecting for metals in the invisible city*. Environmental Technology and Management at Linköping

University, Linköping and Environmental Strategies Research at KTH, Royal Institute of Technology, Stockholm.

Lendager Group (2018). *The Resource Rows*. Retrieved from https://lendager.com/en/architecture/resource-rows/ on December 14th 2018.

Luscuere, P.G. (2018). *Circularity.* (Introduction to Circularity with Beyond Sustainability as a contribution to AMS book, that has yet to be published).

Luscuere, P.G., Geldermans, R.J., Tenpierik, M.J. & Jansen, S.C. (2018). Beyond Sustainability in the built environment. *Rumoer* 62, 26-43.

Ministry of infrastructure and the environment and the ministry of economic affairs (2016). *A Circular Economy in the Netherlands by 2050*.

Rau, T & Oberhuber, S. (2016) *Material Matters – Het alternatief voor onze roofbouwmaatschappij.* Haarlem: Bertram + de Leeuw Uitgevers.

Romnée A., Billiet L., Mahieu O. & Vrijders J. (2017*). Deconstruction, preparation for reuse and reuse of salvaged materials on a pilot construction site in Brussels*. (From: International HISER Conference on Advances in Recycling and Management of Construction and Demolition Waste 21-23 June 2017, Delft University of Technology, Delft, The Netherlands)

Slager, B. & Jansen, G. (2018). *Onderzoek voorwaarden gebruik bouwmarktplaatsen*.

Stallone, R. (2011). *What is urban mining?* Retrieved from https://jessestallone.com/2011/04/20/what-is-urban-mining/ on December 17th 2018.

Superuse Studios (2009). *Villa* Welpeloo. Retrieved from http://superuse-studios.com/index.php/2009/10/villa-welpeloo/?lang=nl on December 14th 2018.

UN TEEB, US Geological Survey, BP & Worm et al (2006). *London Metal Exchange*.

Vandkunsten, Lendager Group & 3XN architects (2018). *Circle House - Denmark's first circular housing project.* Denmark: KLS PurePrint.

Vereniging Afvalbedrijven (2015). *Afval in cijfers.*

Wessel van Geffen Architecten (2017). *Afvalbrengstation Den Haag*. Retrieved from https://www.wesselvangeffenarchitecten.nl/blog/afvalbrengstation_lbr_gden_haa.html on December 13th 2018.

Wu, Z., Yu, A.T.W., Shen, L. & Liu, G. (2014). Quantifying construction and demolition waste: an analytical review. *Waste Management* 34 (9), 1683-1692.

## APPENDIX

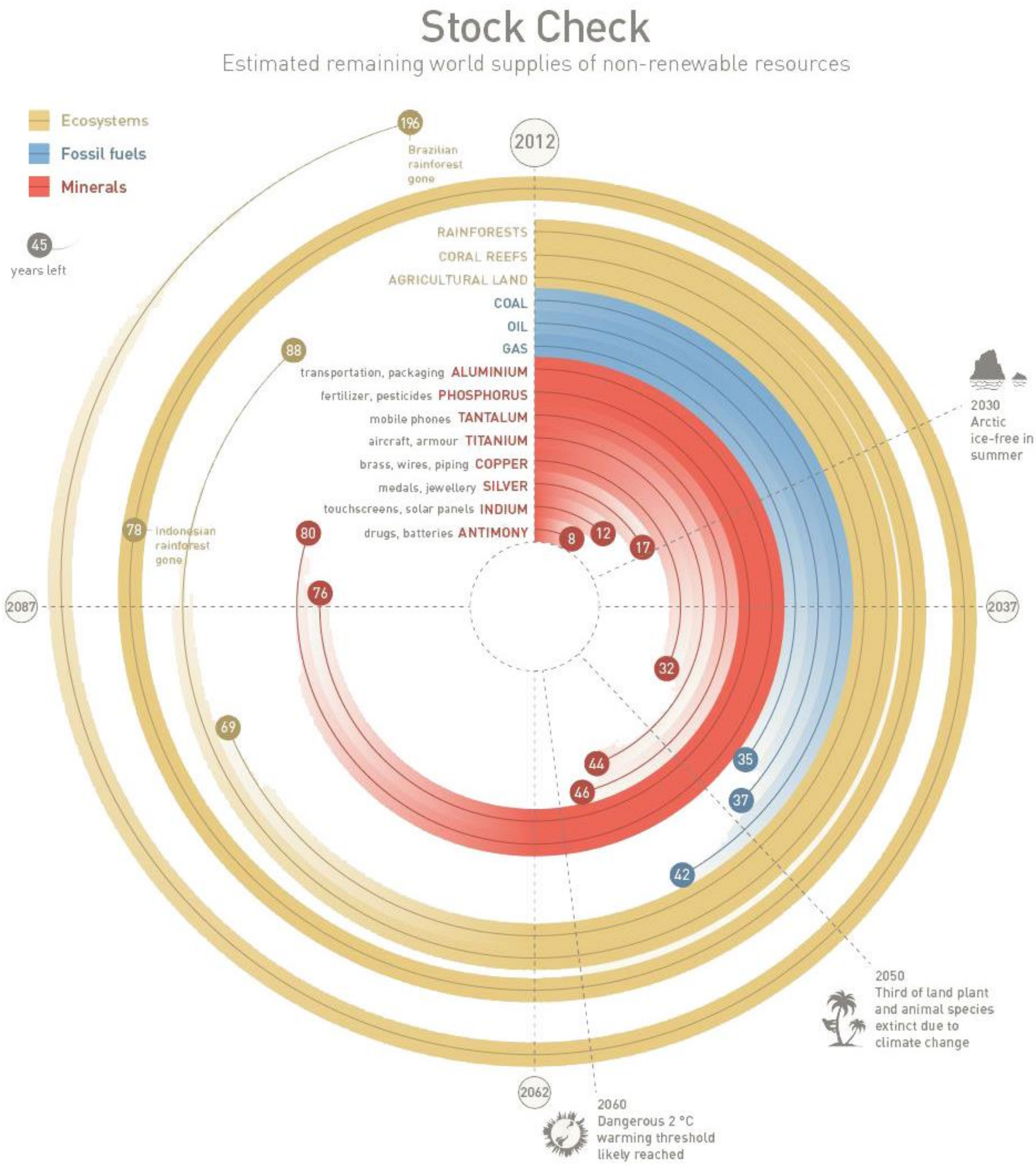


Figure 1. Stock Check. (Sources: UN TEEB, US Geological Survey, BP, Worm et al, 2006).

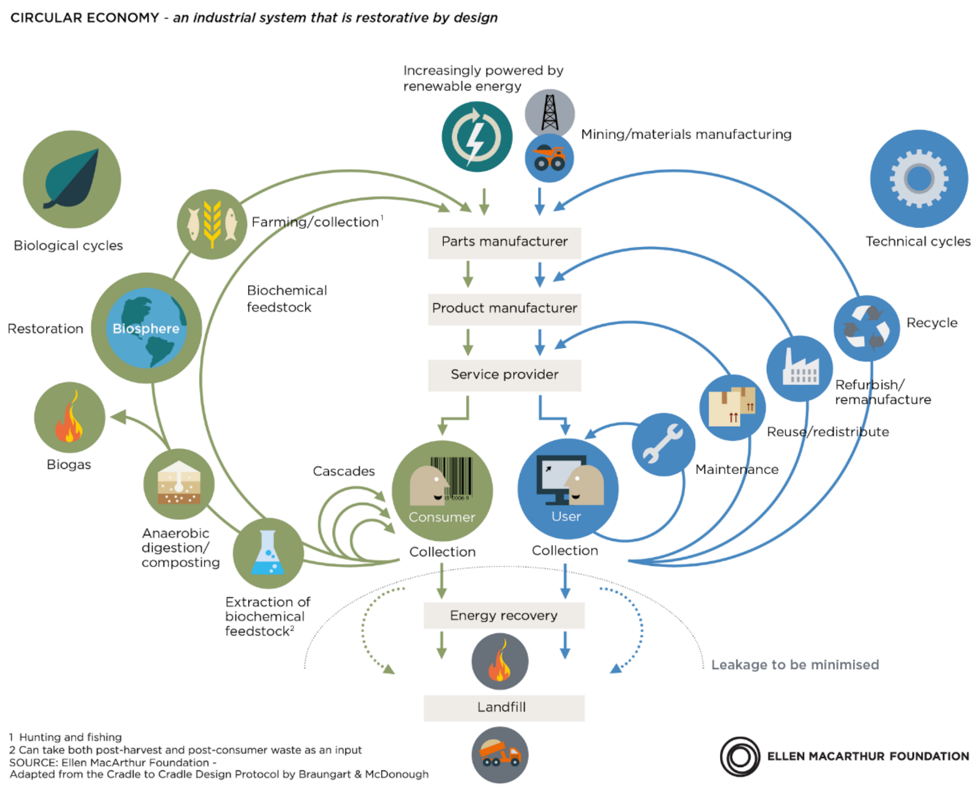


Figure 2. Butterfly scheme by the Ellen Macarthur Foundation (2013)

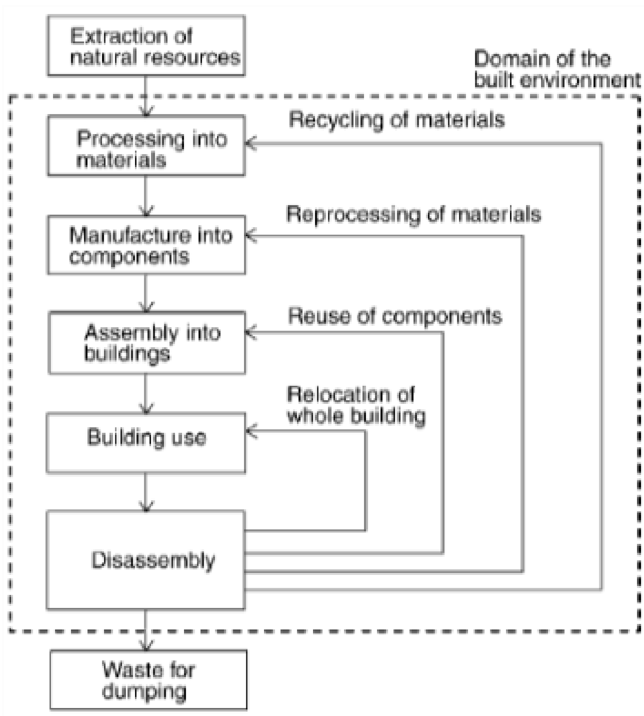


Figure 3. Lifecycle of materials using design for disassembly (Brewer and Mooney, 2008)

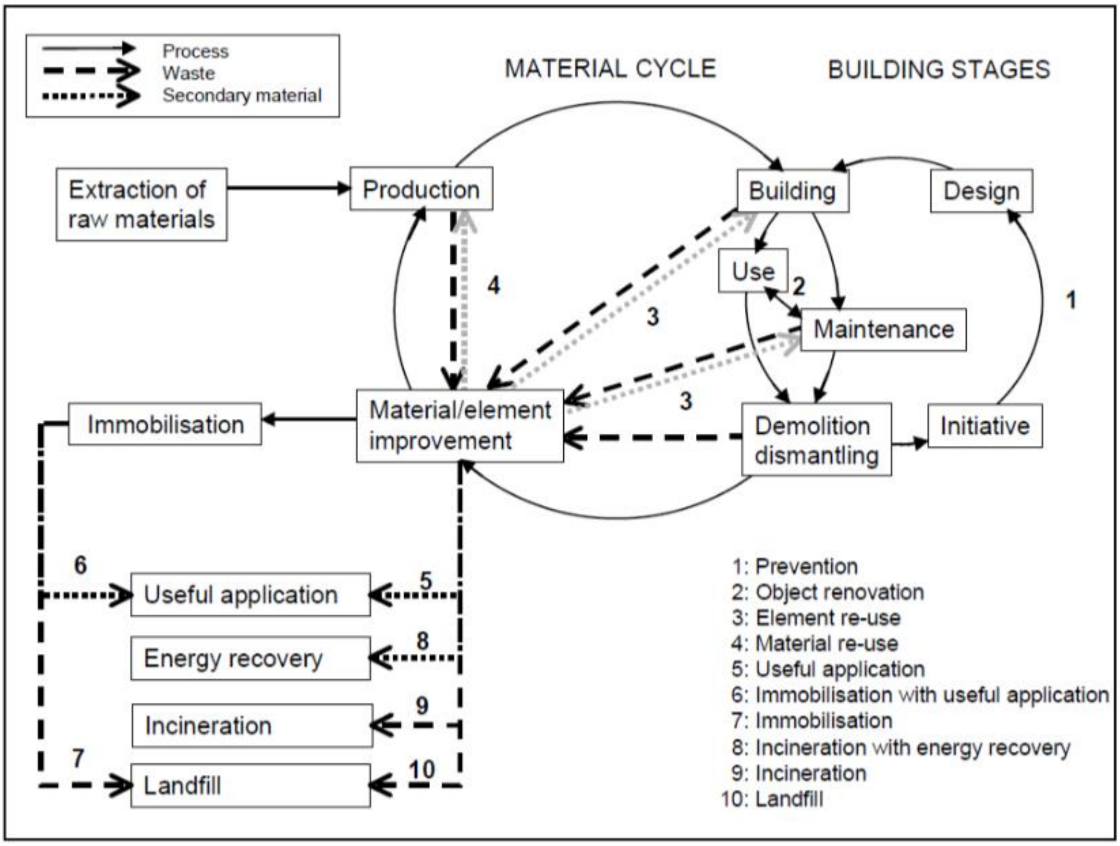


Figure 4. Integral chain management including the Delft Ladder (Dorsthorst et. al., 2000)