HOW TO DETERMINE THE VALUE OF RECLAIMED BUILDING COMPONENTS OF THE BOERHAAVEWIJK

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ABSTRACT

The building industry is one of the most resource-demanding and polluting industries in the world. Therefore there is a need to apply the circular economy principles within the industry enabling the transition towards a circular built environment. This transition requires the reuse of building components. However current practice shows that only components with high building quality or economic value are reused. Meanwhile, most buildings listed for demolition consist of low-quality and low economic valued building components. This is the case in post-war neighbourhoods resulting in a lot of construction and demolition waste. This paper investigates all factors that influence the value of building components in order to increase the rate of reuse. These factors are based on literature and summarized in a table of 23 factors. The post-war neighbourhood Boerhaavewijk in Haarlem serves as a case study to show how to determine the value of building components. The results show that post-war building components have value and reuse potential.

KEYWORDS: *Urban mining, component reuse, value of a building component, post-war neighbourhoods, reuse potential*

INTRODUCTION

The building industry is one of the most resource-intensive and waste-producing industries in the world (Bertino et al., 2021). More than 30% (Benachio et. al., 2020) of the 100 billion tonnes of natural resources that are extracted every year (UNEP, 2016) are used by the construction industry. Additionally, it produces 40% of the global CO_2 emissions and generates an estimated one-third of the world's overall waste (Bertino et al., 2021; Ellen MacArthur Foundation, 2013). In order to reduce natural resource consumption, CO_2 emissions and waste production, it's worth looking up the possibilities of a circular economy (Campbell-Johnston et al., 2020).

The Dutch Government has presented its plans for the transition to a circular economy in a policy programme, entitled 'Nederland circulair in 2050' (IenM & EZ, 2016). On a national and global scale, the building industry is considered one of the key sectors for the transition due to its global share of GDP and environmental impact (Osobajo et. al., 2020). 90% of the construction and demolition waste is generated during the demolition process. To reduce waste, one should look at the possibilities of reuse and deconstruction at the end-of-life phase of a building (Bertino et al., 2021; IenM & EZ, 2016). Currently, in North-West Europe, only 1% of all building components are reused for their original purpose. Whereas for most building components, it is technically possible to reuse them (Bougrain & Doutreleau, 2022).

In the Netherlands, one-third of the current housing stock was built between 1965 and 1986 (CBS, 2022b). In 2012, about half of the dwellings built between 1960-1980 had a bad energy label of E, F or G (CBS, 2012). Based on the latest energy label map of the Netherlands (RIVM, 2022), the majority of buildings in post-war neighbourhoods still do not meet the energy requirements. Recently, new plans have been published under which housing corporations and private tenants will no longer be allowed to rent out homes with an energy label lower than E from 2030 (De Jonge, 2022). These developments will have on one hand a positive impact: homes will be renovated at a higher pace but on the other hand it will, if nothing changes, create a large amount of construction and demolition waste from post-war neighbourhoods.

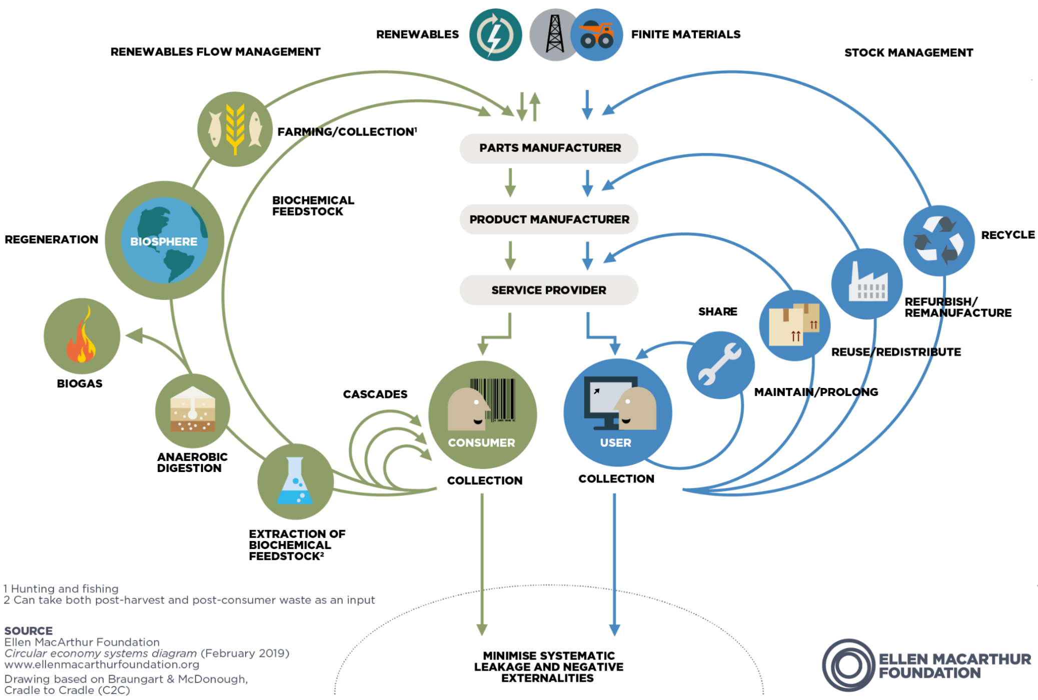
If business continues as usual, the neighbourhoods will be upgraded with a non-circular approach, resulting in a huge amount of demolition and construction waste. Most buildings listed for demolition consist of low-quality and low economic valued building components. The objective of this paper is to define all factors that influence the value of building components in order to increase their reuse rate. The post-war neighbourhood Boerhaavewijk in Haarlem is used as a case study to show how to define the value of, usually considered, low-value building components. A literature review is conducted to identify the factors, followed by the case study of Boerhaavewijk to validate how the factors can be used. The following section explains how the concept of reuse within a circular economy can help the transition towards a more circular built environment.

REUSE

The concept of reusing building components and recycling materials was common practice throughout the world until the industrial revolution in the 19th century (Addis, 2006). The economy used to be circular until it shifted to a linear economy: companies extracted natural resources to manufacture products, which were sold to consumers, who discarded the product when they no longer needed it (Ellen MacArthur Foundation, 2013). The principle of reusing got lost which led to the fact that the circularity of all materials today is only 8,6% (PACE, 2022). However, our planet's resource supply is not infinite and a linear economy has many harmful effects such as a higher amount of greenhouse gas emissions and waste. These effects force the world to move back to a circular economy.

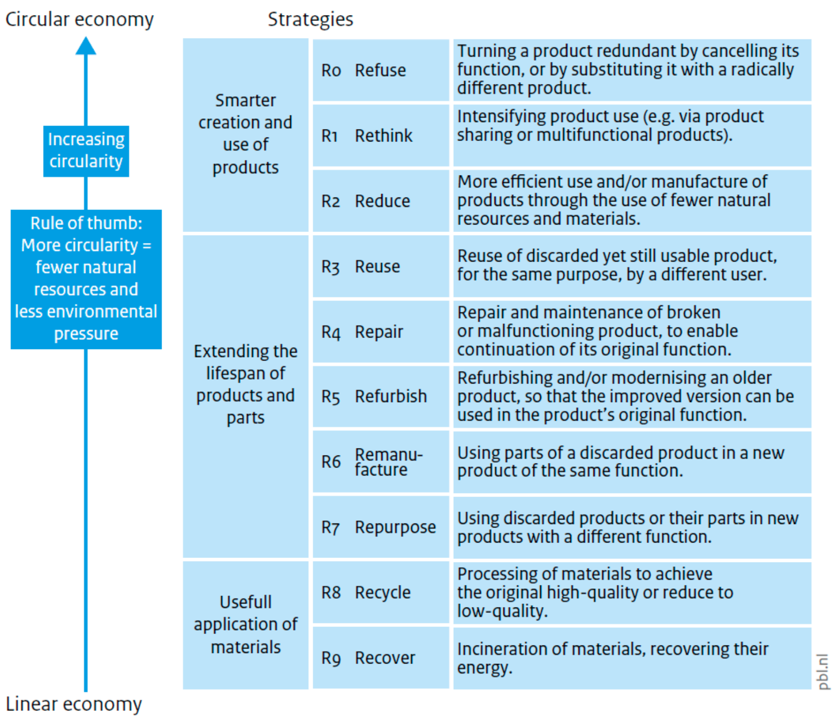
A circular economy is a proven business concept which is driven by value creation. The concept of a circular economy is based on multiple principles. One of these principles is to circulate products and materials at their highest value. First of all, by keeping the materials or product in use. If this is not possible, the components or raw materials should be reused. Nothing goes to waste, and the intrinsic value of products and materials is preserved (Ellen MacArthur Foundation, 2022a). There are several ways to keep products or materials in circulation, shown in the butterfly model (figure 1). Building components fit into the technical side of the butterfly model, so they can be reused, refurbished, remanufactured or recycled. The smaller the circle, the larger the savings of materials, labour, energy etc. (Ellen MacArthur Foundation, 2013).

Figure 1: Butterfly model (Ellen MacArthur Foundation, 2022).



After the publication of "Nederland circulair in 2050" in 2016, the Dutch government published a circularity strategy ladder (figure 2) that aims to reduce natural resource use in product chains. These so-called “R-strategies” are based on product *function* which makes it possible to use different or no products for the same function. For example, DVDs are replaced by streaming services, meaning fewer products are needed to provide the same function. This principle can also be applied in the building industry (Potting et al., 2018). The definition of reuse, repair, refurbish etc. used in this paper are based on this circularity ladder, however, some of these concepts are already shown in the butterfly model. An example of one of these strategies is recycling which prevents construction and demolition waste to end up in landfills but the process is energy intensive and emits a significant amount of greenhouse gasses (Rakhshan et. al., 2020) and is therefore in the 8th place on the ladder (figure 2).

Figure 2: Circularity strategy ladder (R-strategies) (Potting et al., 2018).



The circularity ladder talks about “products” in general while this paper focuses on building components. Next to this, a clear distinction is made between building components and materials. For example, a window is made out of multiple *materials* (glass, wood etc.) but these are combined into one *building component*. The distinction is made because reusing building *components* have a far lower environmental impact than recycling building *materials* (Addis, 2006). Building components have in many cases a higher value than building materials. Subsequently, to make the reuse of building components possible, buildings should be deconstructed instead of demolished. Bertino et al (2021) define deconstruction as the extraction of components (or materials) from buildings with the intention of future reuse. Deconstruction is part of the urban mining process, a concept that is elaborated in the following section.

URBAN MINING

Urban mining is seen as one of the solutions on a macro scale to move towards a more circular built environment (Verhagen et. al., 2021). According to Potting et al. (2018) and Metabolic (2021), urban mining is a process of recovering materials or resources from the built environment for recycling or reuse. The process of urban mining consists of five phases: negotiating, inventorying, harvesting (similar to deconstructing), distributing and documenting (GXN, TU Delft & City of Amsterdam, 2019). Current practice shows that urban mining is done at a national scale (e.g. Oogstkaart (New Horizon, 2022)) or in collaboration with neighbouring countries (e.g. Opalis (Opalis, 2022)). The larger the search area for harvested materials and components, the greater the variety of materials and components available, which makes the design process more flexible. However, the collecting process of materials and components on a large scale is more complex due to many different suppliers from different regions. A more complex data system is required to keep track of the information about the materials, which could be needed for potential future reuse. In addition, if these components are needed in distant locations, their transportation might cause an increased environmental footprint.

The concept of urban mining is, for example, applied on a project scale in a project called "SuperLocal" located in the City Region Parkstad in The Netherlands. The aim of the project was to reuse the materials and components of two vacant post-war high-rise flats in Kerkrade for the construction of circa 130 new dwellings and to set up a new public area all at the same site. One other flat at the site will be transformed and renovated (SuperLocal, 2021). This project shows the advantages and challenges of urban mining on a project scale. The components are harvested from only two flats and distributed within the project. Therefore less transport is needed and components can be stored near the project. However, the SuperLocal project pursued building the new dwellings only with materials from these flats, which narrowed the options of available materials. Another important aspect of the "SuperLocal" project was involving the community and embracing the rich history of the City Region Parkstad. By reusing the materials at the same site, the value of the materials and the new value created in the urban mining process are given back to the community (SuperLocal, 2021; SuperLocal, 2020).

POST-WAR HOUSING: THE CASE OF BOERHAAVEWIJK

After World War II many dwellings were rapidly constructed to address the housing shortage. To be able to provide light, spacious and affordable homes, different building systems (*dutch: systeembouw/bouwsystemen*) were developed. These building systems used new techniques and production methods such as prefabricated concrete building elements which made it possible to reduce construction site work to a minimum. In order to serve the needs of every "type" of resident, three typical typologies were built with building systems: gallery flats, portico flats and row housing (Versluis, 2015; BouwhulpGroep, 2013). Although the building systems were a great development from the 1950s until the 1980s, the majority of post-war "systeembouw" dwellings do not meet today's living standards due to poor insulation and built quality (Versluis, 2015).

Many post-war "systeembouw" dwellings are located in so-called post-war neighbourhoods (Atlas Leefomgeving, 2022). Housing corporations own the majority of dwellings in post-war neighbourhoods, shown in a map of the metropolitan area of Amsterdam (Gemeente Amsterdam, 2022). In addition, 60% of all dwellings that were demolished in 2013 were owned by housing corporations (CBS, 2015). This means that many dwellings in post-war neighbourhoods are demolished. Buildings in post-war neighbourhoods are in need of renovation or need to be demolished (RIVM, 2022). In these kinds of neighbourhoods urban mining on a neighbourhood scale could be a solution. The project "SuperLocal" has shown the possibilities (and success) of urban mining of post-war flats on a project scale.

Urban mining on a neighbourhood scale could minimise waste and offers the possibility of giving the value of the building components back to the community. In order to increase the reuse rate of currently "economically low-valued" components, one should look at all the different factors that influence the value of a component. Every component has value and there are many reasons to reuse it. Giving an overview of all factors that influence the value of components can help designers and other stakeholders in a reuse project to define the value of components and increase the reuse rate.

In this research paper, the Boerhaavewijk is the case study to explore the possibilities of urban mining on a neighbourhood scale. In the Boerhaavewijk live 7955 people (CBS, 2022a) and most dwellings were built between 1950 and 1970 (Atlas Leefomgeving, 2022). It is a typical post-war neighbourhood with "systeembouw" flats (appendix 1). Three housing corporations operate in the Boerhaavewijk; Pre Wonen, Elan Wonen and Ymere (Gemeente Amsterdam, 2022) (appendix 2).

The main question of this paper is: How and which factors influence the value of building components? The following chapter explains which factors influence the value and how the list was compiled. The next chapter shows how the factors influence the value of post-war building components in the Boerhaavewijk. It shows the reuse potential of post-war building components.

FACTORS THAT INFLUENCE THE VALUE

Many studies have been published about aspects affecting the reuse of building components (Rakhsan et. al., 2020). Some are more directed towards the current reuse process in the Netherlands (Icibaci, 2019), while others are more focused on the deconstruction potential of buildings (Bertino et al., 2021). A literature review is conducted to define a list of 23 factors that influence the value of building components. The literature review of Rakhshan et. al. (2020) is used as the main source because it reviewed 74 papers to show the barriers and drivers affecting the reuse of building components. These barriers and drivers gave an insight into why building components are reused or not. Rakshan et. al. (2020) divided the barriers and drivers into 6 domains, which will be used in this paper too, except for the regulatory domain. The factors derived from regulatory barriers or drivers are categorized into the social or organisational domain and in the last column categorisation into "society-related". This is done to show the importance of circumstances in component reuse. The difference between the paper of Rakhshan et. al. (2020) and this paper is that the 23 factors can be assigned to multiple domains, while the barriers or drivers were only assigned to 1 domain. For example, the labour-intensive factor. Deconstructing a labour-intensive component is related to the economic domain because more labour equals higher costs, the social domain because heavy labour is done by workers and the organisational domain due to the large number of workers needed at the site. The clarification of all factors can be found in table 1.

1) **Environmental**: waste, GHG emissions and toxic chemicals affecting the environment.
2) **Economic**: costs, insurance, cash flow, marketing, labour, market and demand.
3) **Technical**: technical aspects of components, deconstruction, design flexibility, resilience etc.
4) **Social**: health, aesthetics, willingness and trust, awareness etc.
5) **Organisational**: organisational aspect of a reuse project, storage capacity, skilled labour, etc.

Table 1: Factors that influence the value of components (references: appendix 6)

Domain	Environmental	Economic	Technical	Social	Organisational	Factors		Quantifiable	Category: Component	Category: Project	Category: Society
1	✓					Embodied energy in MJ/kg	The embodied energy is kept in the material and fewer new components need to be made (which costs energy). The less energy is needed for new components, the more valuable the reused component.	Quantitative	✓		
2	✓		✓			Performance	If a component has a good energy performance (e.g. high-quality insulation or double glass), structural performance or functional performance, the component is more valuable.	Quantitative & Qualitative	✓		
3	✓					Longevity in years	By extending the lifetime of a component, less waste ends up in a landfill. Virgin materials (kg and volume) and water is saved.	Quantitative	✓		
4	✓		✓			Demountability in minutes	If a component takes a lot of time to deconstruct there is more emission of GHGs since the heavy machinery and equipment need to operate for longer periods.	Quantitative	✓		
			✓				If a component is not DfD but with permanent joints, composite joints or hard-to-access joints, deconstruction is more challenging and components are more prone to be damaged.	Qualitative	✓		
		✓				in euros	Deconstruction takes more time than demolition, this influences the price of a component. The longer it takes to deconstruct a component the more money it costs.	Quantitative	✓		
5	✓		✓	✓		Health and Safety	During deconstruction or treating a component for reuse: there is a risk of encountering hazardous, banned or contaminating coatings (or asbestos).	Qualitative	✓		
6	✓	✓	✓		✓	Data transparency	The more detailed information about characteristics, details, certificates and drawings are available, the less over-dimensioning or technical research is needed.	Qualitative	✓	✓	✓
7	✓	✓	✓		✓	Transportability in euros and km	Fewer costs if it is easy to transport and no specialised transport is needed. And harvested near the site resulting in less GHG emissions and components are less prone to be damaged during transport.	Quantitative & Qualitative	✓	✓	

Table 1: Factors that influence the value of components

Domain	Environmental	Economic	Technical	Social	Organisational	Factors		Quantifiable	Category: Component	Category: Project	Category: Society
8		■			■	Insurance in euros	Chance of higher insurance costs. However, not always the case. Recommended to consult insurers early in the process to properly assess and validate with them the best risk mitigation strategy.	Quantitative & qualitative	▼	▼	▼
9		■	■		■	Design flexibility in euros	The design should be able to accommodate alternative dimensions due to the uncertainty of available components and a great variety of components. Design flexibility costs more and requires more skills.	Quantitative & Qualitative	▼	▼	
10		■	■			Resilience	If a component is less damaged during its previous function or post-deconstruction, it is more resilient, so more valuable.	Qualitative	▼		
11		■	■		■	Testing in euros	This is related to the quality of the component (performance test), the way the component is reused in the new project, and regulations from society.	Quantitative & Qualitative	▼	▼	▼
12		■		■	■	Labour intensive in minutes	Deconstructing a component is more labour-intensive than demolition. However, cleaning small components can be done in a sheltered workshop, creating value for society.	Quantitative & Qualitative	▼	▼	▼
13				■	■	Aesthetics	Stakeholders interpreted lower visual appearance as lower quality and some architects do not want to use old wood in visual places. However, sometimes reclaimed components are valued as more beautiful (heritage).	Qualitative	▼	▼	▼
14		■		■		Value for Money in euros	Due to the reuse of a reclaimed component, fewer new materials need to be purchased. Whether it's worth the money depends on the current market.	Quantitative & Qualitative	▼	▼	▼
15		■		■		Demand, Market & Availability in euros	If reclaimed components are cheaper than new ones or if there is scarcity, demand can increase resulting in the growth of the reuse market. Demand and availability determine the price and amount of components reused.	Quantitative & Qualitative		▼	▼
16				■		Willingness & Trust	Clients, contractors and designers should be willing to work with reclaimed components and have trust in the components.	Qualitative		▼	

Table 1: Factors that influence the value of components

Domain	Environmental	Economic	Technical	Social	Organisational	Factors		Quantifiable	Category: Component	Category: Project	Category: Society
17		X		X		Cost of marketing in euros	If components are not used within the same project, it costs money to sell the reclaimed components.	Quantitative		X	X
18	X			X		Society's environ. concerns	If society has more environmental concerns, stakeholders are more prone to reuse components and it receives more acceptance and understanding.	Qualitative			X
19		X		X	X	Skilled labour	The need for skilled workers to deconstruct difficult building components and the lack of skilled workers due to the low image of demolition workers. Skilled workers are more expensive.	Qualitative		X	X
20				X	X	Reliability	The construction sector is against reuse due to potential risks during the deconstruction or the reusing process. Working with skilled people and common reclaimed components minimises this risk.	Qualitative	X	X	X
21				X	X	Awareness	Awareness of the full benefits of reuse among the stakeholders: from a social perspective, positive perception and willingness of all stakeholders. Informality and good relationships among the stakeholders are reported to help reuse.	Qualitative		X	X
22		X			X	Capacity to be stored in m^2	Storage space needs to be available including space for proper separation of the components. The storage of components costs money. Smaller (size/weight) components are cheaper.	Quantitative & Qualitative	X	X	X
23		X			X	Time & cash flow problems in time & euros	It is more complicated to plan when reclaimed components are available influencing the planning and cash flow. Buying components far before they are needed, this problem is reduced when components are reused within the same project.	Quantitative & Qualitative		X	

The factors are not evenly distributed across the domains, more than half of the factors are related to the economic domain, while only 7 factors are related to the environmental domain. Most economic factors are also related to society so they are often influenced by regulations and other circumstances.

The factors can be distinguished between quantitative and qualitative. In the first case, numerical evidence is possible while in the latter, evidence is provided through interviews, case study research and observations. This paper added another categorization to show how the circumstances play a role in the reuse of building components. All the factors influence the value of a component in different ways. The component-related factors are defined by the properties of a component within the building it is harvested from. The value of a component can also depend on the project where the reclaimed component is used (project-related). The last category consists of factors related to regulations and laws from the government and/or European Union or public opinion in general.

About half of the factors do not perfectly "fit" into one category. Some factors are both component-related and project-related. For example, the transportability of components is influenced by the properties of a component (weight, dimensions & fragility) and the distance between the donor building and the new building (project-related). The factor "capacity to be stored" is also related to the same properties and this factor is also project-related: the availability, size and quality of the storage place near the new building. The design flexibility also depends on various properties of a component but maybe even more on the architect, constructor and other people involved in the project, which makes it a project-related factor too.

Some factors are even related to all three categories because they are, for example, influenced by new regulations from the government or European Union (society-related) or the requirements of a client of a project (project-related). Data transparency is one of these examples. Suppose new laws require it to create a material passport for every component used in the building industry. In that case, data transparency of a component (component-related) will improve which is useful on a project scale. Aesthetics is also related to all three categories but not influenced by regulations. Aesthetics are first of all related to the component (condition, colour, etc). However, a designer can implement the reclaimed component in different ways (project-related), making the component perceived differently by society (society-related). In addition, reusing reclaimed components in a visual way increases awareness among local residents and the building's users. So the factor "awareness" can be influenced by the project itself and is related to general thoughts in society (society-related).

CASE STUDY: VALUE OF BUILDING COMPONENTS

To be able to determine the value of reclaimed building components of the Boerhaavewijk, it is first of all necessary to know which components are present in the neighbourhood. In order to make an estimate of the components present, one portico flat will be analysed which is representative of other blocks in the neighbourhood. A portico flat at the Edward Jennerstraat (appendix 4) is chosen as a case study for several reasons. Firstly, the flat is built with the building system "Rottinghuis" which is repeated at least 4 times to build identical building blocks next to the flat (Noord-Hollands Archief, n.d.) (appendix 1). All 5 building blocks (190 dwellings) are owned by housing corporation Ymere (appendix 2) (Gemeente Amsterdam, 2022) and do have bad energetic quality (RIVM, 2022) (appendix 3) and are therefore a great candidate for deconstruction.

The building components in the portico flat (Noord-Hollands Archief, n.d.) at the Edward Jennerstraat are divided into categories based on the paper of Bertino et al. (2021) (appendix 5). The components are first divided into two groups called "component type" (structural vs. non-structural) hereafter they are assigned to a building's part (foundation structure, elevation structures, building envelope, partitions, indoor finishing, and technical installations). Due to new regulations (De Jonge, 2022) it is expected that these portico flats don't meet the requirements anymore in 2030, resulting in a possibility to harvest the building component. If the housing corporation decides to renovate the flat, part of the component mentioned above will still become available. Garritzmann et al. (2015) published a report which stated that the following points are focus areas for renovation: entrance hall/facade; stairwell; installations; bathroom; interior finishing; facades; balconies; insulation in the roof, end wall, ground floor, first floor; asbestos.

There are 23 factors that influence the value of the many components in a portico flat. Due to the complexity and amount of factors and components, 4 components are used to show how the value analysis could be done. Reclaimed windows, concrete stairs, concrete slabs and toilets are evaluated. Based on the outcome of this analysis, a value determination is shown in table 2.

Tabel 2: Value analysis Edward Jennerstraat building components

Reclaimed building components x Factors	**Window**	**Concrete stairs**	**Prefab slab**	**Toilet**
Embodied energy (compared to new)	✓	✓	✓	✓
Performance	medium	good	medium	medium
Longevity (compared to new)	✓	✓	✓	✓
Demountability	hard	medium	really hard	easy
Health and Safety	bad	medium	medium	good
Data transparency	good	good	medium	good
Transportability	medium	hard	hard	easy
Cost of insurance	depends on new function			low
Design flexibility	require a lot of flexibility			less flexibility needed
Resilience	medium	good	medium	good
Cost of testing	high	high	high	medium
Labour intensiveness	high	high	high	medium
Aesthetics	depends on new function			Low
Value for money	depends on new function			Medium
Demand, market & availability	Medium	Medium	Low	High
Willingness & trust	Medium	Medium	Low	High
Cost of marketing	Medium	Medium	High	Low
Society's environmental concerns	n/a	n/a	n/a	n/a
Skilled labour	Yes	Yes	Yes	No

Reliability	Medium	Medium	Low	High
Awareness	n/a	n/a	n/a	n/a
Capacity to be stored	Low	High	High	Low
Time & cash flow problems	less problems due to urban mining on a neighbourhood scale			

There are multiple factors increasing the value of all reclaimed building components. First of all, if a component can be reused it saves embodied energy, the amount depending on whether 1:1 reuse is possible and the amount of embodied energy new components for the same function costs. Reusing components prevents it from ending up as waste and prolongs their lifetime. There are also factors increasing the value of components in this specific project. For example, the transportation costs are because the site is nearby due to mining on a neighbourhood scale. In this project, the reclaimed components can partly be used in visual places at the new building, increasing the awareness of the neighbourhood. The storage will be at the site, where there is enough space and the storage space can have a new function in the future. Finally, the data available about the components is good, there are many drawings and the building is built with a “bouwsysteem” (Rottinghuis).

The value of windows and prefabricated floors is mainly influenced by the factors mentioned above. This is because the individual properties of the components are not very good. Windows are hard to disassemble and it is labour intensive, in addition, they probably contain asbestos. However, this does not mean a window has no component-related value at all. The windows can serve a different function within the new building while making use of the value of glass. This is transparent and it can be used inside a building as a separation wall. By doing so, the bad performance of the glass does not negatively affect the component in its new function. The performance of the concrete stairs is good because it is suitable for the same function without many adjustments. Concrete is a resilient material and reusing it instead of making new concrete stairs has a great environmental impact. Reusing prefabricated slabs saves much energy compared to using new concrete slabs (Küpfer, Bastien-Masse, & Fivet, 2022). The performance of toilets is also good, however, they probably consume more water than a new toilet. Lastly, based on research conducted by van Nunen (1999) and own picture in appendix 9, it is technically possible to reuse concrete slabs and it saves up to 55% of the CO2 emissions.

DISCUSSION

There is a contradiction. The value of components is heavily influenced by economic factors. So, the fact that non-structural components are easier to harvest (Bertino et al., 2021) makes them more valuable in a sense. However, most of the construction waste is structural concrete. So in that case, environmental factors have a bigger influence.

The value of components is strongly related to the project or situation. For example, what degree of circularity is possible, the better the R-strategy the more value a component has. Next to that, integrating reuse from the start into the design process increases the amount of reused components and assigning a reclaimed components management coordinator helps with this. In addition, the client has a big impact on the contractor, if reuse is mentioned in the contractual requirements, the reuse rate will increase. It is proven that if there is good coordination between the owners of the demolition site and the new building, the reuse rate will improve (Rakhsan et. al., 2020). Connecting this to the case study of Boerhaavewijk, using buildings of housing corporations simplifies the coordination between the owner of the demolition site and the new building because the reclaimed materials from multiple dwellings are from one owner. In addition, the majority of dwellings were built with “systeembouw” in post-war neighbourhoods, this is technically useful due to the large amounts and repetition. Housing corporations renovate or demolish multiple dwellings at the same time, which makes it easier to reuse the components. There are bigger quantities, which increases the availability. Finally, the reuse potential based on the current market is shown in appendix 7.

CONCLUSION

The main objective of this paper is to define all factors that influence the value of building components in order to increase their reuse rate. More than half of the factors are related to the economic domain, showing that costs still play an important role in the value of reclaimed building components. Only 7 factors are directly connected to the environmental domain, however, depending on the client, they can still play a decisive role. The social and organisational circumstances influence the value of a component more than the technical aspects of a component. It can be stated that non-structural components have a higher value than structural components due to e.g. less risk, more availability, easier to deconstruct and less design flexibility is needed. If only looking at environmental factors, the impact of reusing structural components is much greater. It saves more energy and creates less waste, in fact, the largest part of a post-war flat consists of structural concrete.

This paper shows that most factors are heavily influenced by regulations and society's opinions. This raises hopes for the future. As awareness rises due to urban mining on a neighbourhood scale and regulations become stricter regarding the use of new materials, reuse will become more often the optimal choice in the future. If circumstances change, for example, a CO2 tax when buying new components, and new regulations that reduce labour costs of deconstruction, building component reuse will be more stimulated by the government.

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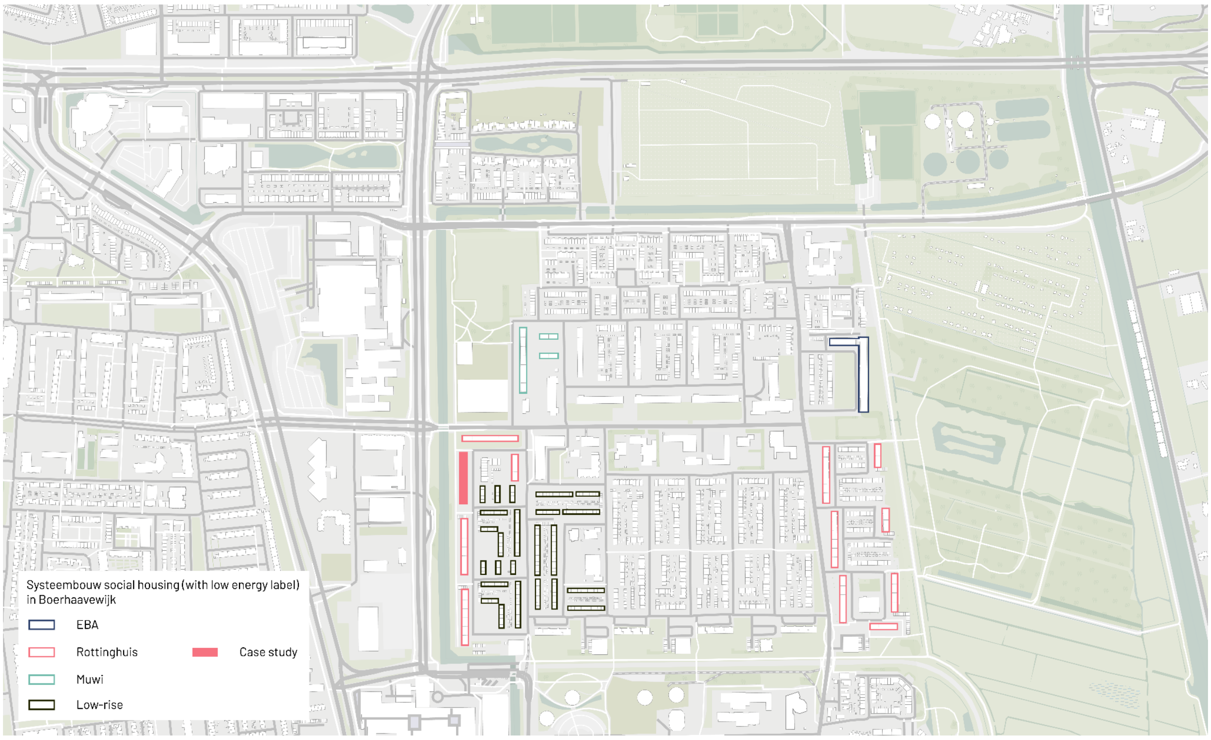
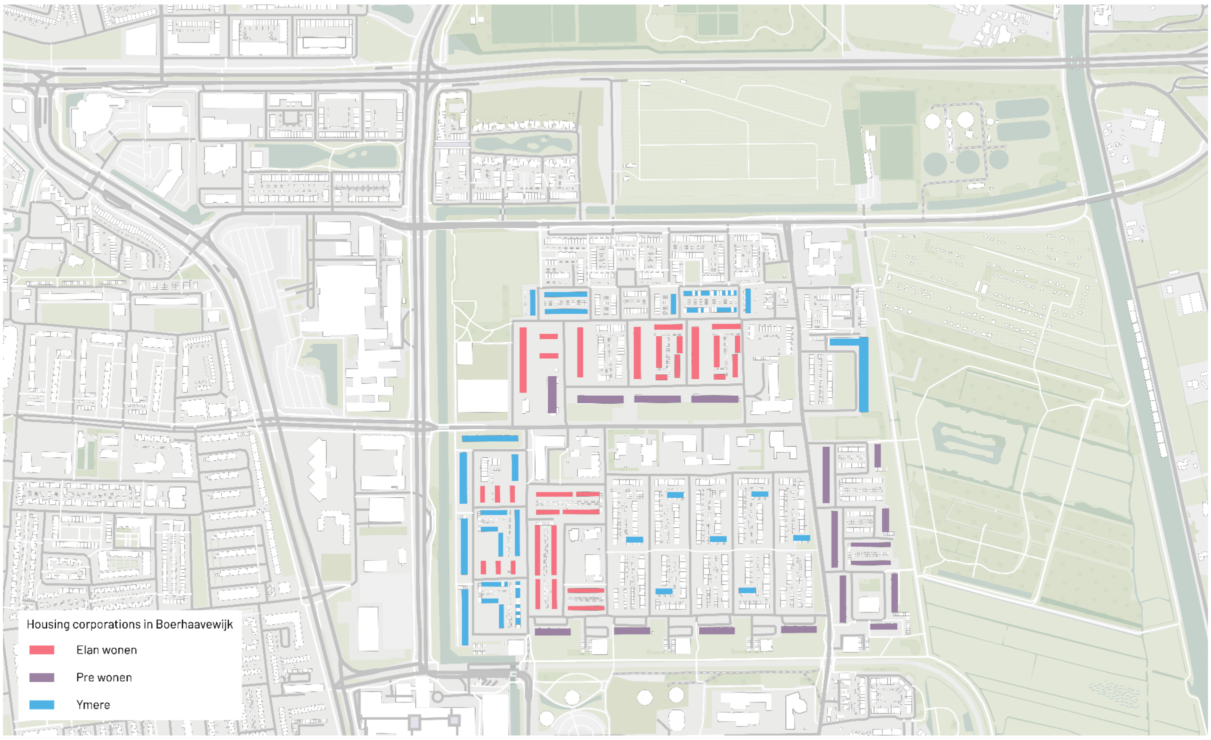
APPENDIX

Appendix 1



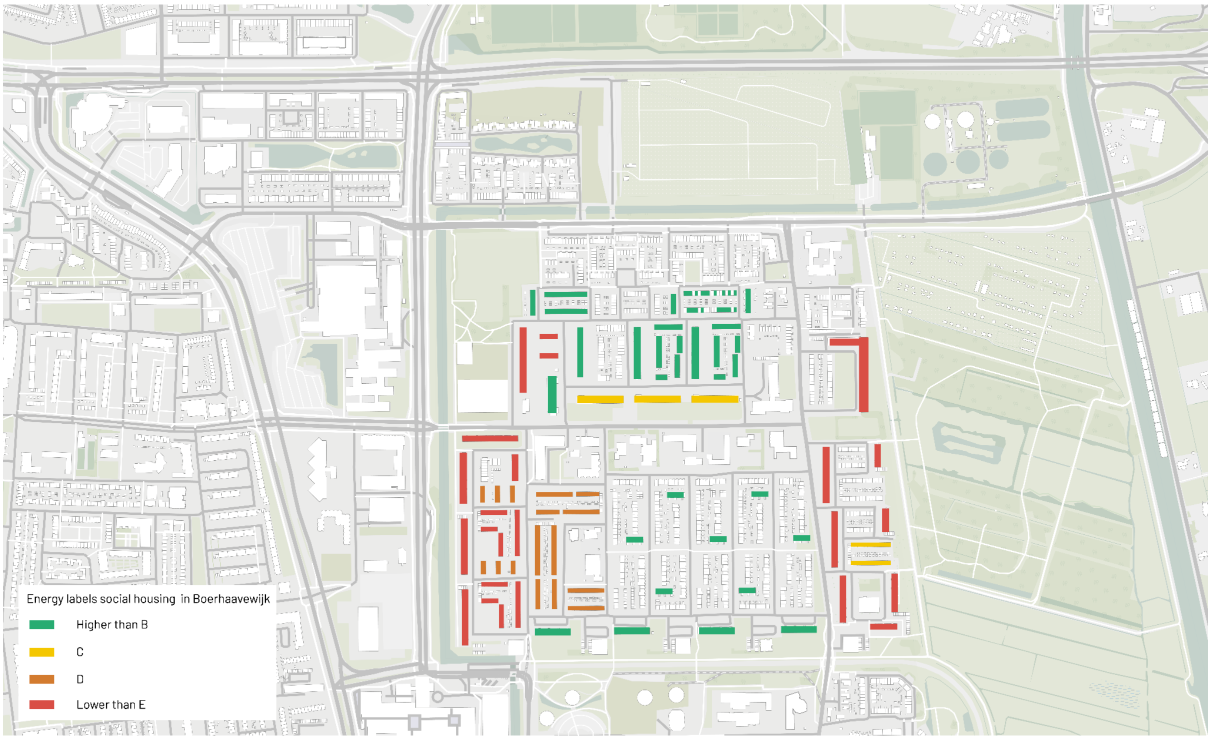
Systeembouw social housing with low energy label in Boerhaavewijk.

Appendix 2



Ownership of housing corporations in the Boerhaavewijk.

APPENDIX 3



Energy label of social housing in Boerhaavewijk.

Appendix 4

Flat 3 at the Edward Jennerstraat (own photo)

Interior photos of an apartment at the Edward Jennerstraat in flat 3 (sociale-huurwoning.com, 2021).

APPENDIX 5

Building components of Edward Jennerstraat flat 3.

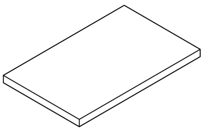
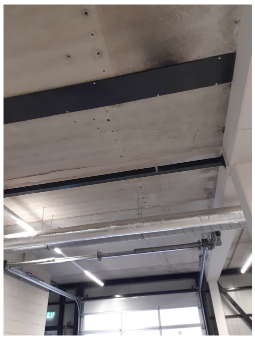
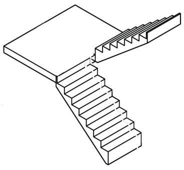
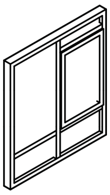
Component type	Building's part	Component	Amount
Structural components	Foundation structure	Foundation structure	n/a
	Elevation structures	Prefabricated slabs	+ 500 x (various sizes)
		Prefabricated walls	+ 250x Various sizes (h: 2600)
		Prefabricated balconies slabs	80x and slightly different sizes
		Bricks	260 m2
		Stairs	20x
Non-structural components	Building envelop	Bricks	mentioned above
		Roof	885 m2
		Insulation	
		Exterior doors	90x h: 2015/2115 mm Various widths
		Windows	268x (various sizes)
		Facade panels	Stone strip: 196x White panel: 48x
	Partitions	Interior doors	475x h: 2015/2115 mm Various widths
		Stairs railing	20x
		Balcony railing	80x (length: 3270 mm)
		Kitchens	40x
		Partition walls	various sizes
	Indoor finishing	Floors/walls	various sizes & materials
	Technical installations	Technical installations	
		Sanitary systems	40x toilets, 45x washbasins
		Thermal systems	320x radiators (new system in new buildings..)
		Electrical systems	
		Fire prevention systems	

Appendix 6

	Orginial sources in the Rakhshan et. al. (2020) paper								
Embodied energy	Brütting et al., 2019	Klang et al., 2003	Tingley et al., 2017	Yeung et al., 2017					
Energy performance	Rakhshan et al., 2020								
Longevity	Chau et al., 2012	Aye et al., 2012	Chinda and Ammarapala, 2016	Tingley et al., 2017	Yeung et al., 2017	Densley Tingley et al., 2012	Sára et al., 2001		
Demountability	Tatiya et al., 2017	Tingley et al., 2017	Huuhka et al., 2015	Ajayi et al., 2015	Chileshe et al., 2015, 2016b	Dunant et al., 2017	Huuhka and Hakanen, 2015	Gorgolewski, 2008	Pongiglione and Calderini, 2014
Health and Safety	Chileshe et al., 2015, 2016a	Huuhka and Hakanen, 2015	Sansom and Avery, 2014	Tingley et al., 2017	Yeung et al., 2015	Rameezdeen et al., 2016			
Data transparency	Gorgolewski, 2008	Gorgolewski et al., 2008	Pongiglione and Calderini (2014)						
Transportability	Pongiglione and Calderini, 2014	Rameezdeen et al., 2016	Gorgolewski et al., 2008	Yeung et al., 2015	Gorgolewski, 2008	Nußholz et al., 2019	Huuhka and Hakanen, 2015	Brambilla et al., 2019	da Rocha and Sattler, 2009
Insurance	Tingley et al., 2017								
Design flexibility	Gorgolewski, 2008	Gorgolewski et al., 2008	Huuhka and Hakanen, 2015						
Resilience	da Rocha and Sattler, 2009	Durão et al., 2014	Huuhka and Hakanen, 2015	Tatiya et al., 2017					
Testing	Dunant et al., 2018	Gorgolewski, 2008	Rameezdeen et al., 2016	Tingley et al., 2017	Yeung et al., 2015				

Labour intensive	Chileshe et al., 2015	Gorgolewski et al., 2008	Rameezdeen et al., 2016				
Esthetics	Durão et al. (2014)						
Value for money	Rakhshan et al., 2020						
Demand, Market & Availability	Chileshe et al., 2016b	Huuhka and Hakanen, 2015	Rogers, 2011	Shaurette, 2006	Tingley et al., 2017		
Willingness & Trust	Nußholz et al., 2019	Arif et al., 2012	Dunant et al., 2017, 2018	Gorgolewski, 2008	Gorgolewski et al., 2008	Sansom and Avery, 2014	Shaurette, 2006
Cost of marketing	Dantata et al., 2005						
Society's environ. Concerns	Chileshe et al., 2016a						
Skilled labour	Dantata et al., 2005	Elias Özkan, 2012	Shaurette, 2006				
Reliability	Rakhshan et al., 2020						
Awareness	MacKinnon, 2000						
Capacity to be stored	Chinda and Ammarapala, 2016	Dunant et al., 2017, 2018	Gorgolewski, 2008	Rose and Stegemann, 2018	Shaurette, 2006		
Time & cash flow problems	Chinda and Ammarapala, 2016	da Rocha and Sattler, 2009	Gorgolewski, 2008	Gorgolewski et al., 2008	Yeung et al., 2015		

Appendix 7

Component	Potential reuse	Real-life example
 **Prefabricated slabs**	- Recycle concrete; - Reuse 1:1; - Repurpose building blocks.	 *Repaired* prefabricated slabs, some parts needed extra support but overall it does work (own photo).
 **Stairs**	- 1:1 reuse (interior stairs stay interior); - exterior stairs have often more damage	 *Reused* stairs with little damage (own photo).
 **Doors and windows**	- Interior space dividers; - Double facade; - Atrium.	 *Repurposed* exterior windows for indoor separation of rooms.
Sanitary systems	- 1:1 reuse, but often not suitable anymore; - Repurpose for landscaping playground	 For sale: toilet for *reuse*, Hoofddorp, Saturnusstraat (New Horizon, 2022).