RESEARCH REPORT

‘Renovation with reclaimed materials as feasible alternative to reconstruction’

AR3AH105 Graduation Studio Adapting 20th Century Heritage

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Introduction

Problem statement, State of the Art, Aims & Objectives

Globally, the building industry accounted for 34% of energy demand and around 37% of energy and process-related CO_2 emissions in 2021 according to the '2022 Global Status Report for Buildings and Construction'. These numbers are only expected to go up following the current trajectory. This way the sector will fail to decarbonize by 2050 as agreed in the Paris agreements. *(UNEP - UN Environment Programme, 2022)* Of the 37% CO_2 emissions, 40% is accounted for by the production of building materials, the so-called embodied carbon. This means that 5.6 Gigatons of carbon is released in our atmosphere for the production of building materials every year. *(Architecture 2030, n.d.)*
Apart from the pollution that results from producing new building materials, there is another urgent reason to drastically lower the production rate: resource scarcity. Ever since 1970 we have been extracting more resources from the earth than it can regenerate and every year we extract even more than the year before. *(Earth Overshoot Day, 2023)* The building sector is also responsible for 35.9% of all solid waste in Europe. *(Weghmann & Public Service International Research Unit, 2023)* Drastically lowering the production rate of new building materials will make a positive impact on the building sectors' share of embodied carbon emissions, resource depletion and waste generation.

The largest proportion of houses in the residential sector was built before the existence of regulations around energy use. As a result, these buildings have little or no thermal insulation and heating and cooling them consumes huge amounts of energy. *(Decorte et al, 2022)* There is an overall need to renovate these buildings. A good example of such residential buildings in need of renewal are the post-war social housing projects built in the 1950s and 1960s. The most typical example of such housing can be found in the Amsterdam New West district, which was created in these years to the urban design of Cornelis van Eesteren under the well-known title General Extension Plan of Amsterdam. Despite the unmistakable heritage value of both the urban plan and the architectural appearance of the buildings, demolition and new construction are taking place on a large scale in Amsterdam New West. *(Eigen Haard, 2021), (Stadgenoot, 2022), (Rochdale, 2021), (De Alliantie, 2018)*. The main reason for this is the high energy consumption of the existing buildings. Replacing poorly insulated energy guzzlers with new energy-efficient buildings is well marketable as being 'sustainable development'. However, the consideration does not seem to include the environmental burden of building a new structure. Research indicates that renovating an existing structure for energy efficiency always results in a lower environmental impact compared to reconstruction. *(Assefa & Ambler, 2017; Alba-Rodríguez et al., 2017; De Larriva et al., 2014; Gaspar & Santos, 2015; Hasik et al., 2019; Marique & Rossi, 2018; Troyan et al., 2024)* Nevertheless, current and planned developments in Amsterdam New West indicate that renovation is rarely chosen as a strategy in a renewal assignment.

Renovating a building for energy efficiency requires adding building materials. If this material has to be produced new, this leads to greenhouse gas emissions and energy use. Reusing building materials is an available strategy to reduce such environmental burdens.

This research seeks to connect the preservation of built structures with the application of used building materials. Mainly because they are the same strategy at heart. Both are about re-use, refraining from demolition and disposal. Specifically, they are about minimizing carbon footprint in a current construction project. This is where preservation and applying used building materials differ from their overarching theme 'circularity'. A lot of circular building solutions focus on re-use in the future, like Design for Deconstruction (DFD) and spatial flexibility. A study on how such strategies can be implemented by housing corporations to renovate their stock circularly has been conducted by Anne van Stijn for the TU Delft in her dissertation 'Developing circular building components – between ideal and feasible' published in April 2023. This research formed the foundation for the handbook 'Woningcorporaties aan de slag met circulair renoveren', a toolbox on circular renovations for housing corporations. *(van Stijn, 2023)* Although these are very valid strategies, their positive ecological impact will only happen when the need for a new construction or function arises. They are still built with new material and still contributing to an ever growing ecological problem. Using less new material, so not only reassuring that material can be reused in the future, is also part of the ambitions by the municipality of Amsterdam. The report 'Amsterdam Circulair 2020-2025', clearly states the ambition to use 50% less new resources by 2025. *(City of Amsterdam, 2020)* This ambition in combination with the large amount of demolition and new construction in Amsterdam New West shows the difference between ambition and action. Vincent van der Meulen, architect and partner at Kraaijvanger Architects, addresses this call for action in his workbook 'Building with a positive footprint' published in November 2022. He states that buildings (in the current industry) always have a negative impact on our planet and the health of its users. Making buildings that make a positive impact, is not even complicated, Vincent states, as long as the whole industry works together. *(van der Meulen, 2022)* A beautiful idea, but practice shows that such an idealistic attitude is rarely capable of making a large scale impact. It calls for a more pragmatic approach. This research seeks to formulate a pragmatic valuation of renewal plans in dwelling. It will try to mediate between two forces. It will challenge the arguments by the established order by making a fair and complete estimate of the environmental burden of construction. On the other hand it will challenge the idealistic attitude of radical sustainability by weighing environmental impact against feasibility.

Research Questions

Main research question

“How can renovation with reclaimed materials become a feasible alternative to reconstruction of the current housing stock?”

Sub questions

“What are the interests of the stakeholders in a renewal task of existing housing?”

“What are the barriers to choosing renovation in a renewal task of existing housing?”

“What is the relative ecological impact of renovation versus newly built construction?”

“What is the relative ecological impact applying reclaimed materials in a renovation project?”

“What are the technical challenges for applying reclaimed materials in a renovation project?”

“What are the logistical challenges for applying reclaimed material in a renovation project?”

Methodology

Theoretical Framework
Loriane Icibaci, a researcher and architect for Superuse North America, published a book in 2019 called 'Reuse of building products in the Netherlands'. The research "positions the object of study from an evolutionary perspective where relations condition the action of reuse" where "relations are dynamic and contextually bounded defining the commercial feasibility of products to be reused rather than wasted". *(Icibaci, 2019)* For her research she describes the theoretical framework which is based on Industrial Ecology. Industrial Ecology is a scientific discipline that takes a systemic approach to sustainability problems. In basis it looks at industrial processes from a perspective of metabolism and ecology since it emulates the natural process of loops and interrelations. In other words, 'circularity' is natural; ecosystems operate in constant loops and are disrupted by linear activity. *(Kapur & Graedel, 2004)* How to mimic these natural loops in industrial processes in order to reduce waste, resource-use etcetera is the basis of Icibaci's research. This research operates in a similar framework. The feasibility of applying reused materials depends heavily on industrial ecology. This research will however leave this macro scale of systems. It will look more into the current state of practice and the graspable interventions needed to make an impact in the current building industry, one that is still very non-ecological, and will try to frame how a diffractive approach to the macro complexity of the industry's challenges can help shift towards a more ecology based system.

Research Methods
To gain insight on environmental consideration between renovation and reconstruction, a literature review has been conducted. To gain insight on environmental consideration between conventional renovation that uses new building material and a circular renovation alternative that uses as much reused materials as possible, a case study has been conducted. A renovation design by Superuse Studios for a 1930 dwelling complex in the Hague has been compared with a circular alternative that was designed for the purpose of this research. The design process forms an integral part of the research. The environmental burden triggered by the production of building materials needed to realize both proposals was then calculated and compared on total building level, per building element and per material type. Interviews were conducted in addition to the literature review and the quantitative data comparison to put the findings in perspective and to gain qualitative insight on practical challenges and barriers in the building industry in regards to sustainability and material reuse.

Literature review

Environmental impact comparison. Renovation versus demoliton and new construction.

To compare the environmental costs of demolition and new construction with renovation, literature was reviewed. There has been a growing interest in the environmental trade-off between new construction and renovation since the last decade. *(Decorte et al, 2022*). Most studies show that renovation has a lower environmental impact than new construction.
(Assefa & Ambler, 2017; Alba-Rodríguez et al., 2017; De Larriva et al., 2014; Gaspar & Santos, 2015; Hasik et al., 2019; Marique & Rossi, 2018; Troyan et al., 2024). Hasik et al. (2019) found a reduction in environmental impact of 53-75% when they compared a renovation proposal with a demolition and new construction proposal of an office building in Philadelphia. One of the six factors, Global Warming Potential (GWP) in kg CO_2-eq, showed a 75% reduction in favour of renovation. Alba-Rodriguez found similar figures, 58-68% reduction in environmental impact, when they compared a demolition and new construction and renovation scenario for an apartment complex in Spain. Environmental impact was measured using six subcategories and expressed in global hectares (gha) a unit for expressing ecological footprint. The construction material category showed a 69.3% reduction. Demolition and new construction counted 543,104 gha and renovation 166,76 gha *(Alba-Rodriguez et al, 2017)*. A study by Marique and Rossi (2018) on a Belgian office building resulted in a 43.7% GWP saving when comparing embodied carbon of the building material for renovation versus new construction. *(Marique and Rossi, 2018)*. Troyan et al (2023) investigated concrete prefabricated houses in Ukraine. New construction would result in 95-115 million tonnes of CO_2 and renovation about 45 million tonnes, representing a 53-61% reduction. *(Troyan et al., 2023)*.

Studies where renovation resulted in less savings also exist. For example, Gaspar and Santos (2015) investigated a detached single-family house in Portugal. Renovation yielded only a 17% impact reduction in this study *(Gaspar and Santos, 2015)* and a study by Assefa and Ambler (2017) on the renovation of a library yielded savings of 20-41%. *(Assefa and Ambler, 2017)*.

The percentages in savings are not entirely comparable. Studies express ecological impact in different units. Studies have also been approached using different factors. The studies that make comparisons based on CO_2 emissions, either in direct amounts of CO_2 or in amounts of CO_2 equivalent (GWP), range in reduction between renovation and new construction between 43% and 75% with the average percentage being 58%.

That results differ, according to Decorte et al (2023), is due to major differences in methodology. Existing guidelines do not provide guidance that allows a fair, robust and consistent comparison of renovation and reconstruction. *(Decorte et al, 2023)* Similarly, Fahlstedt et al (2022), who analysed 106 different publications around carbon reduction through renovation, drew the main conclusion that the lack of comparable outcomes is due to the lack of a unified system. *(Fahlstedt et al, 2022)*

Quantitative Comparative Research

Methodology

Research has been conducted on greenhouse gas emissions and energy use of buildings triggered by the production of its building material. Based on the literature reviewed, it can be said that renovating an existing building emits 43-75 % less greenhouse gases than when it is demolished and replaced by new construction. In the studies described by the literature reviewed, renovation was carried out with new building material. This study, instead of renovation versus demolition and new construction, compares two renovation proposals of the same complex. It compares a conventional renovation plan with new building material with a renovation plan that incorporates as many reused materials as possible. It examines how much greenhouse gas emissions and energy use the circular renovation plan saves, in terms of production of building materials, compared to the conventional renovation plan. The comparison is not between two full LCAs but is a comparison in production charges, which in an LCA fall under A1-A3 'product stage'.

The case study
A case study was chosen for the research. The case study concerns a renovation plan presented by architecture firm Superuse Studios in March 2023 for 'Complex 70' in The Hague. This is a residential complex from 1925 and forms part of a city plan designed by H.P Berlage. To save it from potential demolition, Superuse Studios designed the renovation plan. The analysis of this renovation proposal is described in 'The Case Study Complex 70'

The circular alternative
To compare this renovation plan with a circular alternative, this alternative first had to be designed. Designing in this sene means translating the renovation plan with new material into a design with reused material. How this circular alternative came about is described in 'The Circular Renovation Alternative'

The material inventory
To compare the greenhouse gas emissions and energy consumption of the required production of building materials of both renovation proposals, an inventory of building materials was needed. It was inventoried which building materials are added in both renovation proposals and how much. How this inventory was done and how the total quantities were calculated is described in 'The Material Inventory'

The environmental burden of building materials
This resulted in a listing of building materials in kilograms per renovation proposal. Using existing data on material properties and its production process, the amount of greenhouse gases (in kg CO_2-eq) and energy consumption (in Joules) caused by the production of the building materials of both renovation plans was then calculated. How the environmetal burden of building materials was determined is described in 'The Environmental Burden of Building Materials"

The retrieved data was then compared at total building level, per building material type and per building element.

Quantitative Comparative Research

Methodology: The Case Study ‘ Complex 70’

For the purpose of this study, all available material concerning Complex 70 was released in collaboration with Superuse Studios. The material includes: archive drawings, external reports, a cost estimate and construction drawings of the renovation plan. Complex 70 consists of 390 homes. Superuse Studios’ design drawings describe one link in the complex. In this link are two types of houses ’A’ and ’B’, which have 66 m² and 49 m² of living space, respectively. The link has three floors. Types A and B are located on each floor. The described link is representative of 80% of the entire complex. For this study, a representation of 100% is taken into account so that the analysis of the available information can be used to calculate the whole complex. By analysing the design drawings, the materialisation of the renovation interventions was identified. Based on this analysis, the next step in the study could be taken: translating the renovation design with only new material into a design with as much reused material as possible.

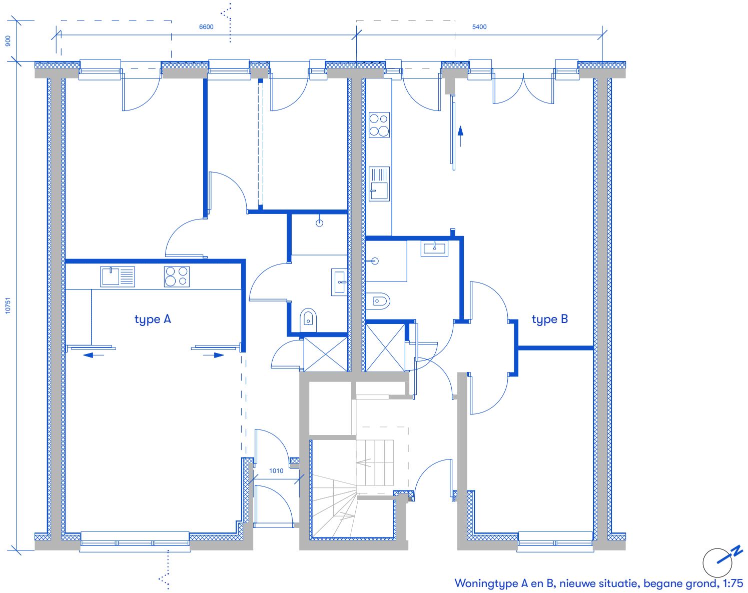


Figure 1: Jongert et al. (2023) floorplan renovation design Superuse Studios

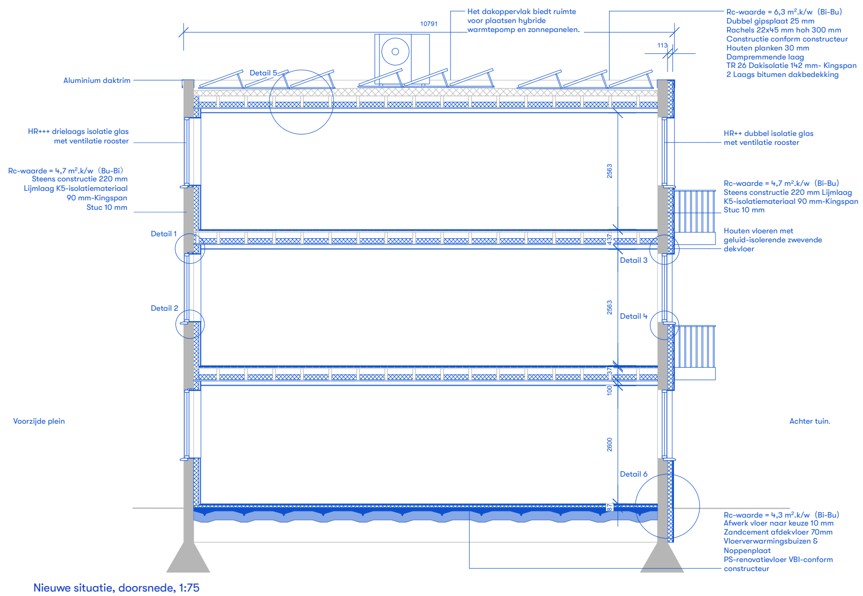


Figure 2: Jongert et al. (2023) section renovation design Superuse Studios

Image 1: Weigeliaplein birdview 1

Image 2: Weigeliaplein birdview 2

Image 3: Weigeliaplein perspective

Quantitative Comparative Research

Methodology: The Circular Renovation Alternative

The circular renovation alternative is a variant of the renovation proposal designed by Superuse Studios for Complex 70. This alternative was created for this study. Establishing the selection of materials was an integral part of the study. As mentioned earlier, the circular renovation alternative consists of as much reused material as possible. What ’as much as possible’ means was the central question for the substudy that led to the materials selection. The availability of materials is a leading factor in a design with reused materials. To identify this availability, research was carried out. Insulation material, different types of sheet material, wooden beams and boards and window frames and exterior doors were examined, as these types of materials are mainly used in Superuse Studios’ original renovation design. The inventory list ’Table 1’ is displayed on the next page.

Based on the outcome of this study, it was then determined which materials from Superuse Studios’ renovation design could be replaced with a reused alternative. Three outcomes were found to be possible in the study:

Outcome 1: the original material is available as a reused material.

Outcome 2: the original material is not available as a reused material but there are alternative materials that have the same functionality and are available as reused.

Outcome 3: the original material is not available as a reused material and an alternative material is also not available or presents technical complications that have been declared as not feasible for this study.

In the case of outcome 3, the material in the circular renovation alternative is unaltered and the calculation takes new material into account.

Material selection explanatory example
In Superuse Studio’s renovation design, Kingspan K5 Kooltherm external insulation boards with a thickness of 90 mm are used as the insulation material for wrapping the façade. At this thickness, this material has a thermal resistance of 4.25 m^2-K/W. This is a phenolic foam-based insulation material and is resistant to water. The inventory list of insulation materials available shows that mainly PIR and EPS are available as water-resistant insulation materials. As EPS is a rather fragile material, PIR was chosen as a circular alternative for the K5 Kooltherm boards. Achieving the same thermal resistance of 4.25 m^2-K/W with this material requires more material, namely 110 mm thickness. For further calculations of the circular renovation design, 110 mm PIR foam is therefore used. Although it was suspected, no evidence was found that PIR undergoes appointable degradation over the years that should be taken into account in relation to thermal resistance. As a margin, the calculation takes the lowest possible lambda value of PIR.

Material type	units	d	w	l	price / unit	price / m2	Location	Supplier
Insulation								
Polyblue foam foam	80	40	600	2500	1,5	5	Rijsbergen	Snellen
Glass wool insulation	300	50	600	1200	1,44	2	Rijsbergen	Snellen
PIR isolation	10		500	1000	0,63	1,25	Rijsbergen	Snellen
EPS insulation		90	990	2980	35,4	12	Rijsbergen	Snellen
EPS insulation	225	85	990	2980	35,4	12	Rijsbergen	Snellen
PIR iso + aluminium foil	460	25	695	1670	11,6	10	Rijsbergen	Snellen
XPS Insulation Plate	77	200	600	1250	26,25	35	Sint-Oedenrode	A van Liempd
PIR isolation	20	90	600	1200			Sint-Oedenrode	A van Liempd
glass wool insulation	805	15	600	1200	1,08	1,5	Weert	M Spierings
glass wool insulation	268	20	600	1500	1,8	2	Weert	M Spierings
PIR	180	30	1200	2500	13,5	4,5	Weert	M Spierings
PIR	200	40	600	1200	4,32	6	Weert	M Spierings
PIR	319	50	600	1200	5,4	7,5	Weert	M Spierings
PIR + aluminium foil	5	40	100	5000	30	6	Weert	M Spierings
Rockwool	463	15	600	600	0,54	1,5	Weert	M Spierings
Rockwool	175	15	600	600	0,54	1,5	Weert	M Spierings
Rockwool	248	20	600	600	0,72	2	Weert	M Spierings
EPS	26	100	1000	1200	10,8	9	Weert	M Spierings
EPS	352	60	500	850	2	5	Weert	M Spierings
Sheet material								
Concrete plywood	200	20	1500	2570	50	12,8	Oosterhout	Heezen
Plywood	4	25	1220	2440	50	16,78	Oosterhout	Heezen
OSB	119	18	1220	2440	32	10,78	Sint-Oedenrode	A van Liempd
OSB	66	11	1220	2440	18	6,06	Sint-Oedenrode	A van Liempd
HPL (collection)	243	13	1300	3050	250	63	Sint-Oedenrode	A van Liempd
Plastic System Panels	208	35	200	2400	6	12,5	Weert	M Spierings
Drywall	70	9	590	1100	1,25	0,81	Rijsbergen	Snellen
Gyproc Drywall	100	13	1200	3000	2,95	0,82	Rijsbergen	Snellen
Birch plywood	16	18	1250	2500	50	16	Haarsteeg	Circulaire Bouwmaterialen
Chipboard	56	28	1250	2500	20	6,4	Haarsteeg	Circulaire Bouwmaterialen
Underlayment + PIR 25mm	8	43	1220	1800	29,5	13,2	Haarsteeg	Circulaire Bouwmaterialen

Chipboard	30	12	1190	3050	15	4,14	Haarsteeg	Circulaire Bouwmaterialen
Chipboard	14	38	920	2200	25,3	12,43	Haarsteeg	Circulaire Bouwmaterialen
Chipboard	57	38	920	4250	48,88	12,53	Haarsteeg	Circulaire Bouwmaterialen
Chipboard	47	38	920	5250	60,38	12,5	Haarsteeg	Circulaire Bouwmaterialen
Chipboard	200	15	1200	2500	x	x	Utrecht	Adex Groep
Drywall	200	12	1185	2600	x	x	Utrecht	Adex Groep
MDF	118	19	1300	3050	x	x	Krimpen aan de Lek	x
Beams and planks								
Beamwood	500	50	70	2700	5		Utrecht	
Beamwood	100	75	210	4000	x	x	Doorwerth	
Beamwood	64	70	190	3900	16		Utrecht	
Spruce beams	77	50	150	3200	16		Sint-Oedenrode	A van Liempd
Spruce beams	60	70	170	4000	28		Sint-Oedenrode	A van Liempd
Beams planed	47	60	115	1800	7		Sint-Oedenrode	A van Liempd
Spruce beams	35	75	175	3500	24,5		Sint-Oedenrode	A van Liempd
Spruce beams	33	75	175	3800	26,6		Sint-Oedenrode	A van Liempd
Spruce beams	32	75	175	3000	21		Sint-Oedenrode	A van Liempd
Treated wooden beams	30	70	195	3800	22		Sint-Oedenrode	A van Liempd
Beamwood	26	90	320	4000	115		Sint-Oedenrode	A van Liempd
Spruce ribs	26	50	750	3300	6		Sint-Oedenrode	A van Liempd
Spruce beams	20	70	195	3000	24		Sint-Oedenrode	A van Liempd
Beamwood	250	70	175	3800	20		Rijsbergen	Snellen
Roof boarding	25	20	80	2400	3,4	16,5	Rijsbergen	Snellen
Roof boarding	94	20	85	2400	4,9	24	Rijsbergen	Snellen
Roof boarding	88	20	80	2750	3,52	16	Rijsbergen	Snellen
Spruce battens / rachels	460	15	70	5000	2		Rijsbergen	Snellen

Window frames						
Aluminium frame double glazing	1	2215	1155	145	Rijsbergen	Snellen
Wooden frame double glazing	1	1952	1600	160	Rijsbergen	Snellen
Wooden frame double glazing	1	2000	1780	170	Rijsbergen	Snellen
Wooden frame single glazing	1	1205	990	50	Rijsbergen	Snellen
Wooden frame doube glazing	1	1640	1170	80	Rijsbergen	Snellen
Wooden frame double glazing	1	1110	2310	425	Sint-Oedenrode	A van Liempd
Wooden frame double glazing	1	1050	2310	350	Sint-Oedenrode	A van Liempd
Wooden frame double glazing	1	855	1310	150	Sint-Oedenrode	A van Liempd
Wooden frame double glazing	1	1825	2345	300	Weert	M Spierings
Plastic frame double glazing	1	1250	1250	150	Weert	M Spierings
Plastic frame double glazing	12	1920	1920	195	Weert	M Spierings
Plastic frame double glazing	8	2465	1370	195	Weert	M Spierings
Wooden frame double glazing	7	890	1500	150	Haarsteeg	Circulaire Bouwmaterialen
Doors (exterior)						
Wooden front door	1	900	2080	90	Sint-Oedenrode	A van Liempd
Wooden front door	1	900	2105	90	Sint-Oedenrode	A van Liempd
Wooden front door	1	820	2005	100	Sint-Oedenrode	A van Liempd
Wooden front door	1	1005	2325	100	Sint-Oedenrode	A van Liempd
Wooden front door	1	935	2335	90	Sint-Oedenrode	A van Liempd
Wooden front door	1	950	2365	90	Sint-Oedenrode	A van Liempd
Wooden front door	1	1010	2410	110	Sint-Oedenrode	A van Liempd
Wooden front door	1	965	2330	90	Sint-Oedenrode	A van Liempd
Plastic back door	1	880	2080	150	Weert	M Spierings
Plastic back door	1	970	2100	250	Weert	M Spierings

Quantitative Comparative Research

Methodology: The Material Inventory

Now that the materialisation of the interventions of both renovation proposals was established, it was possible to calculate how much of this material should be added throughout the complex. As a precise calculation of the amount of material was not possible within the framework of this study, calculations were made using two approximations.

The approach method described applies to both Superuse Studios' renovation plan and the circular renovation alternative.

Approach 1: 'the typical package'

1 m² of 'typical package' was taken for the different building sections. This means that a sample of 1 by 1 metre was taken for the façade, roof, storey floors and ground floor. The thickness of the package is equal to the actual thickness. The 'typical package' is most representative of the entire building section. Figure 3 illustrates how this 'typical package' should be interpreted.

It was then calculated for each material how many kilograms of it are in 1 m² of typical package.

Approach 2: 'simplified model of Complex 70'

To translate the results of the calculations within the typical package to the scale of the entire Complex 70, a simplified model of this was constructed. Figure 4 illustrates the construction of this model. From this simplified model, the surface dimensions of the building sections were taken. Thus, the total square metres of façade, roof, storey floor and ground floor were approximated. This took into account recesses for window frames and doors.

By multiplying the number of kilograms of each material in the typical package by the total square metres of the relevant building section, the number of kilograms of each material to be added to implement the renovation plan was calculated.

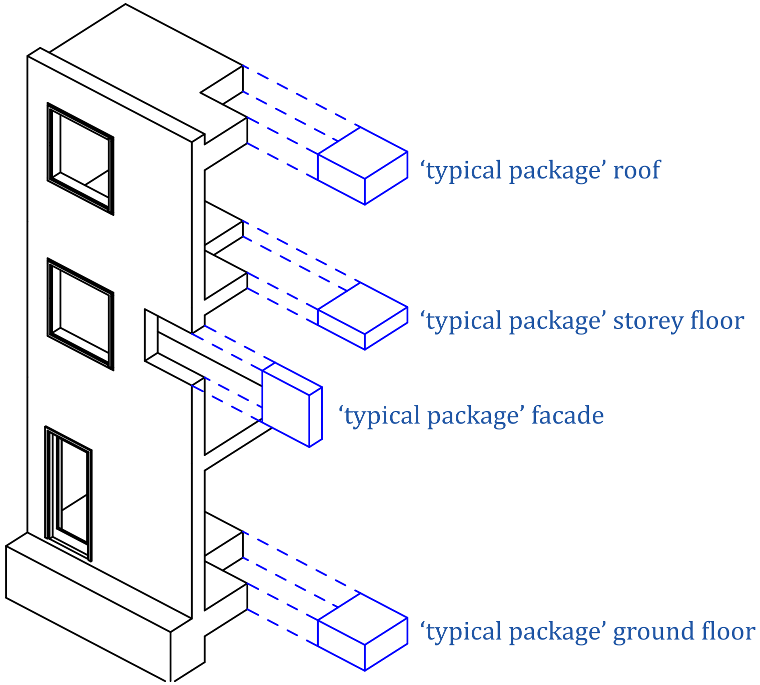


Figure 3: typical package

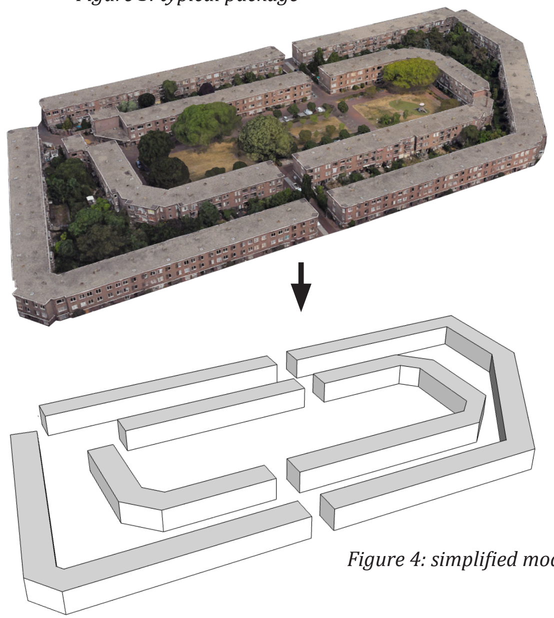


Figure 4: simplified model of Complex 70

Quantitative Comparative Research

Methodology: The Environmental Burden of Building Materials

Having established how much of which materials are added for both renovation plans, a translation can be made into greenhouse gas emissions and energy use. A comparison is made in this study between the emissions and energy use generated by the production of the building materials. This is expressed in terms of embodied carbon and primary production energy.

Embodied carbon
Embodied carbon is expressed in kilograms of CO_2-eq per kilogram of material produced. This figure indicates how many kilograms of greenhouse gases are released in producing one kilogram of the material. This includes greenhouse gases released during the mining of the raw materials, transport to and from factories and processing stations, processing of the raw materials and optional assembly.

Primary production energy
Primary production energy is expressed in Mega Joules per kg of material produced. This number indicates how much energy it takes to produce one kilogram of the material. Again, this includes the energy required for mining the raw materials, transport to and from factories and processing stations, processing the raw materials and optional assembly.

It is important to be aware of the distinction between the two. Embodied carbon has a direct effect on global warming. Primary production energy initially only indicates the energy required. How this energy is generated determines the effect on global warming. In the current status of the (construction) industry, it can be assumed that the vast majority of this energy is generated with fossil fuels and can therefore ultimately be expressed in greenhouse gas emissions. However, this is not a determined fact and may change in the future due to possible sustainable transistions in the industry.

The embodied carbon and primary production energy of building materials were taken from Granta Edupack's Material Universe. "The MaterialUniverse is a comprehensive database with information about materials: their properties, their character, what they are used for, where they come from, their environmental characteristics and much more. The database is continuously maintained, updated and expanded, and records are kept of the origin of the data and the reasoning used to select the data for inclusion." *(Ashby, Fernandez, Gray, 2022)*

The material properties included in this database stem from academic research and are related to the Department of Engineering at the University of Cambridge and the Department of Architecture at Massachusetts Institute of Technology (MIT). *(Ashby, Fernandez, Gray, 2022)*

Environmental burden of unforeseen reused materials
In 2012, the European Union introduced the EN15804 standard. This standard specifies how (mainly) construction companies should prepare the EPD (Environmetal Product Declaration) of their products. To prepare an EPD, an LCA (Life Cycle Assessment) of the product must first be prepared. In their publication 'Bepalingsmethode Milieuprestatie Bouwwerken', the National Environmental Database describes, among other things, the determination method for unforeseen reuse of building materials. This determination method is based on the EN15804 standard and thus conforms to European agreements. The reused materials used in this study in the circular renovation alternative fall under the category of unforeseen reuse. The determination method describes that a generic factor 'H' is applied to modules A1-A3, C3, C4 and D for an unforeseen reused material. This factor is 0.2. As embodied carbon and primary production energy are both a factor under module A1-A3 'product stage', 20% (0.2*100) of its original embodied carbon and primary production energy will be charged for the reused materials. *(Nationale Milieu Database, 2022)*

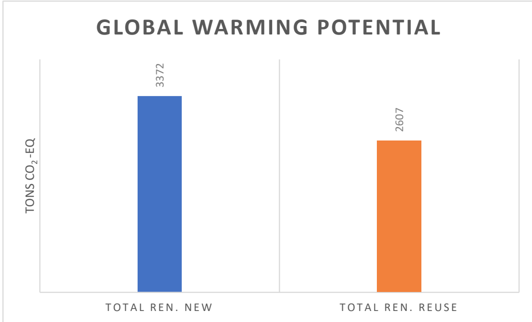
Quantitative Comparative Research

Results and comparrison on total building level

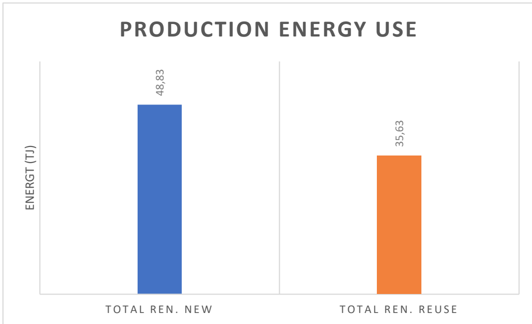
Table 2 shows an overview of Superuse Studio's renovation design. The table shows how many kilograms of material are contained in one square metre of 'typical package' and how many kilograms of this material must then be added throughout the project. The table indicates which Edupack material was used as a reference to retrieve the material properties and the Embodied Carbon (kg/kg) and Primary Production Energy (MJ/kg) of this material. Based on this data, the Global Warming Potential (kg CO_2 eq) and Production Energy Use (MJ) of each material in the project were calculated. The sum of these values forms the final number in the calculation. For the renovation plan with new materials, this amounts to **3.372.071 kg CO_2** eq what the required building materials emitted in their production process and **48.832.785 MJ** of energy required to produce these materials.

Table 3 shows the same overview but of the renovation with as much reused material as possible. By comparing the tables, it can be seen how most of the materialisation is the same between the two renovation designs. This is because the material originally chosen is also readily available on the second-hand market. The reused alternative here is therefore the same material, of which 20% of the original environmental impact is charged. The insulation materials in particular differ; in both the façade and roof packages, the original material is replaced by PIR. The mineral wool used in the storey floors and as part of the floating screed is the same in both proposals and is again charged 20% of its original environmental impact when reused. The list shows which materials are reused and which are used as new. Reused materials can be recognised by the 'r' in the second column. It can be seen in the table how only the windows with double-glazing have a reused alternative. The windows with triple glazing are applied as new. Summing up the Global Warming Potential and Production Energy Use of the combination of new and reused material of the circular renovation alternative comes to **2.607.825 kg CO_2-eq** and **35.622.668 MJ**.

Within the framework of this study, the circular renovation alternative saves **23% CO_2-eq** emmision and **27% energy use** compared to the conventional renovation design with new material. In absolute numbers this is **764.246 kg CO_2-eq** and **13.310.097 MJ** of energy. To put these numbers in perspective, 764 tonnes of CO_2 is equivalent to the emissions of an entire airplane flying 6 times from Amsterdam to New York or the annual emissions of 382 petrol cars. 13,000,000 MJ (or 13 TJ) is the amount of energy it takes to heat and provide hot water to 1,400 homes a year. This means you could supply Complex 70, with 400 homes, with heat and hot water for 3.5 years. *(Carbon debits, 2023) (Climate Neutral Group, 2023)*



Graph 1: GWP comparison on total building level



Graph 2: energy use comparison on total building level

Table 2: Superuse Studio's renovation design: overview document, quantities, embodied carbon and primary production energy per building material

	d (mm)	V (m3)	rho (kg/m3)	m (kg)	m2	m2	Total (kg)	Edupack material	EC CO2 eq (kg/kg)	PPE (MJ/kg)	Global warming potential (kg CO2 eq)	Production Energy Use (MJ)
Facade												
Bricks	220											
Foam glue	3	0,003	170	0,51	1	15244	7774,44	Polyurethane foam	4,49	93,2	34907	724578
K5-insulation	90	0,09	35,00	3,15	1	15244	48018,6	Phenolic foam	6,44	103	309240	4945916
Stucco	10	0,01	1490	14,9	1	15244	227135,6	Plaster	0,57	3,77	129467	856301
Roof												
Bitumen (2)	8	0,008	1000	8	1	9764	78112	Bitumen	0,3	111	23434	8670432
TR26-insulation	142	0,142	30	4,26	1	9764	41594,64	Polyisocyanurate	5,33	105	221699	4367437
OSB	18	0,018	573	10,314	1	9764	100705,896	Particle board	0,587	16,9	59114	1701930
Wooden roof												
Wooden Rails	22	0,004	500	2	1	9764	19528	Spruce wood	0,253	17,5	4941	341740
Gypsum board (2)	25	0,025	820	20,5	1	9764	200162	Plaster of Paris	0,206	2,31	41233	462374
Floor												
Gypsum bonded pb (2)	20	0,02	1300	26	1	19528	507728	Gypsum bonded pb	0,348	4,88	176689	2477713
Glasswool	10	0,01	35	0,35	1	19528	6834,8	Glass foam	1,04	13,7	7108	93637
Wooden floor												
Glass wool (sound)	30	0,03	35	1,05	1	19528	20504,4	Glass foam	1,04	13,7	21325	280910
Gypsum board (2)	25	0,025	820	20,5	1	19528	400324	Plaster of Paris	0,206	2,31	82467	924748
Ground floor												
VBI PS-floor												
Galvanized steel beams			7 (/m)	7	1	9764	68348	Galvanized steel	2,01	26,4	137379	1804387
EPS filling	180	0,18	32	5,76	1	9764	56240,64	Expanded PS foam	3,14	113	176596	6355192
Concrete		0,07	2600	182	1	9764	1777048	Concrete (portland)	0,13	1,02	231016	1812589
Reinforcement mesh		0,0013	7900	10,27	1	9764	100276,28	Galvanized steel	2,01	26,4	201555	2647294
Sand cement	70	0,07	2200	154	1	9764	1503656	Cement (portland)	0,943	5,23	1417948	7864121
Floor finish	10											
					item	**total items**						
Addons												
Window 2200x1400 D					1	450						
Wooden Frame		0,064	560	35,84	1	450	16128	Spruce wood	0,253	17,5	4080	282240
Rubber		0,000216	880	0,19	1	450	85,536	EPDM rubber	3,59	81,5	307	6971
Double glazing	10	0,031	2490	77,19	1	450	34735,5	Soda Lime Glass	0,742	10,6	25774	368196
Window 2200x1400 T					1	450						
Wooden Frame		0,064	560	35,84	1	450	16128	Spruce wood	0,253	17,5	4080	282240
Rubber		0,000216	880	0,19	1	450	85,536	EPDM rubber	3,59	81,5	307	6971
Triple glazing	15	0,046	2490	114,54	1	450	51543	Soda Lime Glass	0,742	10,6	38245	546356
Window 700x1400 D					1	300						
Wooden Frame		0,037	560	20,72	1	300	6216	Spruce wood	0,253	17,5	1573	108780
Rubber		0,000126	880	0,11	1	300	33,264	EPDM rubber	3,59	81,5	119	2711
Double glazing	10	0,01	2490	24,9	1	300	7470	Soda Lime Glass	0,742	10,6	5543	79182
Window 700x1400 T					1	300						
Wooden Frame		0,037	560	20,72	1	300	6216	Spruce wood	0,253	17,5	1573	108780
Rubber		0,000126	880	0,11	1	300	33,264	EPDM rubber	3,59	81,5	119	2711
Triple glazing	15	0,015	2490	37,35	1	300	11205	Soda Lime Glass	0,742	10,6	8314	118773
Wooden Door 830x2115					1	300						
Oak wood	50	0,09	780	70,2	1	300	21060	Oak wood (quer-robu	0,281	27,9	5918	587574
										Total	**3372071**	**48832785**

Table 3: circular renovation alternative: overview document, quantities, embodied carbon and primary production energy per building material

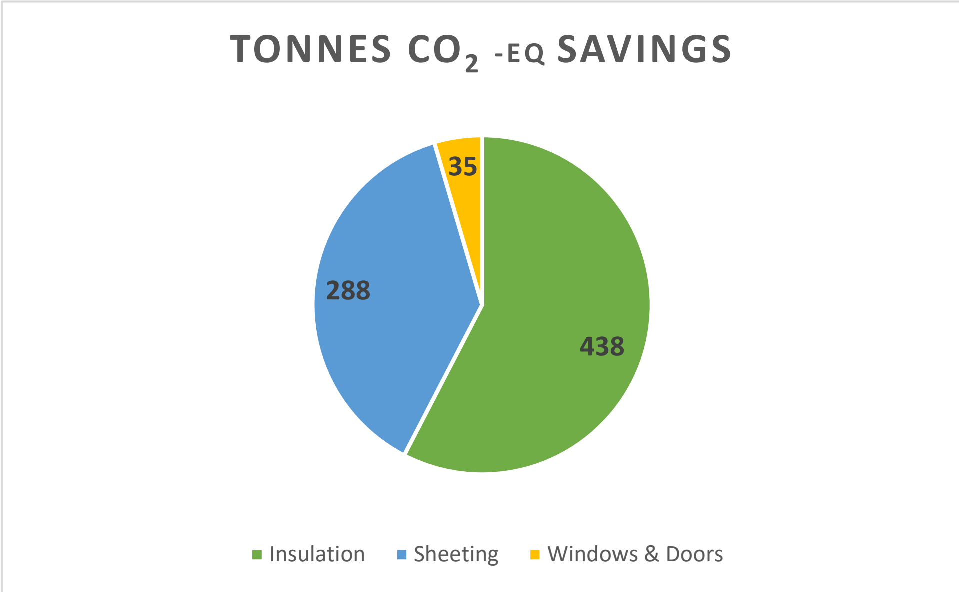
		d (mm)	V (m3)	rho (kg/m3)	m (kg)	m2	m2	Total (kg)	Edupack material	EC CO2 eq (kg/kg)	PPE (MJ/kg)	Global warming potential (kg CO2 eq)	Production Energy Use (MJ)
Facade													
Bricks		220											
Foam glue		3	0,003	170	0,51	1	15244	7774,44	Polyurethane foam	4,49	93,2	34907	724578
PIR insulation	r	110	0,11	35,00	3,85	1	15244	58689,4	Polyisocyanurate	5,33	105	62563	1232477
Stucco		10	0,01	1490	14,9	1	15244	227135,6	Plaster	0,57	3,77	129467	856301
Roof													
Bitumen (2)		8	0,008	1000	8	1	9764	78112	Bitumen	0,3	111	23434	8670432
PIR insulation	r	170	0,17	30	5,1	1	9764	49796,4	Polyisocyanurate	5,33	105	53083	1045724
OSB	r	18	0,018	573	10,314	1	9764	100705,896	Particle board	0,587	16,9	11823	340386
Wooden roof													
Wooden Rails	r	22	0,004	500	2	1	9764	19528	Spruce wood	0,253	17,5	988	68348
Gypsum board (2)	r	25	0,025	820	20,5	1	9764	200162	Plaster of Paris	0,206	2,31	8247	92475
Floor													
Gypsum bonded pb (2)	r	20	0,02	1300	26	1	19528	507728	Gypsum bonded pb	0,348	4,88	35338	495543
Glasswool	r	10	0,01	35	0,35	1	19528	6834,8	Glass foam	1,04	13,7	1422	18727
Wooden floor													
Glass wool (sound)	r	30	0,03	35	1,05	1	19528	20504,4	Glass foam	1,04	13,7	4265	56182
Gypsum board (2)	r	25	0,025	820	20,5	1	19528	400324	Plaster of Paris	0,206	2,31	16493	184950
Ground floor													
VBI PS-floor													
Galvanized steel beams				7 (/m)	7	1	9764	68348	Galvanized steel	2,01	26,4	137379	1804387
EPS filling		180	0,18	32	5,76	1	9764	56240,64	Expanded PS foam	3,14	113	176596	6355192
Concrete			0,07	2600	182	1	9764	1777048	Concrete (portland)	0,13	1,02	231016	1812589
Reinforcement mesh			0,0013	7900	10,27	1	9764	100276,28	Galvanized steel	2,01	26,4	201555	2647294
Sand cement		70	0,07	2200	154	1	9764	1503656	Cement (portland)	0,943	5,23	1417948	7864121
Floor finish		10											
						item	**total items**						
Addons													
Window 2200x1400 D						1	450						
Wooden Frame	r		0,064	560	35,84	1	450	16128	Spruce wood	0,253	17,5	816	56448
Rubber	r		0,000216	880	0,19	1	450	85,536	EPDM rubber	3,59	81,5	61	1394
Double glazing	r	10	0,031	2490	77,19	1	450	34735,5	Soda Lime Glass	0,742	10,6	5155	73639
Window 2200x1400 T						1	450						
Wooden Frame			0,064	560	35,84	1	450	16128	Spruce wood	0,253	17,5	4080	282240
Rubber			0,000216	880	0,19	1	450	85,536	EPDM rubber	3,59	81,5	307	6971
Triple glazing		15	0,046	2490	114,54	1	450	51543	Soda Lime Glass	0,742	10,6	38245	546356
Window 700x1400 D						1	300						
Wooden Frame	r		0,037	560	20,72	1	300	6216	Spruce wood	0,253	17,5	315	21756
Rubber	r		0,000126	880	0,11	1	300	33,264	EPDM rubber	3,59	81,5	24	542
Double glazing	r	10	0,01	2490	24,9	1	300	7470	Soda Lime Glass	0,742	10,6	1109	15836
Window 700x1400 T						1	300						
Wooden Frame			0,037	560	20,72	1	300	6216	Spruce wood	0,253	17,5	1573	108780
Rubber			0,000126	880	0,11	1	300	33,264	EPDM rubber	3,59	81,5	119	2711
Triple glazing		15	0,015	2490	37,35	1	300	11205	Soda Lime Glass	0,742	10,6	8314	118773
Wooden Door 830x2115						1	300						
Oak wood	r	50	0,09	780	70,2	1	300	21060	Oak wood (quer-robu	0,281	27,9	1184	117515
											Total	**2607825**	**35622668**

Quantitative Comparative Research

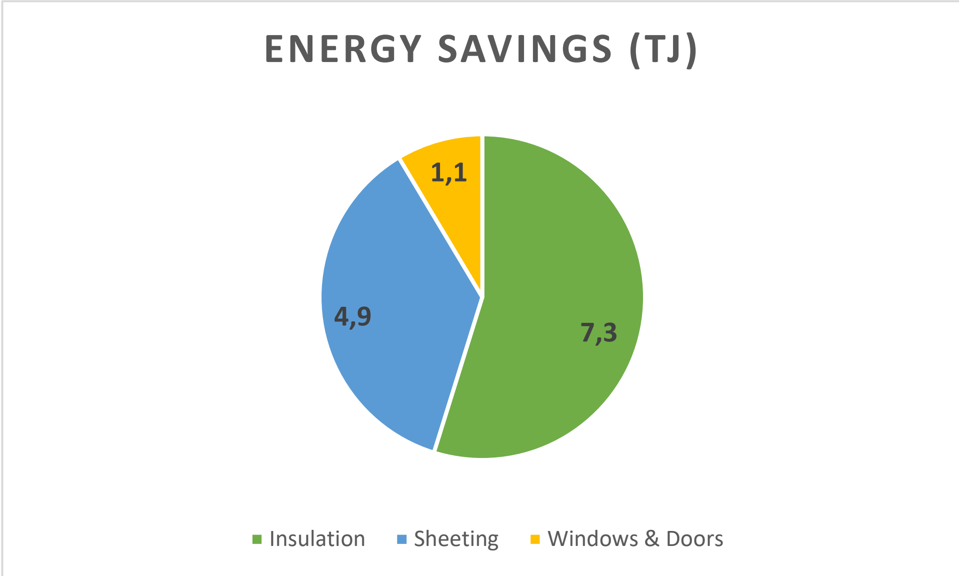
Results and comparrison per building material type

In Table 4, the data found from Tables 2 and 3 is arranged by type of building material. A distinction has been made between insulation material, sheet material and windows and doors. This distinction was made to provide insight into the impact that can be made with the different types of building materials. It shows how much CO_2-eq and energy can be saved per type of building material. Striking is the amount of CO_2 and energy that can be saved within the insulation material category. Of the total savings of 764 tonnes of CO_2-eq and 13.3 TJ of energy, focusing on reuse within insulation saves 438 tonnes (58%) and 7.3 TJ (55%). The board material is also responsible for substantial savings in CO2 and energy. The share of window frames and doors is the lowest.

As mentioned, this calculation counts 20% of the original environmental load for a reused material. So these figures say less about the savings per material type, but more about the opportunity to make an impact. If a material is readily available on the second-hand market, then it is included as a reused material in the list, making the overall share of saved CO2 and energy higher in its category.



Graph 3: tonnes CO_2 savings per material type



Graph 4: energy savings per material type

Insulation

Renovation New

		CO_2 eq (kg)	Energy (MJ)
K5 insulation		309240	4945916
TR26 insulation		221699	4367437
Glasswool		7108	93637
Glasswool (sound)		21325	280910
EPS filling		176596	6355192
Total		**735968**	**16043092**

Renovation Reuse

		CO_2 eq (kg)	Energy (MJ)
PIR insulation	r	62563	1232477
PIR insulation	r	53083	1045724
Glasswool	r	1422	18727
Glasswool (sound)	r	4265	56182
EPS filling		176596	6355192
Total		**297929**	**8708302**
Total Ren. New.		**735968**	**16043092**
Total Ren. Reuse.		**297929**	**8708302**
Savings		**438039**	**7334790**

Sheeting

Renovation New

		CO_2 eq (kg)	Energy (MJ)
OSB		59114	1701930
Gypsum board (2)		41233	462374
Gypsum bonden pb		176689	2477713
Gypsum board (2)		82467	924748
Total		**359503**	**5566765**

Renovation Reuse

		CO_2 eq (kg)	Energy (MJ)
OSB	r	11823	340386
Gypsum board (2)	r	8247	92475
Gypsum bonden pb	r	35338	49543
Gypsum board (2)	r	16493	184950
Total		**71901**	**667354**
Total Ren. New.		**359503**	**5566765**
Total Ren. Reuse.		**71901**	**667354**
Savings		**287602**	**4899411**

Windows / Doors

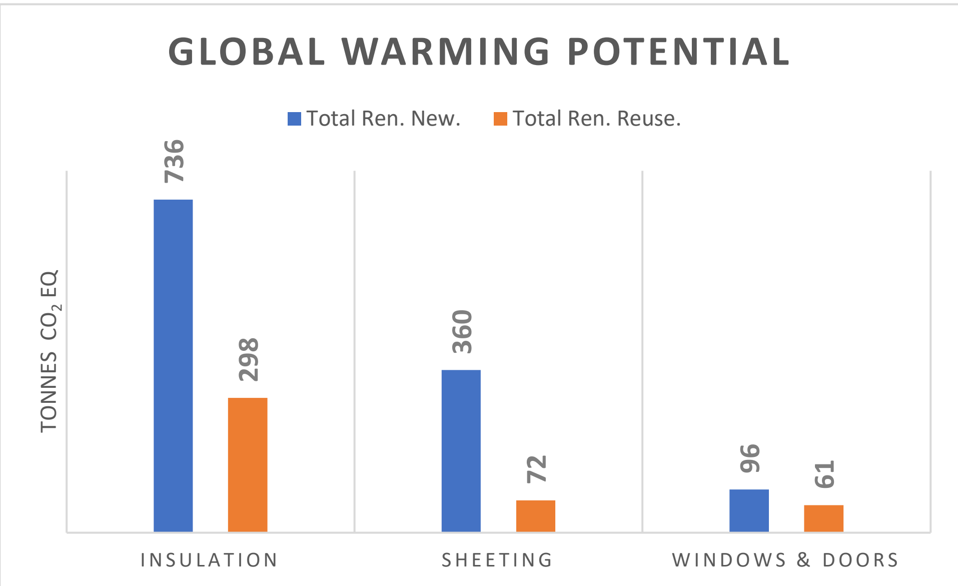
Renovation New

	CO_2 eq (kg)	Energy (MJ)
Window 2200x1400 D		
Wooden Frame	4080	282240
Rubber	307	6971
Double glazing	25774	368196
Window 2200x1400 T		
Wooden Frame	4080	282240
Rubber	307	6971
Triple glazing	38245	546356
Window 700x1400 D		
Wooden Frame	1573	108780
Rubber	119	2711
Double glazing	5543	79182
Window 700x1400 T		
Wooden Frame	1573	108780
Rubber	119	2711
Triple glazing	8314	118773
Wooden Door 830x2115		
Oak wood	5918	587574
Total	**95952**	**2501486**

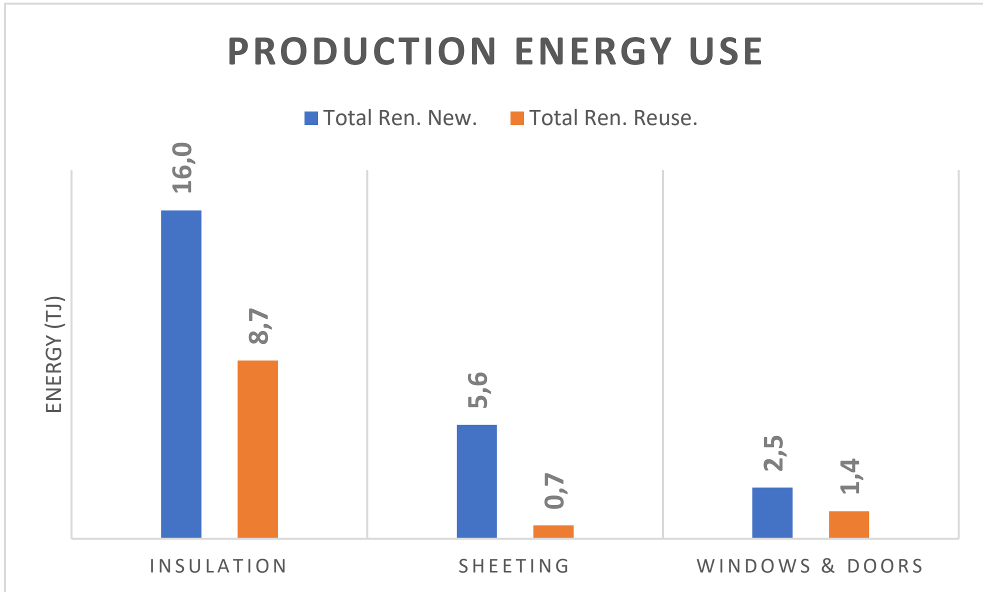
Renovation Reuse

		CO_2 eq (kg)	Energy (MJ)
Window 2200x1400 D			
Wooden Frame	r	816	56448
Rubber	r	61	1394
Double glazing	r	5155	73639
Window 2200x1400 T			
Wooden Frame		4080	282240
Rubber		307	6971
Triple glazing		38245	546356
Window 700x1400 D			
Wooden Frame	r	315	21756
Rubber	r	24	542
Double glazing	r	1109	15836
Window 700x1400 T			
Wooden Frame		1573	108780
Rubber		119	2711
Triple glazing		8314	118773
Wooden Door 830x2115			
Oak wood	r	1184	117515
Total		**61301**	**1352962**
Total Ren. New.		**95952**	**2501486**
Total Ren. Reuse.		**61301**	**1352962**
Savings		**34651**	**1148524**

Table 4: comparrison sheet, global warming potential and production energy use per building material category.



Graph 5: GWP comparison per material type

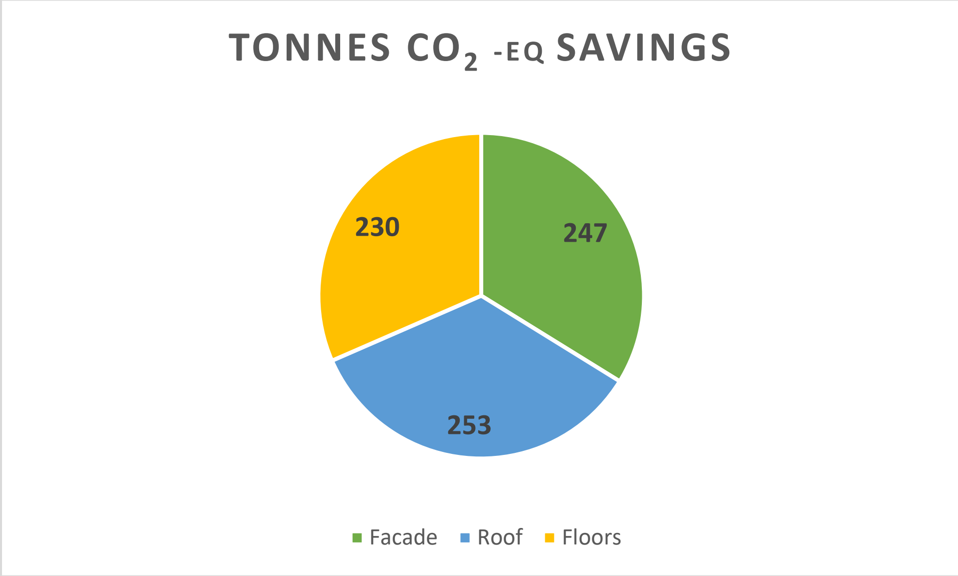


Graph 6: Energy use comparison per material type

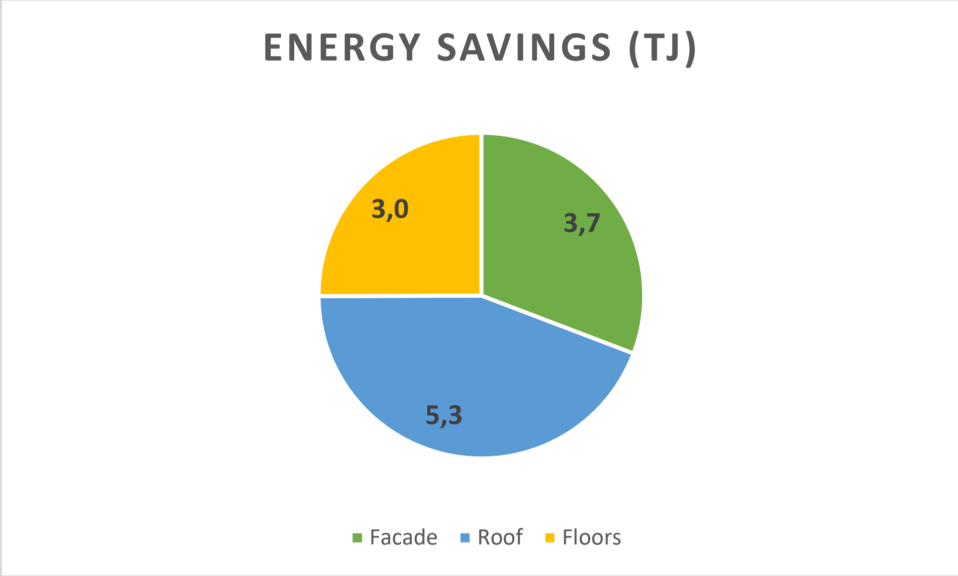
Quantitative Comparative Research

Results and comparrison on building element level

Table 5 shows a different ordering of the data from Tables 1 and 2. This time, CO_2-eq emissions and energy are ordered by building section: facade, roof, storey floor and ground floor. This distinction was made to provide insight into the impact that can be made by focusing on reuse per building section. The ground floor is included in the overview, although in both proposals it consists of completely new material. There is therefore no saving on this building section. The data illustrates the ground floor construction's share of total CO_2 emissions and energy requirements, which is by far the most of any building section. With 2164 tonnes of CO_2 emissions, the ground floor accounts for 64% of CO_2 emissions from production of building materials. Due to its specific structural character, this study chose not to consider a reused alternative. In practice, this would also be a realistic situation. The high environmental burden can be explained by the use of steel, cement and concrete. These are materials that do not occur in all other building sections. Within the building parts where CO_2 and energy savings do occur, it is striking that all three building parts have a very similar share in the context of CO_2: façade (34%), roof (35%) and floors (31%).
In the context of energy saving, the roof scores significantly higher than the façade and floors. This is explained by the large amount (100,706 kg) of Oriented Strand Boards (OSB) in the roof structure. OSB has a high primary production energy relative to its embodied carbon.



Graph 7: tonnes CO_2 savings per building element



Graph 8: energy savings per building element

Facade

Renovation New

		CO_2 eq (kg)	Energy (MJ)
Bricks			
Foam glue		34907	724578
K5-insulation		309240	4945916
Stucco		129467	856301
Total		473614	6526795

Renovation Reuse

		CO_2 eq (kg)	Energy (MJ)
Bricks			
Foam glue		34907	724578
PIR insulation	r	62563	1232477
Stucco		129467	856301
Total		226937	2813356
Total Ren. New.		473614	6526795
Total Ren. Reuse.		226937	2813356
Savings		246677	3713438

Roof

Renovation New

		CO_2 eq (kg)	Energy (MJ)
Bitumen (2)		23434	8670432
TR26-insulation		221699	4367437
OSB		59114	1701930
Wooden roof			
Wooden Rails		4941	341740
Gypsum board (2)		41233	462374
Total		350421	15543913

Renovation Reuse

		CO_2 eq (kg)	Energy (MJ)
Bitumen (2)		23434	8670432
PIR insulation	r	53083	1045724
OSB	r	11823	340386
Wooden roof			
Wooden Rails	r	988	68348
Gypsum board (2)	r	8247	92475
Total		97574	10217365
Total Ren. New.		350421	15543913
Total Ren. Reuse.		97574	10217365
Savings		252847	5326548

Floors

Renovation New

		CO_2 eq (kg)	Energy (MJ)
Gypsum bonded pb (2)		176689	2477713
Glasswool		7108	93637
Wooden floor			
Glass wool (sound)		21325	280910
Gypsum board (2)		82467	924748
Total		287589	3777008

Renovation Reuse

		CO_2 eq (kg)	Energy (MJ)
Gypsum bonded pb (2)	r	35338	495543
Glasswool	r	1422	18727
Wooden floor			
Glass wool (sound)	r	4265	56182
Gypsum board (2)	r	16493	184950
Total		57518	755402
Total Ren. New.		287589	3777008
Total Ren. Reuse.		57518	755402
Savings		230071	3021606

Ground floor

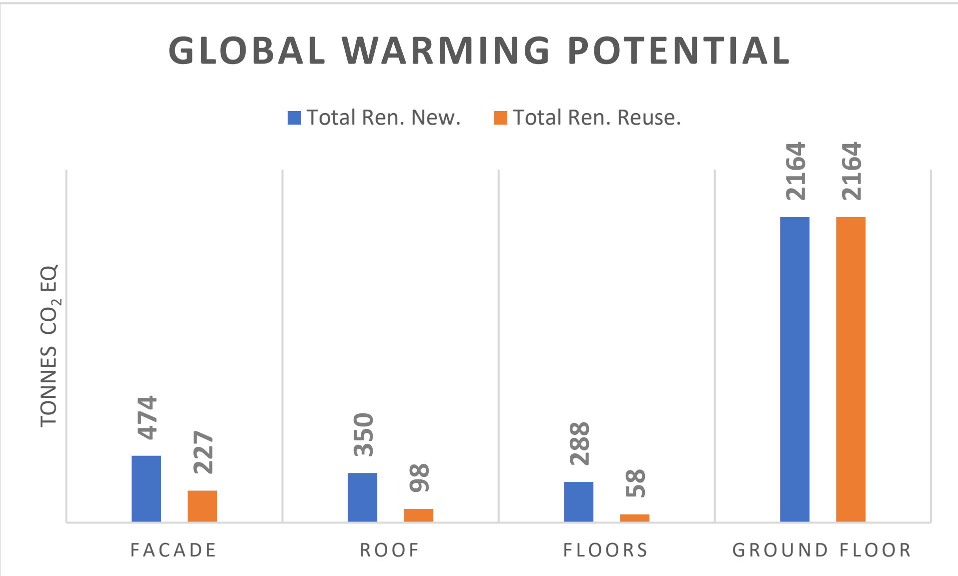
Renovation New

	CO_2 eq (kg)	Energy (MJ)
Galvanized steel beams	137379	1804387
EPS filling	176596	6355192
Concrete	231016	1812589
Reinforcement mesh	201555	2647294
Sand cement	1417948	7864121
Total	2164494	20483583

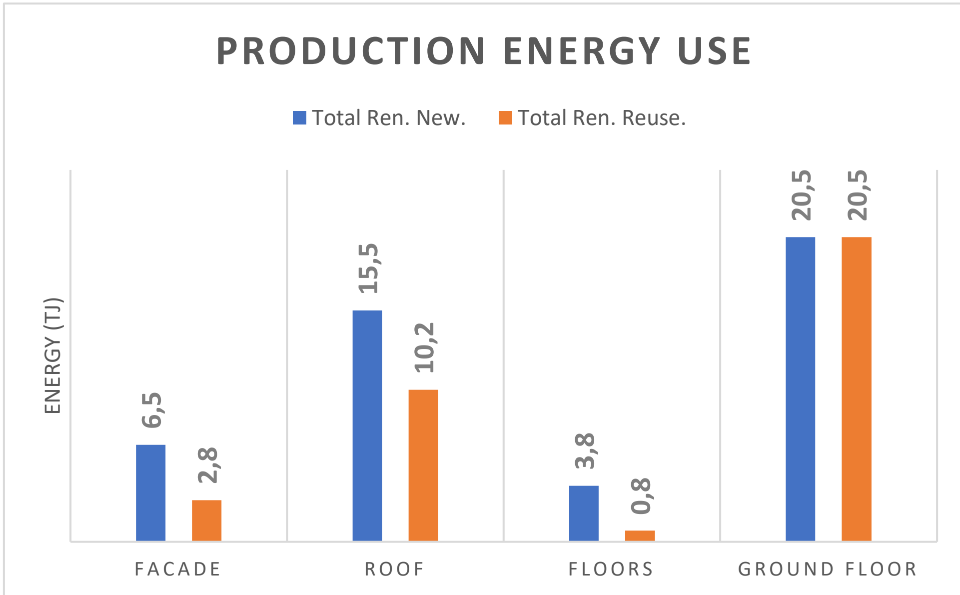
Renovation Reuse

	CO_2 eq (kg)	Energy (MJ)
Galvanized steel beams	137379	1804387
EPS filling	176596	6355192
Concrete	231016	1812589
Reinforcement mesh	201555	2647294
Sand cement	1417948	7864121
Total	2164494	20483583
Total Ren. New.	2164494	20483583
Total Ren. Reuse.	2164494	20483583
Savings	0	0

Table 5: comparrison sheet, global warming potential and production energy use per building element.



Graph 9: GWP comparison per building element



Graph 10: Energy use comparison per building element

Quantitative Comparative Research

Conclusion and discussion

Conclusion

It can be concluded that aiming at applying reused materials, at this scale (390 dwellings), saves a noteworthy amount of greenhouse gases and energy. In percentage terms, the difference came out to less than 25% savings for both emissions and energy use. However, due to the scale of the project, in absolute numbers this translates to a saving of 764 tonnes of CO_2-eq and 13 TJ of energy, a saving whose positive impact on the environment cannot be denied. Plastic-based insulation materials have a high embodied carbon and primary production energy. By 'wrapping' the original building with such material, you create relatively high greenhouse gas emissions and energy use. Applying reused insulation material is therefore a good way to reduce the environmental burden of the project with a relatively simple intervention. Investing in window frames and doors led to little savings for this project. Window frames have a relatively small share of emissions and energy use in both Superuse Studios' renovation design and the circular renovation alternative. The difference between the two designs is also relatively small. This is mainly because half of the window frames are triple-glazed. Triple-glass window frames are not available on the current second-hand market so they are made new in both designs.
In the comparison between building parts: facade, roof, storey floor and ground floor; it was found that the savings are pretty much the same. The ground floor remained unchanged in both proposals. Thus, there is no actual comparison.

Discussion

In the comparison, Superuse Studios' renovation design was translated into a design with reused materials. The ground floor could not be 'translated' using this method. However, this does not mean that a ground floor construction with reused materials is not possible at all. However, a complete redesign was too radical for this study. Because the ground floor used the largest share of total greenhouse gas emissions and energy, 64% and 44% respectively, this means that the relative greenhouse gas and energy savings of the overall equation plummets as a result. If the ground floor construction were not included. The relative savings between the two proposals would amount to 65.6% reduction in greenhouse gases and 44.5% reduction in energy use.

For the environmental burden of reused material, this study was calculated according to European standard. Namely by including 20% of the original burden. It can be questioned how fair this calculation is. The percentage arises from the reasoning that a material pays off its environmental burden over its lifetime. This is rather paradoxical. In fact, it means that a material is not environmental burden free until it reaches the end of its life. The material is then no longer reusable. In addition, besides preventing the production of new material, reuse also reduces waste streams. It seems that these factors are not yet considered in the trade-off.

Interviews

Summary, Q&A

To put the findings of the quantitative comparative research into perspective, two interviews were conducted with people from the construction industry. Interviews were conducted with a representative of AM, the largest property developer in the Netherlands, and with a representative of New Horizon, a circular demolition company.

The aim of the interviews was to get a picture of the challenges that the practice is currently facing in the context of sustainability and to gain more insight into the used building materials market and the availability of materials.

A full report on the conducted interviews can be found in the appendix.

The main questions and answers have been distilled and reformulated:

Interests and barriers in renewal tasks and sustainable building practices.

Q: What interest are there for parties involved when encountering a renewal task?

Answer: The interests are primarily economic.

Q: Is there an economic reason to safe a buildings structure?

Answer: If the existing casco fits the program of requirements for the new building, saving the casco can be considered. The cost of careful demolition is weighed against the potential savings that keeping the casco provides.

Added information: also material value of an existing structure is of use to demolition companies, who trade in these materials.

Q: Is there any other reason to safe (parts) of a building?

Answer: Within inner-city areas, heritage values and protected cityscapes can be taken into consideration. Sometimes laws forbid demolition, sometimes the value of preservation outweighs financial interests.

Q: What are the primary barriers within the sustainability transition of the building industry?

Answer: The main barrier right now is the lack of knowledge. Parties involved in construction projects need to reinvent their businesses. More time is spent on research and discovery which leads to longer processes and higher costs. Also, sustainable building materials like wood are simply more expensive then for example concrete. Whether these prices will drop due to scaleups and knowledge increase is yet uncertain.

Material harvesting, reuse and recycle, availability

Q: How do you acquire the materials you sell on your platform?

Answer: We get materials from so called ‘Donor buildings’. Buildings that are up for demolition are carefully taken apart by us. Reusable and recyclable materials are then taken from these buildings.

Q: You mention reusable and also recyclable. Are most materials directly reusable?

Answer: No. Most material that is extracted from buildings is recycled. Like the concrete we manufacture. Made from recycled concrete and 60-80% reduction in EPD compared to new concrete.

Q: Which materials are directly reusable?

Answer: cable ducts, plaster walls, wooden beams and insulation boards such as EPS and PIR.

Q: Can you give insight in the available quantities of these materials?

Answer: Total quantity is uncertain. Too many factors. Latest reference is 10.000 m^2 reused gypsum wall.

Interviews

Conclusion and discussion

Conclusion

It can be concluded from the interviews that economic interests play the main role in considerations around reuse of existing buildings. Heritage value is also mentioned as a factor that can count, especially if buildings are legally protected. Saving on CO_2 emissions is not mentioned, although this is a theme in new buildings (see appendix for full interview). In the broader theme of sustainability, lack of knowledge is the biggest factor causing decreasing feasibility. Directly reused materials form the smallest group within the circular offering of the demolition company interviewed. Recycled products such as concrete also provide substantial savings compared to conventional materials. Insulation material and plasterboard are the most relevant materials that are readily available as directly recycled materials. A concrete answer on availability remained out but the reference of 10.000 m^2 provides a frame of reference for the feasible scale.

Discussion

Interviews were conducted to collect some qualitative data in addition to the quantitative research. Interviews with practitioners were chosen to highlight this side of the story. Only two interviews were conducted and from two different types of parties. As a result, it was not checked how the answers given compared to other parties in the Netherlands. However, the two parties interviewed were carefully chosen. It can be reasoned that AM, the largest developer in the Netherlands, is a reliable source to create a picture of the status of the market. New Horizon is part of the Circular Design Collective, of which Superuse Studios is also part. This fact is considered reliable in the perspective of this study.

Results & Conclusions

Result Summary
Renovating is always more sustainable than reconstructing. Current research has not yet succeeded in determining the savings in terms of environmental burden through a uniform method. However, all studies do indicate savings respectively. From the literature review, it can be concluded that a CO_2-eq reduction of about 60% is a plausible starting point.
The case study has shown that 23% CO2-eq emissions and 27% energy consumption can be saved if efforts are made to apply reused materials in a renovation task. The best opportunities lie in using reused insulation material. This material is widely used in renovation, has high environmental costs as a new product and is widely available on the second-hand building materials market. Deploying sheet material, and mainly plasterboard, is a second good strategy. This material is widely used in renovation and is widely available on the second-hand market. Compared to insulation material, the product has lower production costs and therefore has less impact. Focussing on window frames and doors is the least valuable. Due to the need for triple glazing, the supply on the second-hand market is small. In addition, the production charges of wooden window frames are relatively low.

There is little to no difference in savings between building elements.

In the current state of affairs, CO_2 reduction and energy use are not yet a weighty factor when considering reusing or demolishing a building. Economic interests still weigh most heavily. Heritage values can sometimes outweigh economic interests, especially if protection is laid down by law. More broadly, lack of knowledge is the biggest barrier stakeholders face in making construction more sustainable.

The scale of a construction project is a limiting factor for the feasibility of a circular alternative. The case study examined exceeds in required square metres of material the 10.000 m^2 reference mentioned. In addition, there is still too much uncertainty in the market to guarantee large quantities of material.

Framing Results
The found percentages of savings of 23% and 27% are a lot lower than the known percentages around building with reused materials. Superuse Studios, for example, calculates an average reduction of 70% CO_2. The alternative result, which excludes the ground floor construction from the equation, comes to 65.5% CO_2 reduction. This is a lot closer to the 70% expected by Superuse Studios.

Discussion
The study has a number of limitations. Only material production costs are taken into account in the quantitative comparative study. Transport, assembly, demolition or end-of-life cycle, for example, are not taken into account. Nevertheless, the values are quite comparable as both proposals were tested against the same criteria and using the same methodology. Cost calculation and comparison proved not feasible for this study. The interviews showed that economic considerations always weigh most heavily in the trade-off between reuse and demolition, for this reason it would certainly have been valuable if this information could be included.

Above all, the study showed where opportunities exist to reduce environmental burdens in a renovation task. The results are a product of market availability, production costs and quantity applied.

Further recommendation
Within the scope of this study, a full LCA was not feasible.
The results obtained showed a namable difference between conventional renovation and a circular alternative. A full LCA is recommended to identify this difference in environmental costs even more sharply. In addition, an investigation is recommended

Results & Conclusions

between renovation with reused materials and renovation with new sustainable products such as bio-based building materials. For instance, how does reused PIR compare with new insulation material made of hemp or flax? In addition an economic comparison is advised.

Relevance
This study operates in a very relevant field. Resource use and the environmental burden of the linear systems that dictate our everyday life are a relevant topic in both the architectural profession as in a larger scientific framework. Strategies concerning circularity within the built environment are in full development. Exploring the impact and feasibility of combining material reuse with the preservation of buildings is new to this study. It fills a relevant gap in the knowledge on available strategies for sustainable renewal.

Reflection

From research to design

There is a strong relationship between the research and the design I present. The foundation for this strong relationship lies primarily in the clear similarity between the case study object, the renovation plan for Complex 70 in The Hague, and the chosen design case, the VanTijenflats, in Amsterdam Nieuw West. The renovation plan for Complex 70 was designed with the aim of proving that renovation is possible for this complex. The 1930s housing complex is in danger of being demolished. The need for renovation and improvement of the building's residential quality and energy efficiency is being linked by Hague council, perhaps under pressure from developers and investors, to the "inevitable" solution of demolition and new construction. Superuse's renovation proposal is designed to contradict the inevitability of this solution and present an alternative that, without demolition, brings the residential quality and energy efficiency of the complex to desired levels.

The VanTijenflats in Amsterdam Nieuw West are demolished in 2022.
The six porch flats were the last remnants of the original urban plan designed by Willem van Tijen in 1954 in collaboration with Cornelis van Eesteren and formed an integral part of Amsterdam's General Expansion Plan. Against all protests from heritage association Heemschut and contrary to the 2019 building status report, the flats were demolished. The new construction currently being realised shows awareness of the heritage values of the demolished buildings by copying its architectural elements in the new building. Circular ambitions are even being formulated. (DOOR architecten, 2023) So the question remains why demolition and new construction were chosen after all. In my design, I take a step back in time and assume that the VanTijen flats have not yet been demolished. In my design, I look for opportunities to renew the VanTijenflats where preservation and reuse take a central role. The resulting buildings should not only provide better thermal comfort but also connect to today's society and the surrounding urban fabric which has evolved and changed since the flats were built.

Most of the research I conducted has involved calculating and comparing the impact that the production of building materials brings. This has created a strong awareness in me that every intervention you make in a design translates directly into CO^2 emissions and energy use. Despite one of the conclusions of my research: that renovation is always more sustainable than demolition and new construction, I have become convinced that even in a renovation task, every addition of material must be well substantiated. Is a modification or renovation just a 'nice addition' or is it actually crucial to the success of the design? In my redesign for the VanTijenflats , this question has always been at the forefront of my design decisions. In a nutshell: material is sacred. This radical circular strategy can be summarised in three actions:

Action 1: preserve: Material and building elements that perform adequately within desired design remain intact.

Action 2: reuse. In cases where the material has to be removed anyway, I looked for a new function for this material within the design. This also works the other way round: if I wanted to add something, I first looked at whether I could take this material out of another part of the building where this material was less prominent. These actions ensure the most closed system possible with regard to material use because in this case material is moved and not removed. Eventually, material must also be added. Again, the addition is done only if it is necessary for the success of the design.
This is where the third action in my circular strategy comes in:

Action 3: reclaim.

If 'new' materials was needed to achieve the intended intervention, I have focused on applying second-hand building materials. These materials do not come directly from the building itself but are the residual product of demolitions and renovations in the rest of the Netherlands. This is where the results of the study had the greatest impact. It is also this strategy that was used in the renovation plan for Complex 70. The reused materials applied in it came from the second-hand market.

A primary finding of the study underscores the effectiveness of incorporating reclaimed insulation material and sheet material (such as plasterboard, OSB boards, and chipboard) to minimize the environmental costs of renovation projects. This discovery informed the preference to internal insulation. This is because with

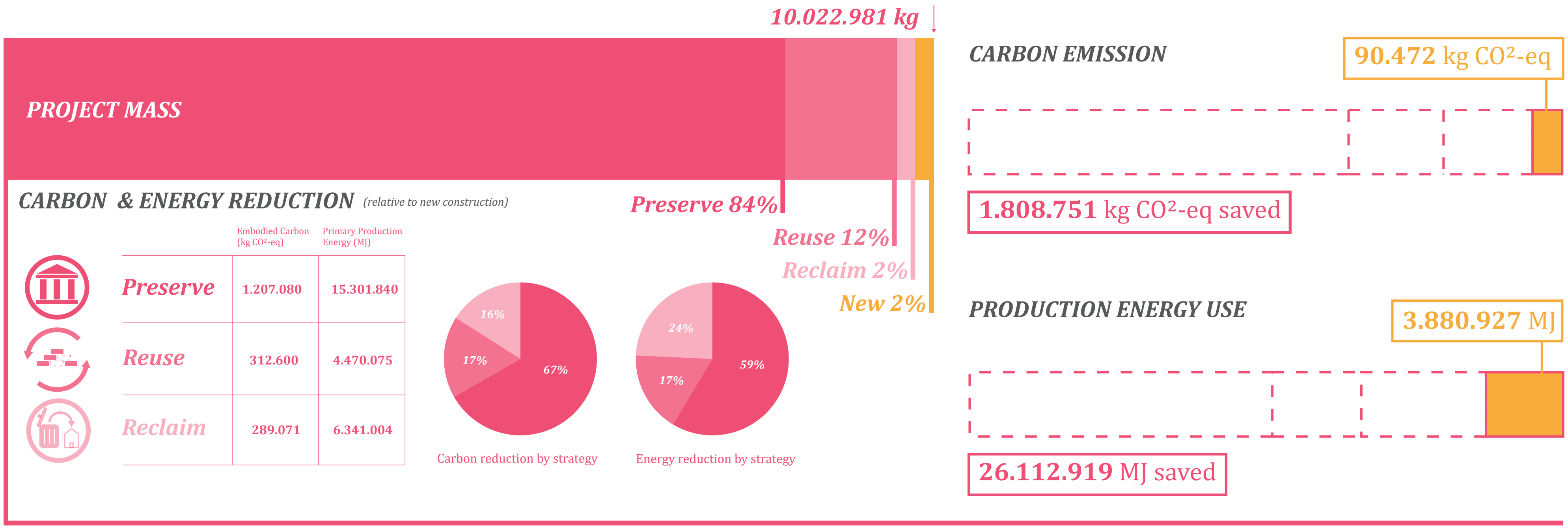


Figure 5: impact overview design case 'VanTijenflats'

internal insulation, you mainly need insulation material and sheet material. With external insulation, you also need to re-clad this package with extra cladding material.

Although seemingly simple, the application of internal insulation as opposed to external has a profound effect on the total design. Especially in combination with appointed heritage values, decisions like these have a direct effect on architectural articulation and definition.

Initially, my approach to the project was pragmatic and systematic, focused on the materials puzzle. The feedback after assessments highlighted that sustainable architecture should encompass more than just clever use of materials. My project, although systematic and sustainable, lacked true architectural value. The value of a building made of 98% preserved, reused, and reclaimed materials seemed logical to me. However, a crucial question arose: “Why this building at all?” What qualities does it add to the city, its surroundings, and its residents? These questions prompted a critical reassessment and revision of my design.

Upon reflection, I realized that while many of these questions were answered in the design, the evidence of such qualities was missing. In other cases, the reassessment led to specific design adjustments such as the redesign of the public plinth on the north side. Initially, this plinth, consistent with the rest of the design, used reclaimed materials, resulting in a closed appearance due to the unavailability of large second-hand glass panes. I then decided to construct this plinth from new materials, creating a high, open plinth with a strong visual and physical connection to the public square. This design choice enhanced the visibility of the arcade interior and better showcased the façade’s preservation. Although it increased the carbon footprint, the architectural value justified the ecological impact.

This balance between carbon reduction and architectural appearance is also recognizable in the reuse of the window frames, although this strategy was proven to be relatively ineffective in my research. There are two reasons my design incorporates this strategy nonetheless. Firstly, the window frames were relocated internally and not retrieved from external sources, relieving the material from transport or the need for active sourcing. Secondly, the window frames provided a visible symbol of the design’s circular ambitions, resonating with residents and passers-by. The façades of the pavilions mirrored the surrounding buildings, reinforcing this visual connection. A comparable principle applies to the in-between spaces created by the double window frame placement.

Conversely, the use of reclaimed PIR insulation material, though effective in reducing CO^2 and energy consumption, lacked symbolic value as it remained hidden behind walls. This dichotomy between visible and hidden sustainable elements highlights the importance of both ecological effectiveness and architectural storytelling in my design.

Finally, I ask myself whether reuse can actually create qualities that new construction can’t. In my project I haven’t been able to proof this. I imagine that a building that is built with materials that are not brand new has a very different atmosphere than a new conventional building. A certain “patina” that gives it a distinctive character.

I found it very hard to simulate this atmosphere however in drawings. As far as established architectural qualities go: space, light, comfort etc. reuse can’t necessarily achieve things new construction can’t. However, measured against climate impact, it can be reasoned that a lot of qualities can be achieved through reuse and that new construction is not always necessary. The quality of the in-between spaces in my design proofs this.

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Figures, Images, Tables and Graphs

Graph 2: energy use comparison on total building level

Graph 3: tonnes CO_2 savings per material type

Graph 4: energy savings per material type

Graph 5: GWP comparison per material type

Graph 6: Energy use comparison per material type

Graph 7: tonnes CO_2 savings per building element

Graph 8: energy savings per building element

Appendix

Full interview report in original language (Dutch)

Interview met Mike Breuker, AM.

De heer Breuker is projectontwikkelaar bij AM. Zijn rol houdt in dat hij verantwoordelijk is voor het managen van alle partijen die bij een bouwopgave betrokken zijn. Nadat AM, meestal doormiddel van het winnen van een tender, een opdracht binnen krijgt wordt het project aan hem overhandigt. Dit betekent dat Breuker niet verantwoordelijk is voor het formuleren van eventuele duurzaamheidsambities, dit is de rol van de ontwikkelingsmanager. Breuker noemt een recent voorbeeld van een gewonnen tender. AM heeft het project gewonnen op duurzaamheidsambities. Het gebouw krijgt een MPG van 0,42. De grenswaarde voor nieuwbouw is 0,8. In zijn uitleg wordt duidelijk dat zo'n duurzaamheidsambitie een hele hoop extra complexiteit met zich mee brengt. Zo kan er niet met beton worden gebouwd of worden gemetseld. Toch zijn de eisen van de verschijningsvorm dat de gevel in 'steenachtig materiaal' wordt opgetrokken. Hoe dan zoiets op te lossen? Een houten constructie met steen strips beplakken lijkt hier het antwoord op te zijn. Een voornaamste barrière is kennis volgens Breuker. In een conventioneel project wist elke partij precies wat ze moesten doen. Je bouwt een betonnen skelet, dat vormt de basis. Vanuit daar is het een kwestie van standaardoplossingen toepassen. Door bijvoorbeeld met hout te bouwen veranderd de techniek en het proces compleet. Dit zorgt ervoor dat partijen zichzelf weer 'compleet opnieuw moeten uitvinden'. Toen er werd gesuggereerd dat deze kennis in de toekomst zal toenemen en daarmee deze barrière wordt doorbroken voegde Breuker daar aan toe dat houtbouw dan nog altijd duurder is dan betonbouw. Of het opschalen van houtbouw zal leiden tot kostenreductie is volgens hem niet zeker. Beton wordt duurder, dat zorgt er vooral voor dat kosten van beide bouwmaterialen naar elkaar toe groeien.

In het kader van vernieuwingsopgaven gaf Breuker de volgende inzichten. Of een bestaand betonnen casco wordt hergebruikt is volledig project afhankelijk. Hierin zijn voornamelijk financiële afwegingen belangrijk. Als het casco goed aansluit op het nieuwe ontwerp kan het zo zijn dat het financieel interessant is om het casco te hergebruiken, omdat dit de materiaal kosten van het project naar beneden haalt. Tegelijkertijd is het ook zo dat zorgvuldige ontmanteling van het bestaande gebouw een stuk kostbaarder is dan grove sloop. De verhouding tussen de sloopkosten en de kostenbesparing op materiaal bepaalt wat er met het casco gebeurt. Ook speelt de materiele waarde van het bestaande gebouw mee. Slopers kunnen belang hebben bij volledige sloop vanwege kostbare materialen die hieruit te winnen zijn. In binnenstedelijke gebieden kan erfgoedwaarde en beschermde stadsgezichten meespelen in de preservatie van gebouwdelen. Zo kunnen gevels bijvoorbeeld bewaard blijven, ondanks de hogere kosten.

Interview met Erik Koremans, New Horizon Material Balance.

Erik Koremans is directeur van New Horizon Material Balance. New Horizon is een circulair sloopbedrijf. Dat wil zeggen dat alle gebouwen die zij 'slopen' zo zorgvuldig mogelijk worden ontmanteld om zoveel mogelijk bouwmateriaal te herwinnen. Material Balance is de tak van New Horizon die gaat over het inzetten van het herwonnen materiaal. New Horizon heeft samen met andere partijen die dezelfde circulaire visie hebben het Urban Mining Collective opgezet. "Het UMC gebruikt de stad als bron. Ze maakt grondstoffen en materialen uit slooppanden geschikt voor hergebruik. Samen werken we aan de transitie richting een circulaire bouweconomie." Material Balance heeft op het moment een aanbod van 60 verschillende circulaire bouwmaterialen. Koremans legt uit dat het niet alleen direct hergebruik betreft, wat hij één op één noemt. Veel van het aanbod bestaat uit materialen die met gerecyclede grondstoffen zijn geproduceerd. Als voorbeeld noemt hij het recyclen van dak bitumen en een circulair betonproduct. Door middel van een 'smart liberator' techniek is New Horizon in staat oud beton terug te zetten tot zijn bestandsdelen: zand, grind en cement. Het nieuwe beton wat hieruit wordt geproduceerd heeft 60 tot 80% reductie op de MKI (Milieu Kosten Indicator). Materialen die geregeld als één op één hergebruikt geleverd kunnen worden zijn kabelgoten, gipswanden, houten balken en isolatieplaten zoals EPS en PIR. Een concreet antwoord op de kwantiteit die geleverd kan worden per product kon Koremans niet geven. Het is heel erg afhankelijk van wat er binnen komt. Als voorbeeld kon hij wel het nieuwe kantoor van de TRIODOS bank noemen, waar via New Horizon 10.000 m2 hergebruikte gipswanden in verwerkt zijn. Voor projecten van grote schaal is het vaak een kwestie van sloop en bouw aan elkaar koppelen. De benodigde hoeveelheden worden in kaart gebracht. Vervolgens wordt er geïnventariseerd of er gebouwen in de nabije toekomst gesloopt worden waar dit materiaal uit kan worden gewonnen. Soms lukt het, soms niet. In praktijk zijn alle circulaire projecten een hybride oplossing. Er wordt zoveel mogelijk met hergebruikt materiaal gewerkt en aangevuld met nieuw.